INSTITUTE OF HYDROLOGY

SPARE

PORT SUDAN WATER SUPPLY

A REVIEW OF THE HYDROGEOLOGY AND WATER RESOURCES OF KHOR ARBAAT

This report was prepared for
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by

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THE KHOR ARBAAT

The study area

The water supply for Port Sudan is taken from a wellfield located in the Khor Arbaat about 30 km north west of Port Sudan. The Khor Arbaat drains a catchment of 4200 km^2 within the Red Sea hills and this basin, which extends about 120 km along the Red Sea/Nile watershed, drains through a narrow rock gorge, 30 m wide, the upper gate, into a small alluvial basin some 10 km long and 12 km^2 in area. It is towards the lower end of this small basin that the wellfield is located. The lower end of the alluvial basin is defined by another rock gorge, the lower gate, where the alluvium is about 450 m wide.

Occasional intense rainfall on the catchment causes flood flows which contribute to recharge of the alluvial aquifers. The perennial baseflow observed at the upper gate represents the slow natural drainage of the alluvium upstream of the gate and this baseflow provides the main recharge of the smaller alluvial basin between the gates. There is no permanent surface flow at the lower gate although the residual flood flows continue down the khor to cross the coastal plain.

Historically, this part of the Khor Arbaat has been used for water supply to Port Sudan since 1924 and the development of this wellfield to the present day is well described by both the Geological and Mineral Resources Department of Sudan[1] and Ewbank and Partners[2]. During this time 68 wells

Hydrogeological investigations of Khor Arbaat Basin by Mohammed Tahir Hussein. Geological and Mineral Resources Department, 1975

Study of Power and Water requirements of Port Sudan/Suakin Area for 1975-1985 by Ewbank and Partners Ltd and Sir Murdoch Macdonald and Partners, 1974 have been constructed but of these only 13 wells are now in production. There are plans, however, for 6 new production wells to be drilled this year by the Rural Water Corporation bringing the total number of wells in production to 19.

Climate

The catchment is in a dry area subject to occasional storm rainfalls. Mean annual temperature varies from 20°C inland to 30°C on the coast and actual sunshine hours are a high percentage of the possible sunshine. Two distinct rainfall seasons result from different climatic conditions.

The summer rains occur from June to October resulting from the movement of the Intertropical Convergence Zone (ITCZ) causing the south west monsoon to penetrate the area. These conditions favour short thunderstorms with variable intensities of rainfall. Rainfall records show a range of between 0 and 160 mm per month in the period 1966 to 1975, with higher values tending to be recorded over the Red Sea hills about 20 km inland from Port Sudan.

The winter rains occur from November to February over the coastal areas. Their effect can be seen in stations as far inland as Erkowit on the eastern edge of the catchment. The wind conditions at this time of year encourage the development of a sea-breeze front which produces thundery storms on the coast, mainly during the mornings.

The runoff measured in the Khor Arbaat is influenced by both summer and winter rains and would, therefore, be expected to be highly variable during these periods in response to short variable thunderstorms.

Geology

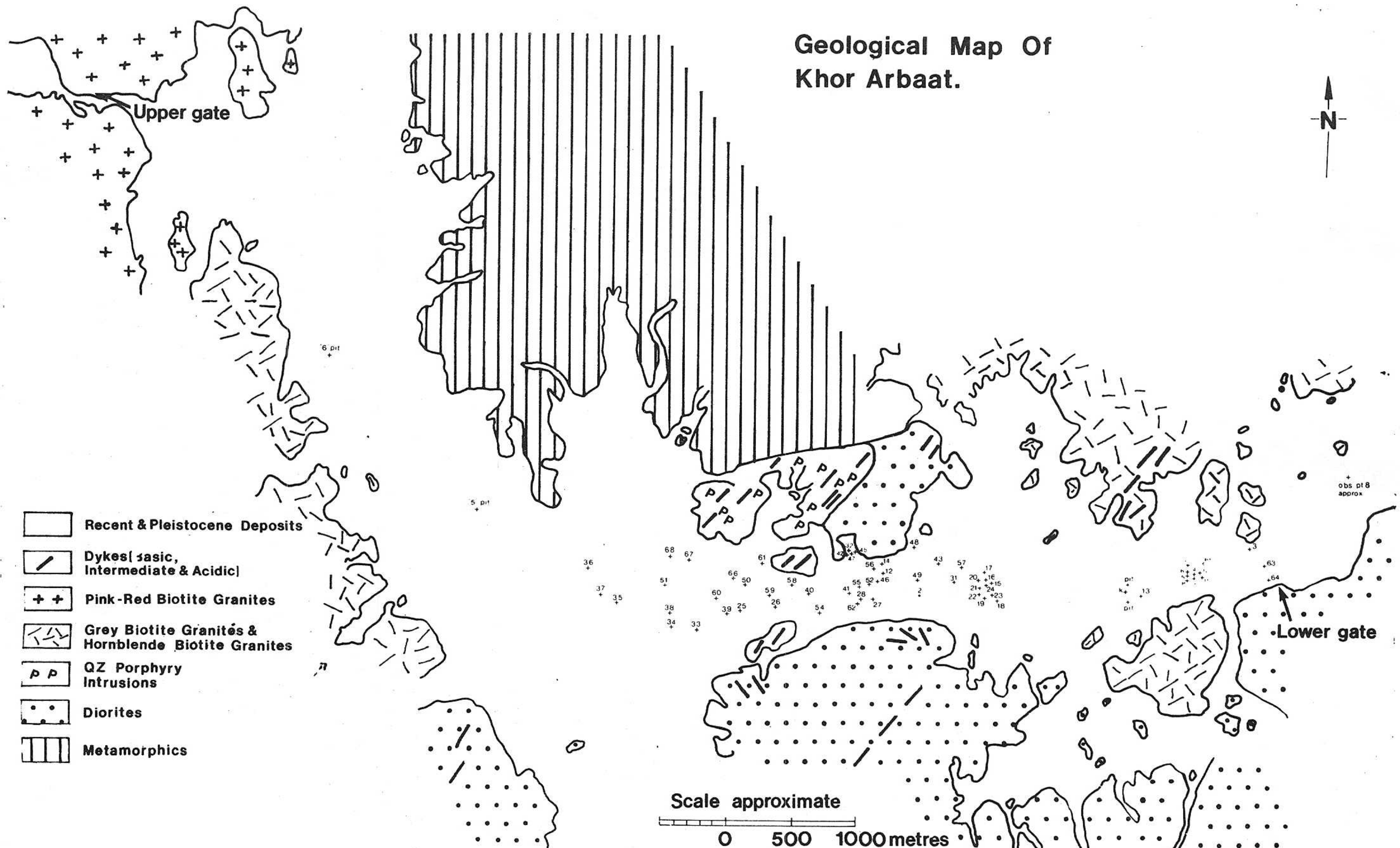
The Red Sea hills comprise rocks of Pre-Cambrian age forming an impermeable crystalline basement of granite and schist. Basic dyke swarms which are aligned north east/south west have penetrated this basement roughly parallel to the strike whereas the main drainage basins within the Red Sea hills run parallel to the north/south strike of the Pre-Cambrian rocks. Most of these basins have now cut through the Red Sea hills and drain through steep khors east/west across the coastal plain to the Red Sea. A geological map of the region between the upper and lower gate, taken from the Geological and Mineral Resources Department report[1], is shown in Figure 1.

Khor Arbaat alluvium

The wadi fill of the Khor Arbaat between the upper and lower gates is the erosion product of the metamorphic and igneous rocks of the Red Sea hills. These deposits range from large boulders to very fine sands and silts and they have been deposited from the Pleistocene to the present day. Lenses of material cemented with calcium carbonate occur throughout the basin and although many of the boreholes in the wellfield have been drilled to bedrock, it is quite possible that some have only been drilled to the cemented beds. This uncertainty can only be resolved by diamond core drilling several metres below the base of the borehole to determine whether a layer of cemented beds or a large boulder have been mistakenly noted as bedrock.

The gravels occurring upstream of the upper gate look superficially much less silty than those between the gates. The sudden drop in flood water velocity at the upper gate accounts for this much higher silt content of the alluvium between the upper and lower gates.

Figure 1


Geological Map Of
Khor Arbaat.
N
Upper gate
Lower gate
Recent & Pleistocene Deposits
Dykes[Basic, Intermediate & Acidic]
Pink-Red Biotite Granites
Grey Biotite Granites & Hornblende Biotite Granites
QZ Porphyry Intrusions
Diorites
Metamorphics
Scale approximate
0 500 1000 metres
obs pt 8 approx

The active river channel between the gates varies in width from about 50 to 200 metres and it is most probable that similar channel widths would be encountered at depth, the remainder of the alluvium having a much higher silt content. It is these active channels within the alluvium which account for the main water bearing strata which will have a much higher hydraulic conductivity than the surrounding alluvium filling the khor.

Very few lithological descriptions of the alluvium have been recorded, but the information that does exist for well numbers 32, 33, 35, 36, 37, 63 and 64 is shown in the well register in Appendix A.

Both resistivity and seismic surveys have been carried out in an attempt to determine the topography of the basement complex underlying the alluvium. The results of these surveys are somewhat contradictory and have most probably been affected by the presence of subsurface cemented beds being mistaken for the basement. However, the results of the resistivity survey and the drilling suggest that the thickness of the alluvium is 8.5 m at the upper gate increasing to thicknesses between 25 and 35 m for the remainder of the khor upstream of the lower gate.

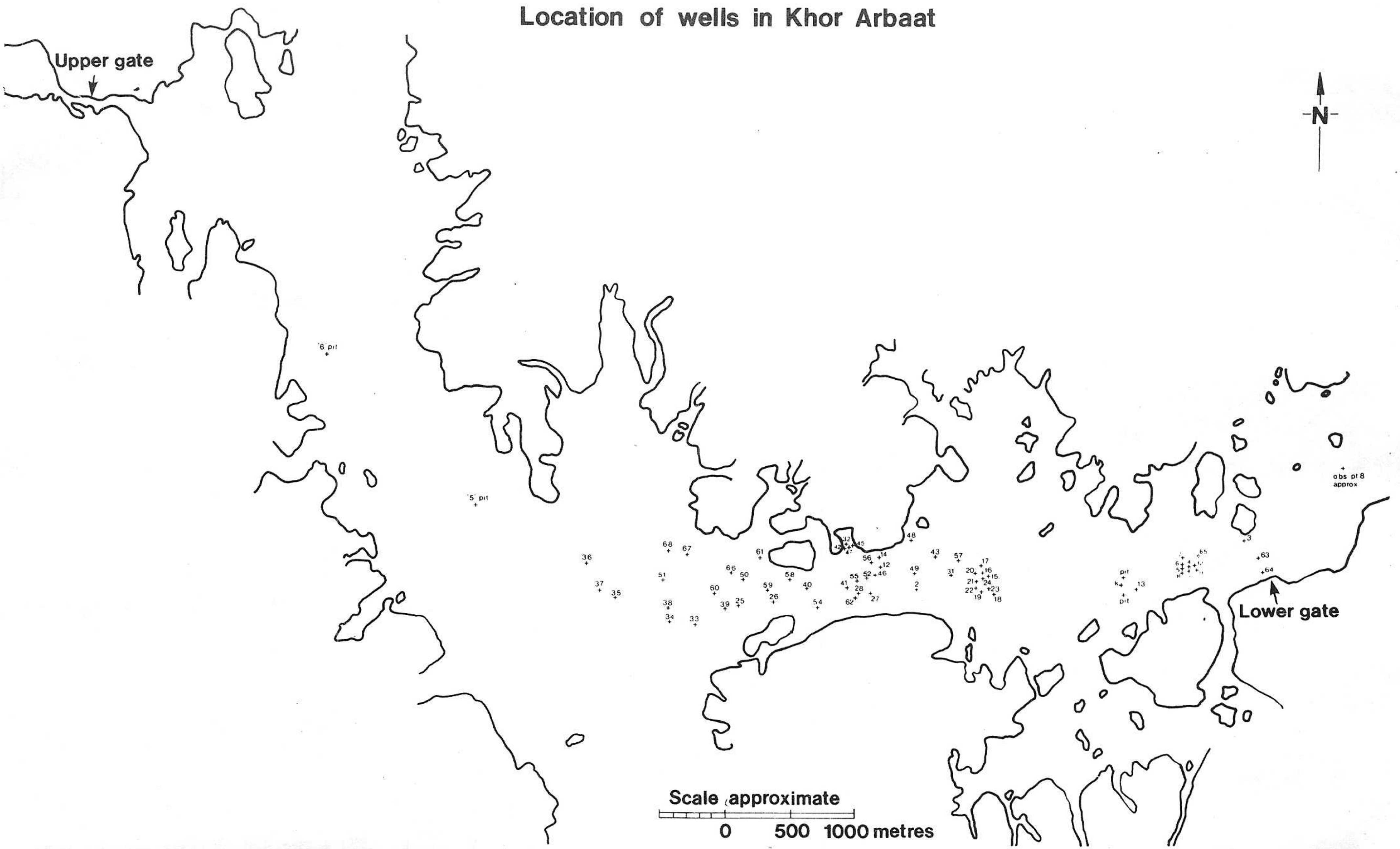
Khor Arbaat wellfield

The history of the development of the Khor Arbaat wellfield from 1924 to the present day is described by both the Geological and Mineral Resources Department[1] and Ewbank and Partners[2].

The location of each well is shown in Figure 2 and the construction details, pump test information, chemistry and water level data where available are shown in the well register in Appendix A. These data have been collected from

Figure 2

Location of wells in Khor Arbaat



the Rural Water Corporation (RWC), Public Electricity and Water Corporation (PEWC) and Geological and Mineral Resources Department files in both Port Sudan and Khartoum.

It should be noted that the location map is only approximate and the well numbering system is that used by the PEWC in Port Sudan.

Many of the wells constructed are not now in production; this is due either to the water table falling below the base of the well or to the well screens becoming clogged. A few of the wells have been damaged by floods and one is completely silted up.

Table 1 shows the dates, from 1957 to January 1978, when each well was in production and also the average daily yield of each well estimated from Table 2 which summarises the available well yield data held by PEWC for part of 1975 and 1976 and the whole of 1977. It can be seen from Table 2 that the yield of each well is not constant throughout the year; the higher yields are normally associated with high water table conditions whenever they occur. The mechanical condition of the pumps also affect the yield, but sufficient information is not available to comment more fully on the relative importance of these factors.

The actual monthly production figures for the Khor Arbaat wellfield are shown in Table 3 (Source: PEWC). The monthly totals do not necessarily equal the sum of the average yields for each well, as these fluctuate daily and also not all the wells are always in full production.

It can be seen from Table 3 that the annual total production from the wellfield has been very constant from 1972 to 1976. The 1977 total of 6.39 million m^3 is most probably too high as six months of data have been estimated from the records of mean daily yield.

TABLE 1

WELLS IN PRODUCTION FROM 1957 TO JANUARY 1978

Well number	Into Production		Out of Production		Average Yield (m^3/day)
20		1957	June	1977	182
21		1957	July	1974	282
22		1957	July	1974	268
24		1957	May	1977	362
35	June	1966	June	1976	407
36	June	1966	January	1978	718
37	June	1966	January	1978	1617
38	July	1968	January	1978	1988
41	July	1968	January	1978	1004
50	September	1968	January	1978	1452
54	August	1971	July	1977	520
55	September	1971	January	1978	584
56	July	1971	February	1977	575
57	July	1970	March	1977	577
58	April	1971	January	1978	2022
59	September	1970	January	1978	1527
60	August	1971	February	1977	947
61	April	1973	January	1978	995
62	April	1973	January	1978	806
63	May	1974	September	1976	375
64	May	1974	May	1974	Nil
65	April	1975	January	1978	1992
66	June	1977	January	1978	1148
67	July	1977	January	1978	1553

TABLE 2

MEAN DAILY YIELD OF WELLS IN KHOR ARBAAT
(m^3/day)

	20	21	22	24	35	36	37	38	41	50	54	55	56
1975													
Jan	184	304	293	381	419	686	1350			1667	764	767	726
Feb	183	290	273	360	400	649	1358	991		1711	749	710	714
March	180	251	238	345	399	632	1292	1348			750	682	631
1976													
May	182			362	402	590	1591	1654	744	1092	306	522	263
June	182			362	379	568	1570	1654	738	1127	319	523	280
July	182			362	390	552	1518	1800	746	1083	301	518	274
Aug	182			362	399	564	1529	1980	759	1136	312	516	290
Sept	182			362	441	632	1616	2120	1065	1519	547	567	547
Oct	182			362	435	664	1659	2033	983	1603	491	556	575
Nov	182			362	388	779	1656	2581	1322	1776	659	585	749
Dec	182			362	448	851	1721	2657	1337	1834	650	717	1046
1977													
Jan	182			362	434	831	1735	2555	1225	1883	633	651	900
Feb	182			362	453	943	1753	2234	1202	1886	626	591	731
March	182			362	450	883	1743	2240	1156	1931	625	575	654
April	182			362	460	803	1795	2090	1137	1729	553	588	586
May	182			362	370	724	1686	1920	1109	1607	441	528	555
June	182				363	640	1651	1842	919	1278	367	524	397
July					347	578	1667	1772	739	896	285	496	285
Aug					370	647	1609	1924	1015	1206	504	563	719
Sept						760	1687	2094	983	1231		552	
Oct						851	1709	2098	926	1192		559	
Nov						855	1671	2127	1005	1293		564	
Dec						849	1627	2019	965	1265		571	

TABLE 2
(continuation)

MEAN DAILY YIELD OF WELLS IN KHOR ARBAAT
(m^3/day)

	57	58	59	60	61	62	63	64	65	66	67	Total (m^3/day)	Total (m^3/mth)
1975													
Jan	347	2509	1497	825	1170	584	422	410					
Feb	328	2361	1653	1305	1162	553	528						
March	312	2054	1597	710	1130	512	380	417					
1976													
May	155	1850	1283	947	934	761	303		1640			15581	483011
June	500	1850	1254	947	960	773	241		1621			15848	475440
July	476	1857	1262	947	889	783	222		1626			15788	489428
Aug	505	1868	1249	947	884	801	291		1705			16279	504649
Sept	508	1827	1231	947	955	869	358		1835			18128	543840
Oct	515	1751	1412	947	933	829	382		2253			18565	575515
Nov	702	2247	1482	947	1023	868	523		2274			21105	633150
Dec	947	2613	1696	947	1186	907	480		2345			22926	710706
1977													
Jan	854	2444	1712	947	1105	876	394		2393			22116	685596
Feb	763	2443	1696	947	1129	896	474		2366			21677	606956
March	777	2410	1714		1168	803	385		2379			20437	633547
April		2312	1785		1167	742	339		2229			18859	565770
May		2206	1824		995	889	323		2188			17909	555179
June		1763	1543		860	803	330		2097			15559	466770
July		1255	1348		831	792			2099	1063	1177	15630	484530
Aug		2699	1573		894	831			1879	1109	1703	18245	565595
Sept		1664	1607		930	854			1755	1223	1750	17090	512700
Oct		1322	1509		861	859			1721	1171	1566	16344	506664
Nov		2102	1635		860	1029			1733	1158	1603	17635	529050
Dec		2108	1548		850	909			1706	1163	1521	17101	530131

TABLE 3

MONTHLY PRODUCTION FROM KHOR ARBAAT WELL FIELD (m^3)

	1972	1973	1974	1975	1976	1977
January	422973	408198	486654	381467	439270	541660
February	401639	418427	445940	412731	415453	536603
March	427989	418377	481427	485385	443070	578482
April	418312	407749	399754	453217	429463	542689
May	432266	415475	427273	456920	434740	556650
June	446371	415536	461387	429918	414880	506689
July	482861	410378	492645	433850	389174	484530*
August	462970	508311	473268	450713	450157	565595*
September	429230	481223	490507	454503	531720	512700*
October	411436	500224	511181	466507	536538	506664*
November	390313	463320	490274	440174	702300	529050*
December	405791	463320	481971	454636	446436	530131*
Total million m^3	5.13	5.31	5.64	5.29	5.63	6.39

* *Estimated from mean daily yield from Table 2*

Water quality

Detailed chemical analysis of samples taken throughout the khor have been carried out by the Geological and Mineral Survey Department, and the chemical character of the groundwater is summarised in Table 4. With the exception of calcium all of the concentrations exceed the highest desirable level but are less than the maximum permissible level as defined by the World Health Organisation. Calcium however exceeds the WHO maximum permissible level of 200 mg/litre.

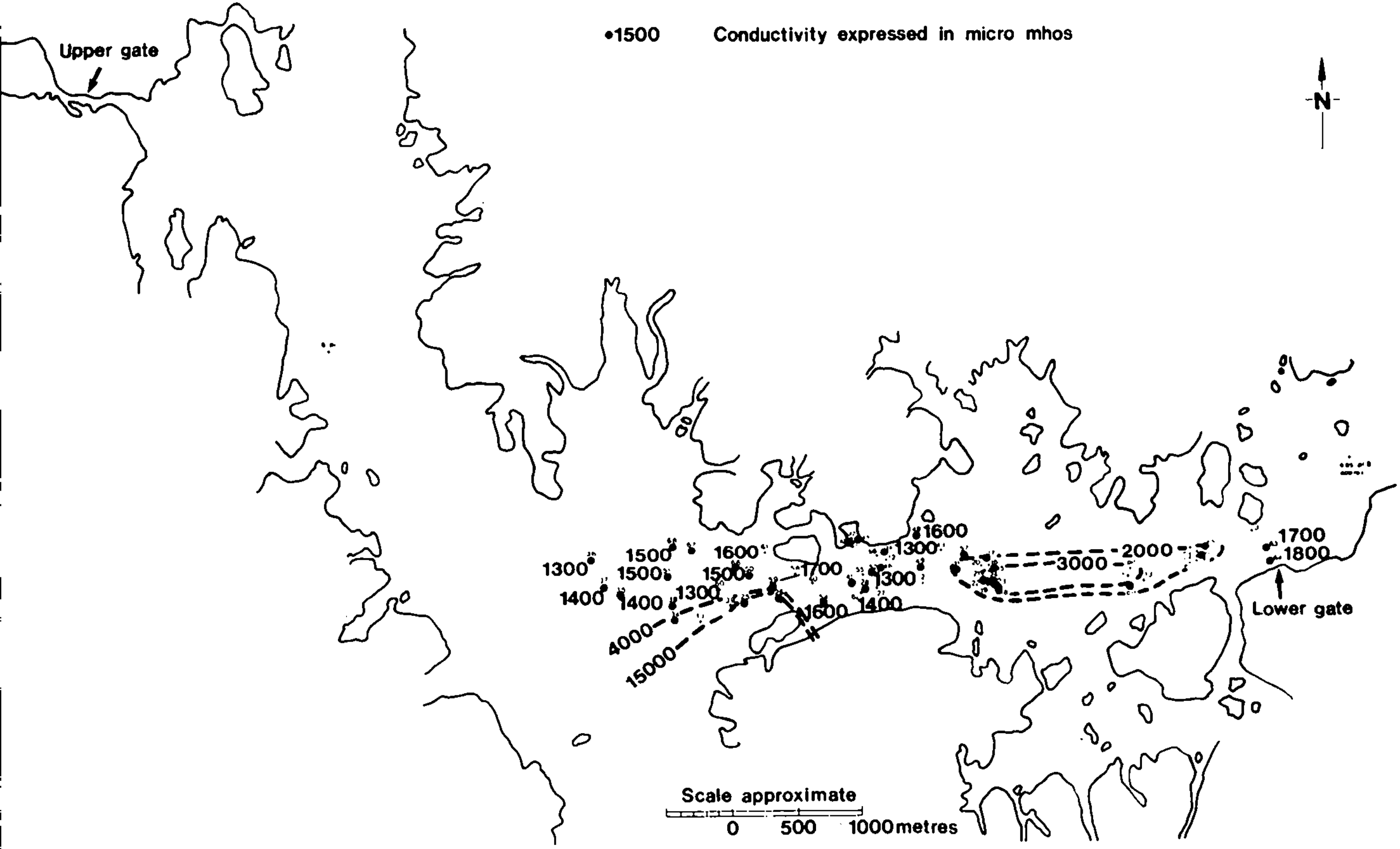
The electrical conductivity of the groundwater was measured during our survey. The detailed results are shown in the well register in Appendix A, and a summary map is shown in Figure 3. It can be seen that in general the electrical conductivity is less than 2000 μmhos except in the region of wells between borehole 31 and 65 where it ranges from 2500 to 3750 μmhos.

Very poor quality groundwater exists around wells 34 and 25 where the conductivity suddenly increases from 4000 to 15000 μmhos. Detailed chemical analysis of the groundwater from the nearby well 26 has been made and the results are shown in the well register in Appendix A.

Stable isotope analyses of the groundwater from wells 36, 41, 59 and 67 show that concentrations of deuterium and oxygen-18 are very similar to that of the surface water flowing at the upper gate; whereas the sample taken from well 26 shows different characteristics indicating that the groundwater from this well is not derived directly from the surface water input to the system. These data, summarised in Table 5, suggest that the marked local deterioration in water quality results from highly mineralised fissure discharge from the underlying basement rock or from seepage of poor quality groundwater from the small side khor to the south of the wells. However, in general, the isotope analyses confirm that the main body of groundwater derives from the recharge of runoff at the upper gate.

Figure 3

Electrical conductivity of Khor Abaat well field



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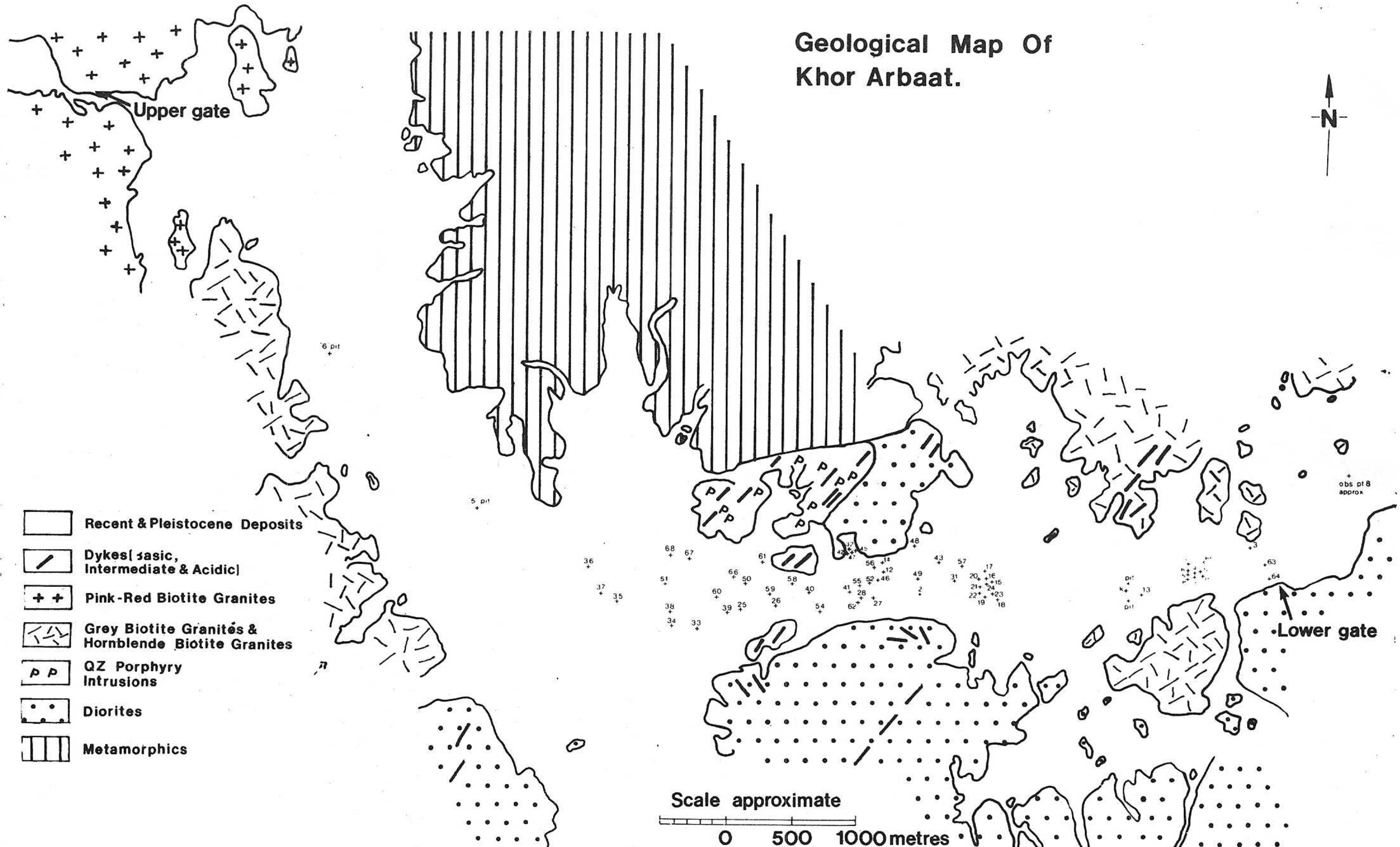
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Upper gate
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obs pt 8 approx
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Figure 2

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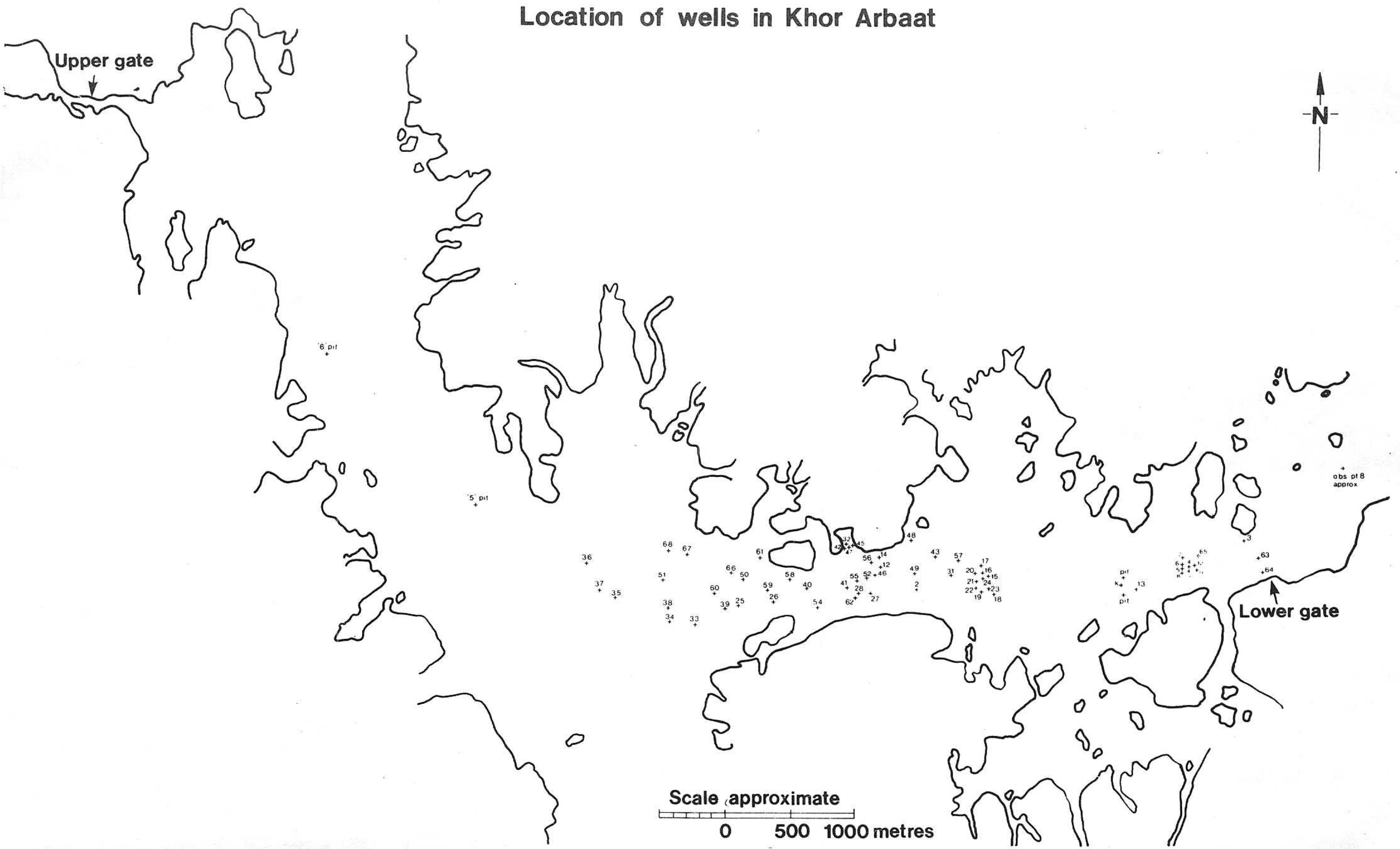

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Total million m^3	5.13	5.31	5.64	5.29	5.63	6.39

* *Estimated from mean daily yield from Table 2*

Figure 3

Electrical conductivity of Khor Abaat well field

•1500 Conductivity expressed in micro mhos

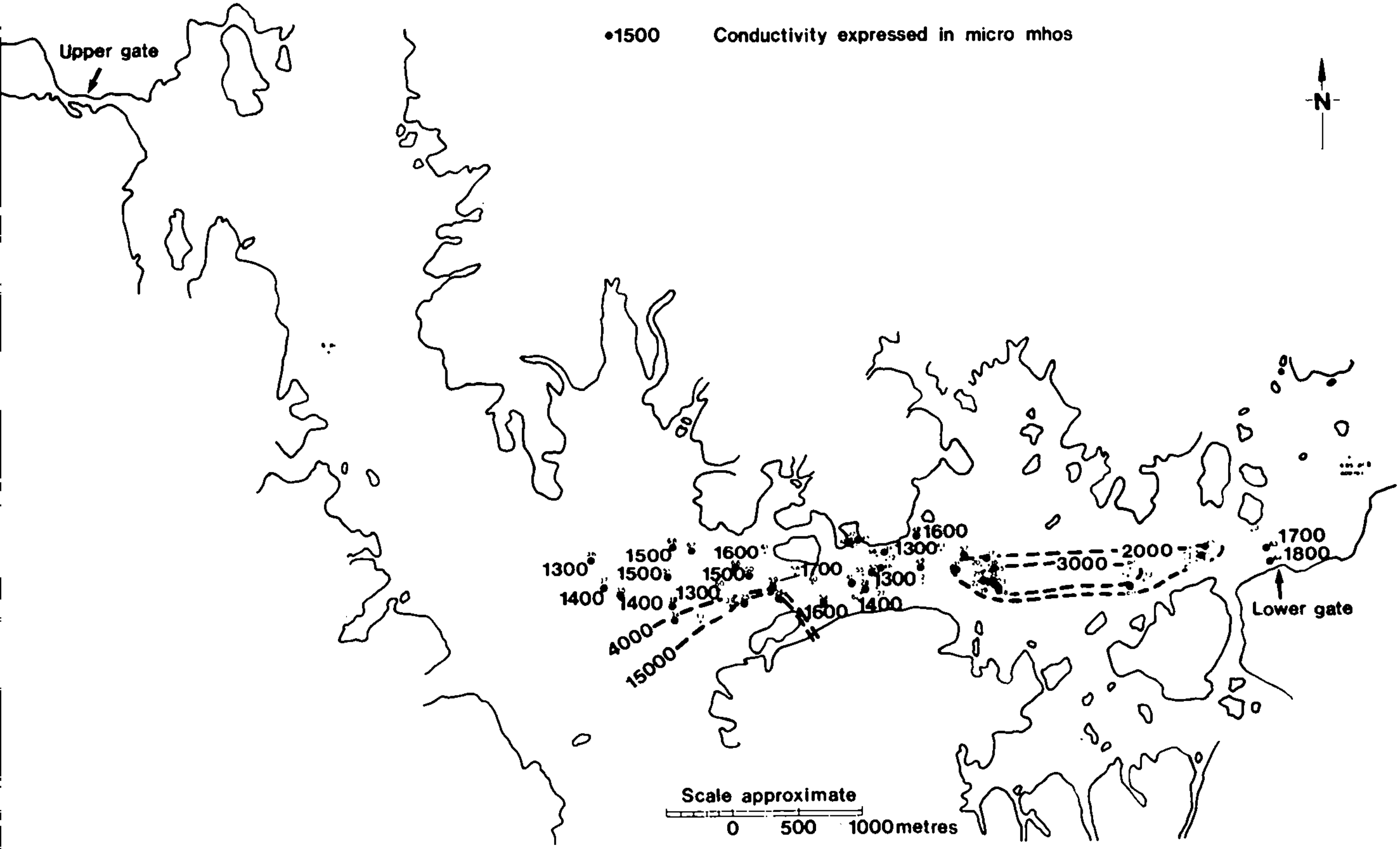


TABLE 4

GROUNDWATER QUALITY IN KHOR ARBAAT
(mg/l)

Ion	Concentration	WHO maximum permissible concentration
Sodium Na^{+}	12- 16	
Calcium Ca^{++}	240- 270	200
Magnesium Mg^{++}	80- 130	150
Carbonates as CO_3^{--}	90- 180	
Chloride Cl^{-}	305- 495	600
Sulphate SO_4^{--}	107- 360	400
Total dissolved solids	815-1120	1500
Total hardness	300- 410	500

TABLE 5

STABLE ISOTOPE DETERMINATIONS FOR KHOR ARBAAT
(parts per thousand)

Source of water	Deuterium	Oxygen 18
Upper gate	- 3	-1.1
36	0	-0.4
41	- 4	-0.6
59	0	-0.4
67	- 1	-0.3
26	-23	-4.4

HYDROGEOLOGY OF THE ALLUVIAL BASIN

Groundwater occurrence

The alluvium between the upper and lower gates contains groundwater in both unconfined and semi-confined states. Sufficient data are not available to define the extent of the semi-confined aquifer, but borehole records for wells 66 and 67 show that water was encountered when drilling at depths beneath the subsequent rest water level. Although lithological records are not available for these wells, the confining strata would most likely be silts and clays or cemented beds.

Water level contour maps for the alluvial basin are shown in Figures 4 and 5 for April 1973 and January 1978 respectively. These maps are based on a survey of water levels carried out by Tahir in 1973 and a similar survey carried out during our field reconnaissance.

The overall position and gradient of the water table has not changed appreciably in the period between surveys except in the region near the lower gate where water levels have fallen nearly 5 m and the gradient increased from 0.003 to 0.006. These changes are attributable to both the overall level of abstractions and changes in the pattern of abstractions.

The depth to groundwater in the vicinity of the wellfield during January 1978 varied from 8.38 m to 12.31 m below ground level, with an average depth of 10.17 m.

Aquifer characteristics

Despite the large number of wells that have been constructed in the khor, very few pumping tests have been carried out to determine the transmissivity and storage

Figure 4

Groundwater level contours for April 1973

Source Geological Survey and Mineral Resources Department

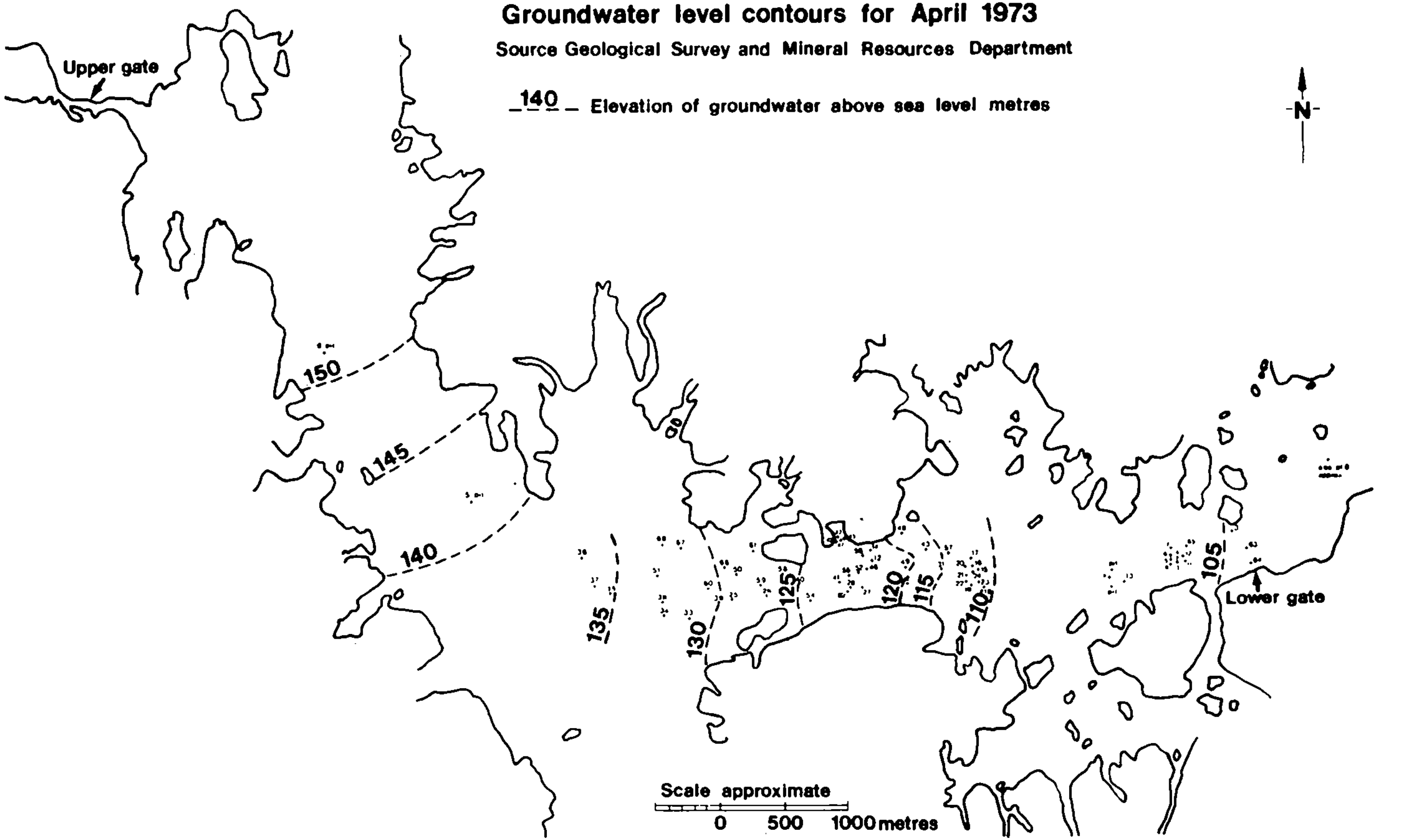
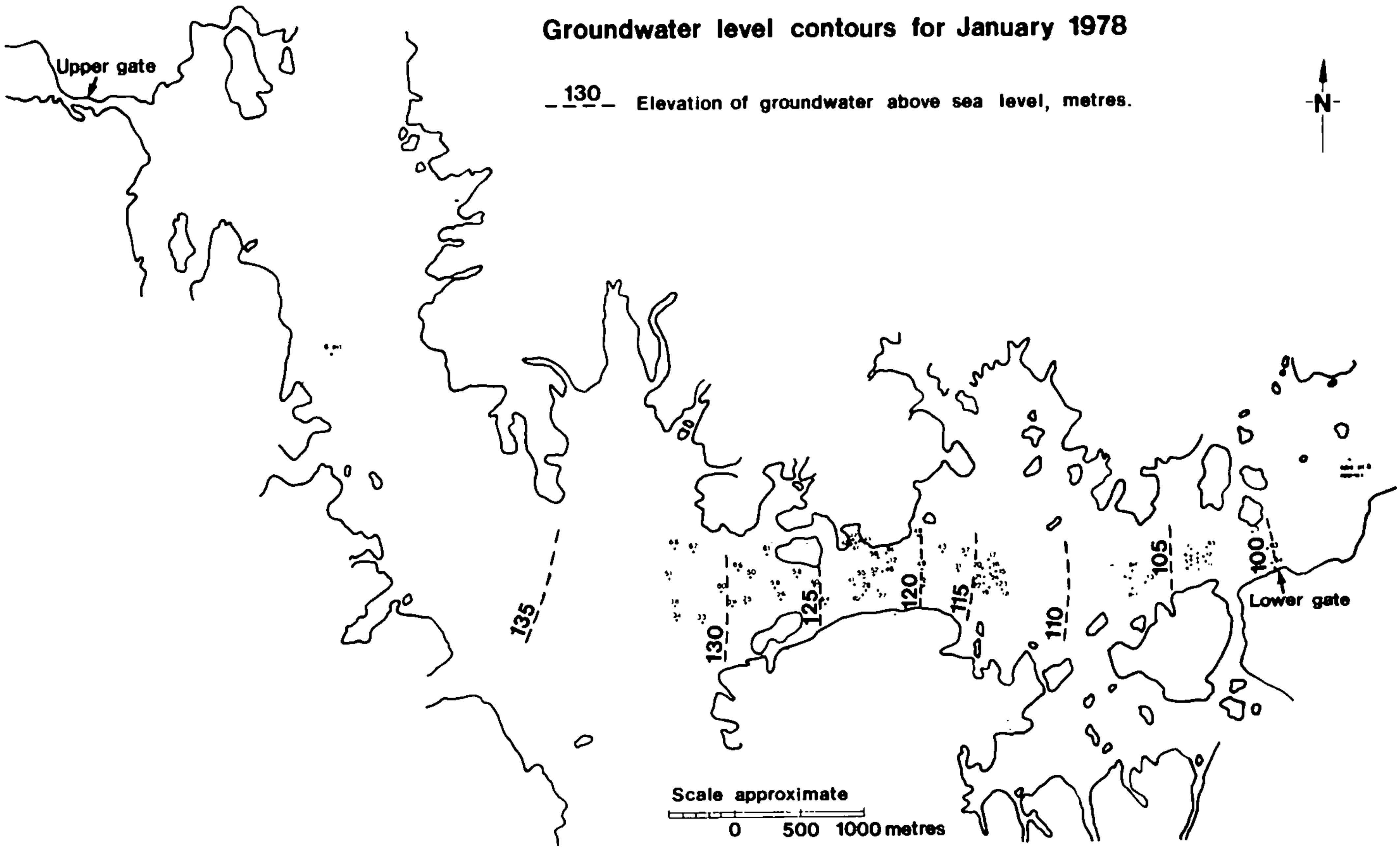


Figure 5

Groundwater level contours for January 1978



coefficient of the aquifer. Those tests that have been carried out by the Rural Water Corporation and by the Geological and Mineral Resources Department are shown in Table 6. Where possible the field data has been re-analysed and our best estimates for transmissivity are also shown. All of these tests were of very short duration, ranging from 4 to 6 hours and there were no step drawdown tests, which would have enabled aquifer and well losses to be estimated.

With the exception of the test on well 38, the data show the transmissivity of the aquifer to be very low, less than 200 m^2/day. While partly due to the fine silts, this result is in keeping with our observations in heavily cemented alluvial aquifers, such as those in Oman, where a mean transmissivity of 223 m^2/day was obtained from 22 tests.

Many of the wells were yield tested on completion and for some of these drawdown data are also available. Although the pumping time has not been recorded, Table 7 shows the approximate specific capacity of these wells. We have not attempted to derive an empirical relationship between specific capacity and transmissivity as the estimates of transmissivity are poor.

The pumping test of well 38 used well 34 as an observation borehole and analysis of these data gave a storage coefficient of 0.08 percent indicating that the aquifer is semi-confined in this area. Lithological logs are not available for this well but the confining layer is most likely to be of silty clay or cemented beds.

Groundwater baseflow through the upper gate

In order to calculate the quantity of groundwater flowing through the upper gate, the width of the aquifer (w), gradient (i) and transmissivity (T) need to be known. At the time of our survey, the gradient was measured as 0.0018

TABLE 6

AQUIFER TRANSMISSIVITY

Well number		Reported transmissivity (m^2/day)	Recalculated transmissivity (m^2/day)
Observation well 26	Pumped well 59	3888	Not analysed, pump rate not constant
Observation well 34	Pumped well 38	Data not analysed	2121
38		415	200
63		277	26
64		257	25

TABLE 7

SPECIFIC CAPACITY OF WELLS

Well number	Yield (m^3/day)	Specific capacity (m^2/day)
25	1637	715
27	1637	1799
28	1637	1799
29	1637	1860
32	327	61
34	655	226
35	1091	661
36	1855	2441
37	1855	2441
38	1027	590
62	1091	97
63	766	84
64	600	69
66	2400	315
67	2400	562

and the width 30 metres. No pumping tests have been carried out at the upper gate and a value of 500 m^2/day will be assumed for the transmissivity; thus groundwater flow through the upper gate, Q = Tiw m^3/day, is 27 m^3/day. Even if we had used an unrealistically high value of transmissivity, say 5000 m^2/day, the groundwater flow of 270 m^3/day would still be less than 2 percent of the average surface water baseflow through the gorge of 12000 m^3/day. Thus we can consider the groundwater baseflow to be an insignificant component of recharge to the alluvium between the upper and lower gate.

Groundwater baseflow through the lower gate

Previous estimates of the groundwater baseflow through the lower gate have been made by Bazin[3], the Geological and Mineral Resources Department[1] and by Ewbank and Partners[2]. Each of these authors used the basic equation, Q = Tiw, to determine the groundwater baseflow and Table 8 summarises the assumptions made.

The transmissivity of 3456 m^2/day used by Bazin was the result of the pumping test carried out on well 59 using the drawdown data from observation borehole 26. A critical review of the field data for this test suggests that the pumping rate was not kept constant throughout the test and consequently we have made no attempt to use these data. Even if this high transmissivity is correct, it only applies to a part of the aquifer which is about 4 km upstream of the lower gate and as such bears no resemblance to the aquifer properties at the gate. However, only limited pump test data were available at that time and no pumping tests had been carried out at the lower gate.

Subsequent pumping tests on boreholes 63 and 64 at the lower gate have been analysed by Tahir and transmissivity values of 277 m^2/day and 257 m^2/day have been derived. We

[3] *Port Sudan Water Supply Investigations by F Bazin, Grenoble Sogreah 1969*

TABLE 8

PREVIOUS ESTIMATES OF BASE FLOW THROUGH LOWER GATE

Author	Transmissivity (m^2/day)	Gradient	Width (m)	Baseflow (m^3/day)
Bazin	3456	0.0066	450	10264
Tahir	276	0.0066	450	820[1]
Ewbank	673[2]	0.0066	450	2000

Notes: *8200 in report*

inferred from report

have re-analysed these field data for wells 63 and 64 and feel confident that the transmissivity values should be 26 m^2/day and 25 m^2/day respectively.

It is not clear from the Ewbank report how they justify using a transmissivity of 673 m^2/day, a value that we have inferred from their suggestion that the subsurface baseflow at the lower gate is 60000 m^3/month (2000 m^3/day). However, compared with the field value of say 25 m^2/day, it does seem unreasonably high.

We have checked the gradient of the aquifer in the region of the lower gate during our field reconnaissance and would agree that a value of 0.0066 is realistic and that the maximum width of the aquifer at this point is 450 metres. Using these data, and the revised estimate of transmissivity, it would appear that the groundwater leakage through the lower gate is about 74 m^3/day which is about 0.5 percent of the average rate of abstraction in recent years. It is worth noting that for the groundwater leakage to be significant, say 10 percent of the abstraction rate, the transmissivity would have to be about 2500 m^2/day which is unrealistically high. Without further data we must conclude that groundwater baseflow is negligible and, as at the upper gate, it can be ignored in any water balance of the alluvial aquifer.

Fluctuations in groundwater level

There is no continuous record of groundwater level covering the whole period of wellfield abstractions. The longest record, levels at observation point K, covers the period 1946 to 1968. In recent years, detailed records were collected by the Geological and Mineral Survey for wells 23, 26, 34 and observation point 8 and the Public Electricity and Water Corporation started routine monthly observations at wells 23, 26, 34 and 46 in July 1976. Hydrographs for point K and well 23 shown in Figures 6 and 7 illustrate the historic fluctuations in groundwater level.

Figure 6

Water level at point K

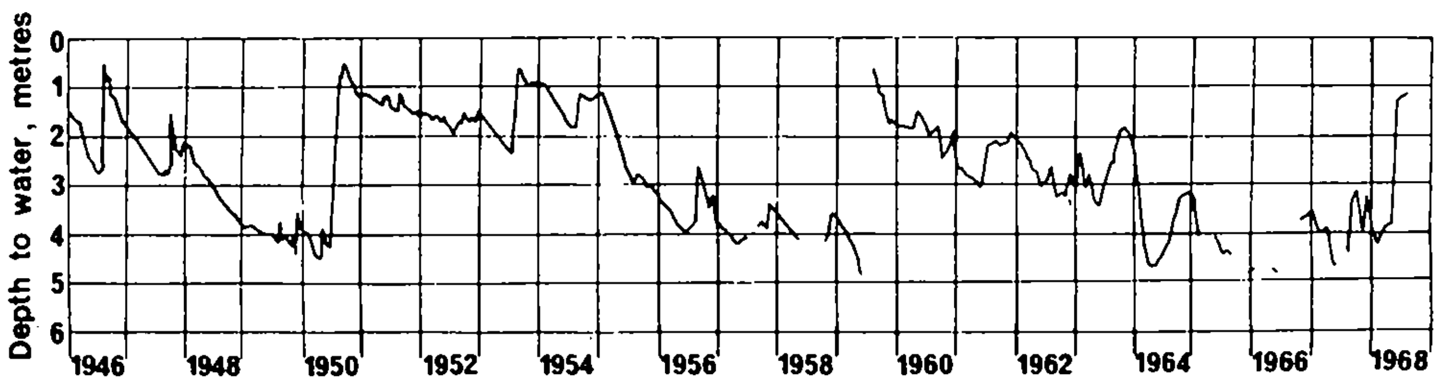
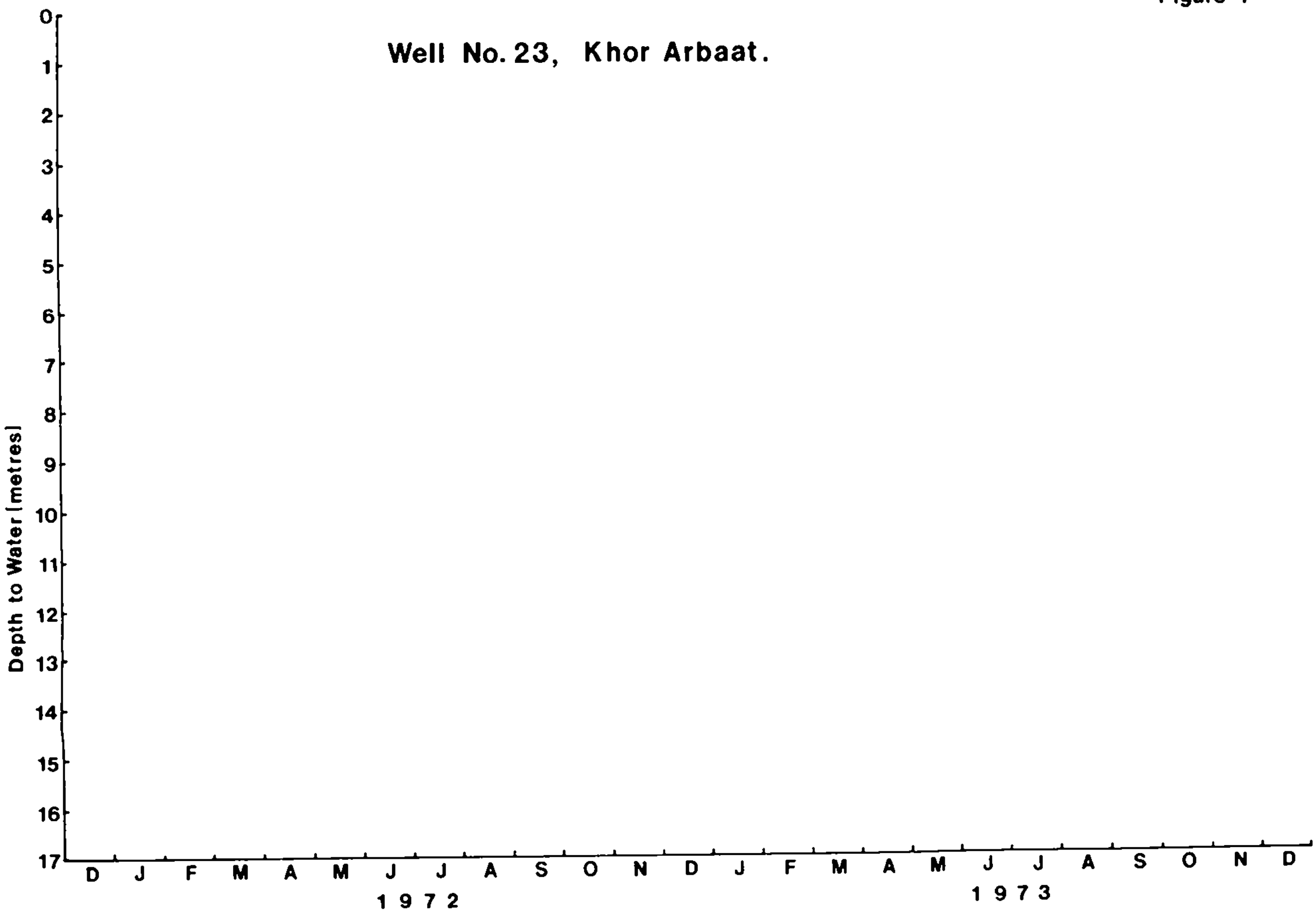


Figure 7


Well No. 23, Khor Arbaat.
Depth to Water [metres]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
D J F M A M J J A S O N D J F M A M J J A S O N D
1972
1973

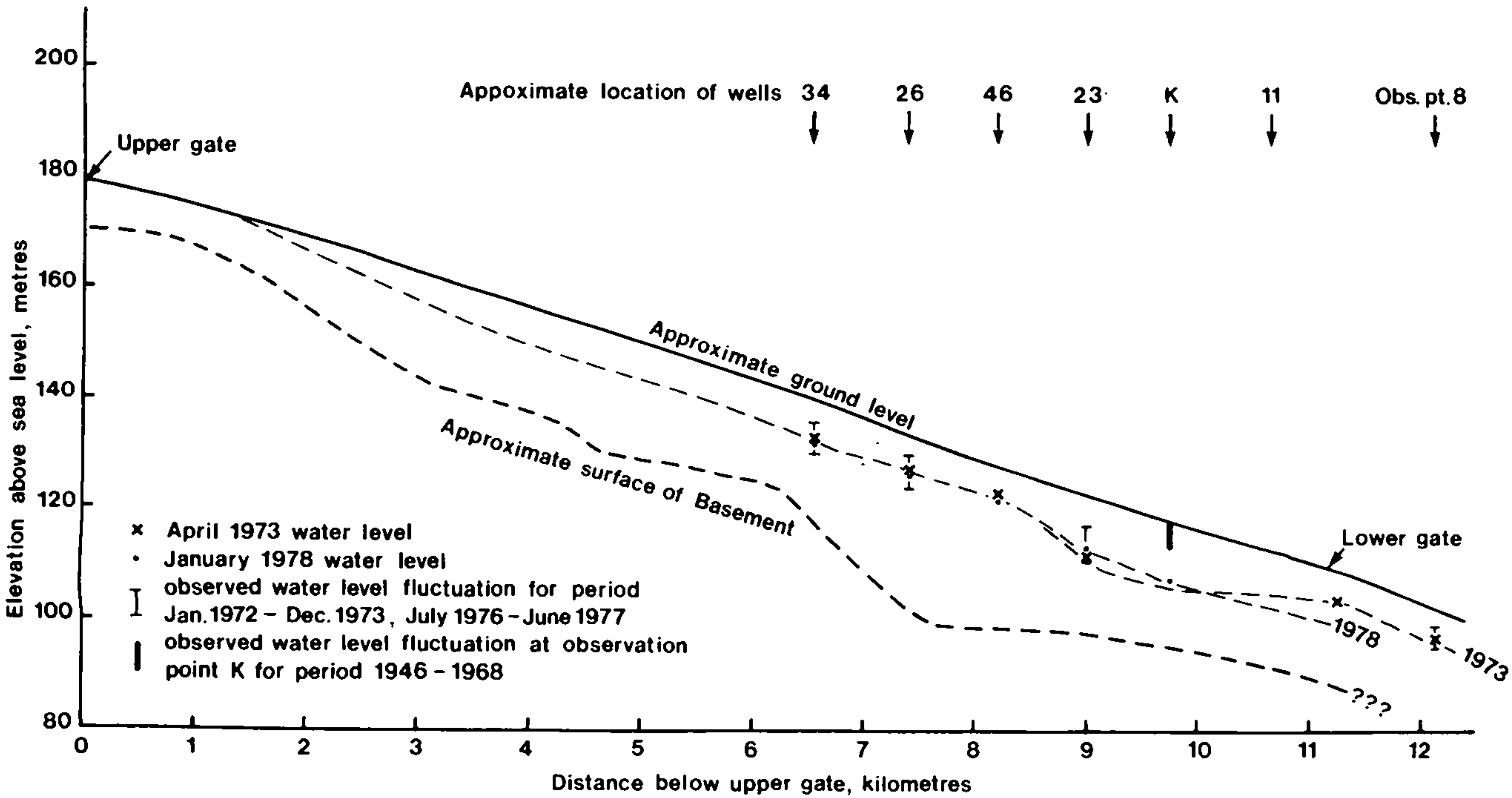
The hydrograph for point K shows that the groundwater level approached the surface on several occasions and dropped to about 5 metres below the surface in 1957, 1958, 1965 and 1966. Before 1957 abstractions were taken only from collector well 11 which is downstream of point K. In 1957, wells 20, 21, 22 and 24 were brought into operation and since 1966 more wells were drilled and brought into production, nearly all of them being upstream of point K (Table 1). The sparse wellfield production records suggest that total abstractions have increased from about 0.35 million m^3/month, prior to 1967 to about 0.45 million m^3/month subsequently. This increase in abstraction rate, together with the relocation of the wellfield further upstream has resulted in the water level at observation point K dropping to its present position of about 11 m below the surface.

The detailed water level records for 1972 and 1973 suggest that groundwater levels now fluctuate over a range of about 6 m and do not rise above a level of 7 m below the surface. This lowering of the groundwater level, together with the observed fluctuation in water level, is shown in Figure 8.

It would appear from the scarce water level data available that the general lowering of the water table in the area of the wellfield and downstream could be permanent. Recharge from flood flows is not sufficient to replenish the aquifer fully and we can only infer that increasing the total abstractions from the wellfield would lower the general level still further. Recharge from floods appears to be limited by the infiltration rate of the aquifer and not by the storage deficit alone as it probably was during the period when water level was being measured at point K. It must be emphasized however, that this conclusion has been drawn from very limited data; continued water level measurements are necessary to verify it.

Figure 8

Water level fluctuations in Khor Arbaat



During periods when no floods occur, abstractions from the wellfield are normally greater than recharge of the surface baseflow at the upper gate; consequently, water levels fall as storage is drawn down. Detailed analysis of these periods of recession should lead to estimates of the storage coefficient of the aquifer. Conversely, as flood flows produce excess recharge, water levels rise and analysis of these periods should provide an estimate of the recharge coefficient associated with flood flows.

Response of the aquifer system during recessions

Table 9 shows the observed baseflows at the upper gate, wellfield abstractions and water level changes at well 23, for the three recessions in the detailed record. The difference between the total abstractions and the total baseflow should be related to the fall in water level and a constant representing the product of the area of the aquifer and the storage coefficient.

Unfortunately, the three recession periods do not give a very consistent result; indeed the second period shows a declining water level associated with zero net change in storage. However, assuming a surface area of the active storage of 4 km^2, 10 km long by 400m wide, the storage coefficient suggested by the data for the other two recessions would be about 5 percent. This value would apply to water level fluctuations around 10 m below ground level.

In our analysis of water resources in the last section of this report, we estimate a range in storage of 3.3 million m^3 for the period when water levels fluctuated over the 5 m range

TABLE 9

THE AQUIFER SYSTEM DURING RECESSIONS

Upper Gate

		Surface base flow (million m^3)	Well field abstractions (million m^3)	Water level change (m)
1	1972	0.42	0.42	-1.2
2		0.34	0.40	-1.3
3		0.33	0.43	-0.2
4		0.22	0.42	0
Total		1.31	1.67	-2.7
11	1972	0.45	0.39	-1.0
12		0.48*	0.41	-0.2
1	1973	0.45	0.41	-0.8
2		0.39	0.42	-0.5
3		0.32	0.42	-0.5
4		0.39	0.41	-0.6
5		0.35	0.42	-0.5
6		0.47	0.42	-0.5
Total		3.30	3.30	-4.6
9	1973	0.32	0.48	-0.4
10		0.33	0.50	-0.4
11		0.42	0.46	-0.4
12		0.43	0.46	-0.3
Total		1.50	1.90	-1.5

* *Estimated values*

monitored at point K. Assuming the same active area of aquifer, the storage coefficient associated with the surface layers of the aquifer would be about 16 percent.

While these estimates must be regarded as tentative it is possible to draw some broad inferences. We can reasonably assume that the active length of the storage remains fairly constant. Thus it is likely that either the storage coefficient decreases with depth as the alluvium becomes more compacted and the occurrence of cemented beds increases, or the active width of the channel varies. It is most probably a combination of these two factors.

Response of the aquifer system to floods

Detailed records for the two periods covering the floods of 1972 and 1973 are shown in Table 10 where the last column indicates the average fall in water levels which would have occurred in the absence of recharge from floods. Thus the net rise in water level during the two periods is 5.8 and 2.0 m respectively. Using the storage coefficient of 5 percent derived in the previous section, these changes in water level are equivalent to 1.16 and 0.4 million m^3 over an active area of aquifer of 0.4 km By water balance these net volumes of recharge would require a contribution from flood flows equivalent to 7 and 1 percent of the flood flows in the two periods.

These figures are not unrealistic; the alluvium contains much fine silt and the recharge coefficient is not likely to be as high as that for the cleaner gravels upstream of the upper gate. While the difference between the values obtained for the two periods is relatively large, it does reflect differences in the pattern of flood flows; in 1972, the floods lasted for a total of 32 days, whereas the much greater flood volume of 1973 was concentrated into 11 days. On average, we would expect the recharge coefficient to lie between these values; the 1972 floods were of longer than average duration and the 1973 floods of exceptional volume.

TABLE 10

THE AQUIFER SYSTEM DURING RECHARGE

Date	Upper gate: Surface base flow (million m^3)	Upper gate: Flood flow (million m^3)	Upper gate: Flood duration days	Well field abstraction (million m^3)	Water level change (m)	Water level change during recession (m)
5 1972	0.35*			0.43	+0.6	0.55
6	0.37	0.07	4	0.45	+0.8	0.55
7	0.43	0.21	4	0.48	+0.1	0.55
8	0.38	7.22	8	0.46	+0.8	0.55
9	0.35	6.67	13	0.43	-0.6	0.55
10	0.53	5.42	3	0.41	+0.8	0.55
Total	2.41	19.59	32	2.66	2.5	3.30
7 1973	0.35	31.54	7	0.41	+1.6	0.55
8	0.29	35.92	4	0.51	-0.7	0.55
Total	0.64	67.46	11	0.92	0.9	1.10

* *Estimated values*

WATER RESOURCES AND AQUIFER YIELD

Water resources

Concurrent records of baseflows and floods at the upper gate, together with abstractions from the wellfield, are available for the years 1972 to 1976, excluding 1974. These data are summarised in Table 11, and serve to show that by far the greater part of the available resource derives from the baseflows which are known to contribute fully to recharge. As we have shown earlier, the flood flows, though large, are unable to replenish the storage completely now that it has been drawn down substantially, probably because of the limiting infiltration capacity of the alluvium. Thus we must infer from the short period of concurrent data that recharge from floods is probably of the order of 4 percent of the flood flows and could well be less should depletion of the storage have been significant over the period considered.

Since it appears unlikely, with increasing abstractions, that the alluvial storage will be replenished to the level of the 1960s, we can assume that the groundwater resource of the khor is the long term average baseflow at the upper gate plus a small fraction of the long term average flood flows. We must therefore determine the best estimate of these variables before we can estimate the yield of the aquifer.

The longest record available is that of rainfall at a number of stations in the region, but preliminary analysis suggested that the correlation between rainfall and flood flow was poor even on the annual basis. Thus it is unlikely that knowledge of the long term rainfall could be used to improve the estimate of average flood flow based on 18 years of record. The flood flow data, shown in Table 12, have a highly skewed distribution and we shall use the median value

TABLE 11

COMPARISON OF BASEFLOWS, FLOOD FLOWS AND ABSTRACTIONS FOR THE YEARS OF CONCURRENT DATA

(million m^3)

	Base Flow	Flood Flow	Abstraction
1972	4.65	23.10	5.13
1973	4.50	67.60	5.31
1975	3.56	7.16	5.29
1976	4.00	18.10	5.63
Total	16.71	115.96	21.36

Note:

If the average change in storage over these years is zero, the average recharge from floods would be:

$$(21.36 - 16.71)/115.96 \equiv 4 \text{ per cent}$$

TABLE 12

THE EXTENDED RECORD OF BASEFLOWS
(million m^3)

	Flood flow	Baseflow
1957	14.68	4.48
1958	9.85	4.51
1959	51.66	5.18
1960	10.08	3.44
1961	10.34	5.58
1962	9.65	4.24
1963	7.46	3.31
1964	5.17	3.50
1965	(9.79)	2.99
1966	9.15	2.53
1967	13.53	5.04
1968	(27.00)	6.50
1969	0.52	7.12
1970	9.24	5.35
1971	0.17	4.88
1972	23.10	4.65
1973	67.60	4.50
1974		3.87
1975	7.16	3.56
1976	18.10	4.00
1977	5.08	3.37
Mean	15.1	4.4
Median	9.8	

Notes: *The baseflows shown are derived from flood flows up to 1968 and are measured values thereafter*

The flood flows for 1965 and 1968 are estimated values of 9.8 million m^3/year as the best estimate of the likely average flood flow as the marginal value of the few very high flood flows could be small.

Baseflows derive from groundwater storage upstream of the upper gate and analysis of the monthly records for the period 1972-77 suggests that baseflow declines exponentially in the absence of floods and that an increase in baseflow usually coincides with known flood flows. Thus by representing the storage upstream of the upper gate by a simple conceptual groundwater reservoir, we can derive monthly baseflows from 1957 on the basis of the monthly flood records and a recharge coefficient. In practice, the calculation is slightly complicated by the fact that we know the flood flows at the upper gate and not at the inflow side of the upstream storage. Thus we cannot take account of small floods which in reality might not reach the upper gate. Partly to compensate for this, we have adopted a slightly lower rate of recession for baseflows. The capacity of the upstream storage and the recharge coefficient were chosen so as to reproduce the known baseflows of the later years. An annual summary of these baseflows and the flood flows is given in Table 12, which shows that our best estimate of long term average baseflow is 4.4 million m^3/year, a figure close to the mean recorded baseflow of the last 9 years.

We have shown by analysis of the short period of detailed water level data that the recharge coefficient associated with flood flows between the upper and lower gate is in the range 1 to 7 percent. This conclusion is supported by the gross estimate of 4 percent derived above. Thus, given long term estimates of baseflows and floods of 4.4 and 9.8 million m^3/year respectively, the long term average recharge of the khor alluvium is between 4.5 and 5.1 million m^3/year for the range of recharge coefficient. As expected, the effect of uncertainty in estimating the recharge coefficient for flood flows is relatively small.

The annual water balance of the aquifer is shown in Table 13 for the years 1957 to 1973. We have considered recharge coefficients for flood flows of 1 and 7 percent and abstraction rates of 4.2 million m^3/year up to 1966 and 5.4 million m^3/year thereafter based on the records of actual abstractions. The results for cumulative change in storage, given the higher recharge coefficient, suggest that the aquifer should be replenished fully in the 1970s following declining levels in the late 1960s. This does not accord with observations of water level and we must infer that the 7 percent recharge coefficient is too high. The lower value of 1 percent leads to a more realistic conclusion and suggests that the range of fluctuation in groundwater storage has been about 5.4 million m^3 over the period. In this analysis we have taken account of a reduction of recharge when the aquifer is fully replenished.

During the period when groundwater levels were measured at point K the range of storage indicated by the water balance model is 4.25 or 2.41 million m^3 for the alternative recharge coefficients. We have used the average of these figures, 3.3 million m^3, to infer a storage coefficient for the upper 4.5 m of the aquifer earlier in this report.

Aquifer yield

In the long term the maximum yield of the aquifer is equal to the long term average recharge if there is sufficient storage available to allow for periods of deficient inflow. Table 14 shows the changes in storage that would have occurred over the 17 year period 1957-1973 had abstractions taken place at a rate of 4.5 million m^3/year, equivalent to our best estimate of the long term recharge.

The range of storage required is about 6 million m^3 which is within the capacity of the aquifer. Thus we can conclude

SUMMARY OF MODEL OF HISTORIC SEQUENCE OF FLOWS
(million m^3)

	Annual baseflow	Annual floodflow	Change in storage over year 1	Change in storage over year 2	Cumulative change in storage over year 1	Cumulative change in storage over year 2
1957	4.48	14.68	0.43	1.00	0.43	1.00
1958	4.51	9.85	0.41	0.00	0.84	1.00
1959	5.18	51.66	0.16	0.00	1.00	1.00
1960	3.44	10.08	-0.79	-0.19	0.21	0.81
1961	5.58	10.34	0.79	0.19	1.00	1.00
1962	4.24	9.64	0.00	0.00	1.00	1.00
1963	3.31	7.46	-0.91	-0.52	0.09	0.48
1964	3.50	5.17	-0.65	-0.34	-0.56	0.14
1965	2.99	9.79	-1.11	-0.52	-1.67	-0.38
1966	2.53	9.15	-1.58	-1.03	-3.25	-1.41
1967	5.04	13.53	-0.22	0.59	-3.47	-0.82
1968	6.50	27.00	1.37	1.82	-2.10	1.00
1969	7.12	0.52	1.73	0.00	-0.37	1.00
1970	5.35	9.24	0.04	-0.07	-0.33	0.93
1971	4.88	0.17	-0.52	-0.77	-0.85	0.16
1972	4.65	23.10	-0.52	0.84	-1.37	1.00
1973	4.50	67.60	-0.22	-0.30	-1.59	0.70

Notes:

Denotes lower estimate based on a recharge coefficient of 1 percent to Khor Arbaat

Denotes higher estimate based on a recharge coefficient of 7 percent to Khor Arbaat

Abstraction = 4.2 million m^3 per year from 1957 to 1966 and

5.4 million m^3 per year from 1967 to 1973

Since the storage deficit at the start of 1957 was assumed to be 1 million m^3, 1.00 in the last two columns indicates that the storage is fully replenished

TABLE 14

SUMMARY OF MODEL OF FUTURE SEQUENCE OF FLOWS

(million m^3)

	Annual Baseflow	Annual Floodflow	Change in storage over year	Cumulative change in storage over year
1	4.48	14.68	0.16	0.16
2	4.51	9.85	0.05	0.21
3	5.18	51.66	0.78	0.99
4	3.44	10.08	-1.26	-0.27
5	5.58	10.34	1.12	0.85
6	4.24	9.65	-0.23	0.62
7	3.31	7.46	-1.18	-0.56
8	3.50	5.17	-1.01	-1.57
9	2.99	9.79	-1.47	-3.04
10	2.53	9.15	-1.94	-4.98
11	5.04	13.53	0.62	-4.36
12	6.50	27.00	2.21	-2.15
13	7.12	0.52	2.57	0.42
14	5.35	9.24	0.56	0.98
15	4.88	0.17	-0.52	0.46
16	4.65	23.10	0.32	0.78
17	4.50	67.60	0.15	0.93

Note: Rate of abstraction = 4.50 per year
Recharge coefficient = 1 per cent

that if the aquifer were now full and abstractions were started at the rate of 4.5 million m^3/year, there would be sufficient storage to maintain this yield.

However, it would seem that in recent years abstractions have exceeded the estimates of yield derived above. This has, at least in part, caused a permanent lowering of the water table reducing the storage in reserve. Eventually abstractions at the present rate or any higher rate are likely to cause a progressive lowering of the water table until such time as there remains insufficient storage to allow the rate of abstraction to continue. It would then be necessary to reduce abstractions for a period of possibly several years while water levels recovered.

This unattractive conclusion is of course based on relatively few data. The baseflow record is short and there are important gaps in our knowledge, particularly in terms of the water level fluctuations over the aquifer as a whole and the lack of refined pumping tests to determine aquifer characteristics precisely. However, we cannot advise increasing abstractions from the aquifer with present knowledge.

This current analysis has highlighted the poor infiltration characteristics of the aquifer which leads to very little recharge being gained from the flood flows. Thus the most promising direction for future development of the khor would be some temporary flood storage upstream whereby the baseflows following floods could be augmented. Since flood flows tend to be large but infrequent, it will be necessary to consider fairly large flood storage to achieve any significant benefit.

Alternative water sources

Most of the khors rising in the Red Sea hills have a very small catchment area, less than 400 km^2. The Khor Sallom, catchment area 2200 km^2, which is 40 km south west of Port Sudan, and the Khor Baraka, catchment area 4500 km^2

some 150 km south of Port Sudan, are considered to be the only two major resources which are worth exploring to augment the Port Sudan water supply.

A hydrological survey of the Tokar Delta, which is recharged by the Khor Baraka, has been carried out by the Rural Water Corporation[4] and a surface resistivity survey by the Geological and Mineral Resources Department[5]. The Tokar Delta is an alluvial fan of area 900 km^2. The average annual discharge of the khor is about 300 million m^3/year, but only a small fraction of this would be available for recharge. Exploratory boreholes have been drilled in the area to depths not exceeding 32 m and the pumping test results show the aquifer transmissivity to be in the range 500 to 4000 m^2/day with a storage coefficient of less than 1 percent.

The geophysical survey in this area has identified a major aquifer beneath the one described by RWC and the total saturated thickness may extend to 200 m. Further detailed exploratory drilling to depths exceeding 200 m are now needed, together with pumping tests, before the water resources of the Tokar Delta can be evaluated. It is known that salt water intrustion has taken place and any exploitation of the delta must be limited in such a way as to prevent further intrusion.

The Khor Sallom, which was not visited during our survey, has been described in the Ewbank and Partners report. They suggests that exploratory drilling be carried out downstream of the Tutali/Okwat confluence, where they would expect a wellfield to yield up to 150000 m^3/month.

Hydrogeology of the Tokar Delta by Salah El Natiq, Rural Water Corporation, 1976

Geophysical report of Tokar Delta, Geological and Mineral Resources Department, 1977

APPENDIX A

Well register

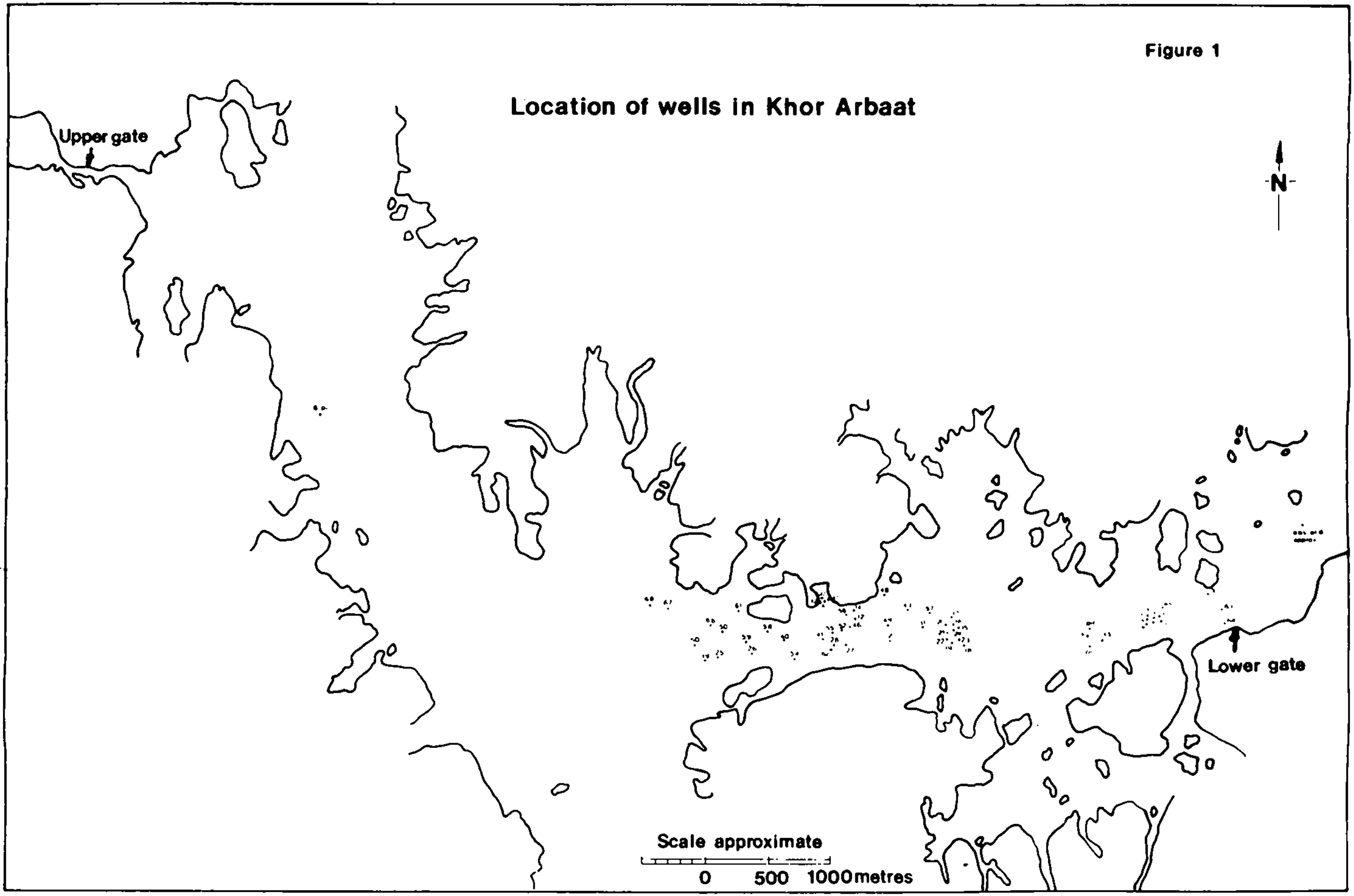
A summary of the construction details, pumping test results, water level data and water chemistry data are contained in the following well register.

The location of the wells and boreholes are shown in Figure 1 and the well numbering system is that used by the Public Electricity and Water Corporation, Port Sudan.

These data have been extracted from records held by the Rural Water Corporation, Geological and Mineral Resources Department and the Public Electricity and Water Corporation in both Port Sudan and Khartoum.

Figure 1

Location of wells in Khor Arbaat



Reference No: 11 Collector well	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1936	Yield: ∿ 8640 m^3/d
Contractor:	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

From 1936 - mid 1940 was only well for town supply. Pump trough in area makes well useless now except with high wt

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 113 masl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH

WATER LEVEL OBSERVATIONS FOR OBSERVATION POINT 8

KHOR ARBAAT

Source Geological Survey Bulletin 28

Date	SWL	Date	SWL
7.12.71	5.70	25.10.72	4.90
14.12.71	5.90	13.11.72	5.10
21.12.71	5.80	21.11.72	5.29
28.12.71	5.85	28.11.72	5.39
14. 1.72	5.90	5.12.72	5.51
18. 1.72	5.92	12.12.72	5.40
24. 1.72	5.94	17.12.72	-
10. 2.72	6.00	26.12.72	5.80
21. 2.72	6.87	20.12.72	5.60
24. 2.72	7.05	3. 1.73	5.90
6. 3.72	7.20	10. 1.73	6.06
15. 3.72	7.15	21. 1.73	6.10
20. 3.72	7.20	27. 1.73	6.20
27. 3.72	7.25	6. 2.73	6.40
3. 4.72	7.50	12. 2.73	6.60
8. 4.72	7.50	24. 2.73	7.55
27. 4.72	7.60	6. 3.73	6.70
6. 5.72	7.70	14. 3.73	7.70
13. 5.72	7.75	26. 3.73	7.70
20. 5.72	6.75	5. 4.73	7.62
10. 6.72	6.55	17. 4.73	7.62
17. 6.72	6.30	6. 5.73	dry
2. 7.72	6.30	15. 5.73	
10. 7.72	6.10	23. 5.73	
19. 7.72	6.20	5. 6.73	
26. 7.72	6.30	13. 6.73	
2. 8.72	6.14	19. 6.73	
16. 8.72	5.70	26. 6.73	
20. 8.72	5.69	19. 7.73	
30. 8.72	4.63	22. 7.73	
4. 9.72	5.30	2. 8.73	
12. 9.72	5.20	9. 8.73	7.70
20. 9.72	5.18	25. 8.73	8.37
27. 9.72	5.10	1. 9.73	8.49
4.10.72	5.05	1.10.73	6.70
11.10.72	5.20	16.10.73	6.76
18.10.72	5.30	5.11.73	7.20

Reference No: 12	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1942/43	Yield:
Contractor:	Drawdown:
Depth: 12.14 m	Length of test:
Diameter: 4.40 m	Pump setting:
Casing:	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 3.0 m agl

Lithology: 130 m asl (Geol Survey)

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	11.740					
				22.1.78	2200	

Reference No:	Grid Reference:
Name: Pit upstream of 13	Location: KHOR ARBAAT PORT SUDAN
Date Constructed:	Yield:
Contractor:	Drawdown:
Depth:	Length of test:
Diameter: ~ 1 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum:

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	7.5 m			16.1.78	3750	

WATER LEVEL OBSERVATIONS FOR POINT K

KHOR ARBAAT

Date	SWL	Date		SWL
July 1964	114.62	July 1966		Dry
Aug	114.72	Aug		Dry
Sept	115.15	Sept		115.18
Oct	115.72	Oct		115.27
Nov	115.76	Nov		115.29
Dec	115.85	Dec		115.41
Jan 1965	115.71	Jan 1967		115.07
Feb	114.87	Feb		115.00
March	Dry	March		115.11
April	Dry	April		114.35
May	114.93	May		114.23
June	114.82	June		Dry
July	114.02	July		Dry
Aug	114.16	Aug		114.03
Sept	114.00	Sept		114.00
Oct	Dry	Oct		114.47
Nov	Dry	Nov		115.83
Dec	114.12	Dec		115.02
Jan 1966	114.17	Jan 1968		114.73
Feb	114.20	Feb		115.05
March	Dry	March		115.12
April	Dry	April	) Most	115.72
May	114.22	May	) severe) floods for	117.78
June	114.10	June	) 60 years	117.83 max

Reference No: 14	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1965/66	Yield:
Contractor:	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing: Mild steel in open well	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum:

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
Casting top high above ground level						

Reference No: 15	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (12.54 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 31 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.75 m agl 128 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.730 m			16.1.78	3100	

Reference No: 16	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (15.50 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 30 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.80 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.667 m					

Reference No: 17	Grid Reference:
Name:	Location: KHOR AREAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (14.65 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 33 cm	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.70 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.360 m			16.1.78	2500	

Reference No: 18	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN.
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (11.58 m on 16.1.78)	Length of test:
Diameter: -	Pump setting:
Casing: Mild steel 31 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.70 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	8.91 m			16.1.78	3000	

Reference No: 19	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
16.1.78	Dry					

Reference No: 20	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN.
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (17.28 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.37 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
16.1.78	9.870			16.1.78	2750	

Reference No: 21	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (18.20 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.98 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.930			16.1.78	3100	

Reference No: 22	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (12.10 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 1.00 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.105 m			16.1.78	2800	

Reference No: 23	Grid Reference:
Name: Obs point No 1 (RWC)	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (12.80 m on 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 31 cm	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 1.05 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.36 m			16.1.78	3200	
July 1976	9.94					
Aug	10.00					
Sept	9.45					
Oct	9.40					
Nov	9.26					
Dec	8.73					
Jan 1977	8.74					
Feb	8.77					
March	8.85					
April	8.78					
May	9.07					
Jun	9.11					

WATER LEVEL OBSERVATIONS FOR WELL NO 23

KHOR ARBAAT

Source Geological Survey Bulletin 28

Date	SWL	Date	SWL
7.12.71	7.00	25.10.72	8.55
14.12.71	7.00	13.11.72	9.20
21.12.71	7.50	21.11.72	9.20
28.12.71	7.70	28.11.72	9.30
14. 1.72	8.10	5.12.72	9.40
18. 1.72	8.80	12.12.72	-
24. 1.72	8.50	17.12.72	-
10. 2.72	9.50	26.12.72	9.45
21. 2.72	10.00	30.12.72	9.50
24. 2.72	10.25	3. 1.73	5.90
6. 3.72	10.40	10. 1.73	9.90
15. 3.72	10.50	21. 1.73	10.80
20. 3.72	10.55	27. 1.73	10.00
27. 3.72	10.55	6. 2.73	10.10
3. 4.72	9.45	12. 2.73	10.25
8. 4.72	10.50	24. 2.73	10.25
27. 4.72	10.55	6. 3.73	9.92
6. 5.72	10.52	14. 3.73	7.16
13. 5.72	10.60	26. 3.73	10.34
20. 5.72	10.30	5. 4.73	7.58
10. 6.72	9.50	17. 4.73	10.23
17. 6.72	9.25	6. 5.73	10.80
2. 7.72	9.20	15. 5.73	12.70
10. 7.72	9.22	23. 5.73	12.65
19. 7.72	9.30	5. 6.73	12.70
26. 7.72	9.40	13. 6.73	12.60
2. 8.72	9.20	19. 6.73	12.70
16. 8.72	8.70	26. 6.73	12.80
20. 8.72	8.80	19. 7.73	12.85
30. 8.72	8.60	22. 7.73	9.80
4. 9.72	8.70	2. 8.73	11.60
12. 9.72	8.90	9. 8.73	10.60
20. 9.72	9.00	25. 8.73	11.70
27. 9.72	8.94	1. 9.73	11.90
4.10.72	9.10	1.10.73	9.90
11.10.72	9.20	16.10.73	10.20
18.10.72	9.30	5.11.73	10.42

Reference No: 24	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1956/57	Yield:
Contractor:	Drawdown:
Depth: (20.45 m in 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 31 cm	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.75 m agl 121 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.78	9.775 m			16.1.78	2500	

Reference No: 25 (Geol Survey 1)	Grid Reference:
Name:	Location: KHOR ARBAAT, PORT SUDAN
Date Constructed: 1963/64	Yield: 1637 m^3/d
Contractor:	Drawdown: 2.29 m
Depth: 30.48 m (28.50 m 16.1.78)	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 22 cm diam	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity: 715 m^2/d

Water quality: Date of test: Temperature (°C):

Screen: Very small slots from 15.42 m

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production 1965. Out production 1966. Screens blocked failed to clear

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 138.0 m asl (Geol Survey) 138.6 m amsl (PEWC) Casing 0.44 m agl

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
25.4.64	5.29 m					
16.1.78	9.50 m			16.1.78	> 10000	

Reference No: 26 (Geol Survey 2)	Grid Reference:
Name: Obs point no 3 (RWC)	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: Small
Contractor:	Drawdown:
Depth: 31.09 m (27.40 m 16.1.78)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 23 cm diameter	Pump capacity:
Screen: Very small slots	

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production 1973/74

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Very saline but after 1973 August floods quality improved

Surface datum: 135.0 m asl (Geol Survey) 135.9 m amsl (PEWC) Casing 0.14 m agl

Lithology:

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
25.4.1964	4.10 m			16.1.1978	15,000	
16.1.1978	9.105 m					
July 1976	11.45					
August	11.38					
September	10.12					
October	10.72					
November	10.55					
December	10.12					
Jan 1977	10.08					
February	10.60					
March	10.63					
April	10.67					
May	10.79					
June	10.90					

WATER LEVEL OBSERVATIONS FOR WELL NO 26
KHOR ARBAAT

Source Geological Survey Bulletin 28

Date	SWL	Date	SWL
7.12.71	4.70	25.10.72	5.99
14.12.71	4.90	13.11.72	6.20
21.12.71	4.10	21.11.72	6.49
28.12.71	5.00	28.11.72	6.55
14. 1.72	5.30	5.12.72	6.70
18. 1.72	5.74	12.12.72	7.00
24. 1.72	5.70	17.12.72	7.00
10. 2.72	6.23	26.12.72	7.05
21. 2.72	6.25	30.12.72	7.03
21. 2.72	6.60	3. 1.73	9.50
6. 3.72	6.50	10. 1.73	7.24
15. 3.72	6.50	21. 1.73	7.15
20. 3.72	6.70	27. 1.73	7.20
27. 3.72	6.40	6. 2.73	7.20
3. 4.72	-	12. 2.73	6.65
8. 4.72	6.90	24. 2.73	-
27. 4.72	7.00	6. 3.73	8.00
6. 5.72	7.05	14. 3.73	10.31
13. 5.72	7.07	26. 3.73	7.66
20. 5.72	7.00	5. 4.73	10.05
10. 6.72	6.10	17. 4.73	7.88
17. 6.72	-	6. 5.73	9.85
2. 7.72	7.45	15. 5.73	10.00
10. 7.72	5.40	23. 5.73	10.30
19. 7.72	8.00	5. 6.73	10.20
26. 7.72	6.00	13. 6.73	10.30
2. 8.72	5.97	19. 6.73	10.20
16. 8.72	5.80	26. 6.73	10.20
20. 8.72	5.90	19. 7.73	-
30. 8.72	5.90	22. 7.73	-
4. 9.72	5.90	2. 8.73	7.25
12. 9.72	5.88	9. 8.73	-
20. 9.72	6.00	25. 8.73	-
27. 9.72	6.05	1. 9.73	-
4.10.72	6.10	1.10.73	-
11.10.72	6.10	16.10.73	-
18.10.72	6.20	5.11.73	7.80

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TELEX 337273

Your Ref.

ANALYSIS OF A SAMPLE OF WATER received 9.3.78 Our Ref. E/3/1724

from R.B. BRADFORD, INSTITUTE OF HYDROLOGY, CROWMARSH GIFFORD, WALLINGFORD, OXON.

Labelled Sample of Water marked No. 26 23.1.78

Date

Taken by Witness Signed

RESULTS IN MILLIGRAMMES PER LITRE

Appearance Faint opalescence with many large black particles

Turbidity (Formazin, A.P.H.A., units) 5

Colour (Hazen) 7 (filtered) Odour Nil

pH 6.5 Free Carbon Dioxide 3

Electrical Conductivity 15,000 Dissolved Solids dried at 180°C. 11500
Reciprocal Megohms (Micro-Siemens) per cm. at 20°C.

Chlorine in Chloride 5200 Alkalinity as Ca CO_3 5

Hardness as Ca CO_3: Total 5,400 Carbonate 5 Non-carbonate 5,395

Nitrogen in Nitrate 0.0 Total Organic Carbon

Nitrogen in Nitrite Absent Permanganate Value 0.8
4 hrs. at 27°C.

Ammoniacal Nitrogen 0.06 Residual Chlorine

Albuminoid Nitrogen 0.08 Fluorine in Fluoride

Iron 2.45 Zinc 3.0 Copper Absent Lead Absent Manganese 0.98

Cadmium Not detected less than 0.001
("Absent" refers to a detection limit of 0.03 of each metal unless otherwise stated)

signed

PSWaterhouse

RBB

P.S. WATERHOUSE
for: THRESH BEALE & SUCKLING

PSW/EEH
29th March, 1978

Reference No: 27 (Geol Survey 3)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: 1637 m^3/d
Contractor:	Drawdown: 0.91 m
Depth: 30.48 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 23 cm diameter	Pump capacity:
Screen: Very small slots from 13.72 m	

Transmissivity:	Coefficient of storage:	Specific capacity: 1799 m^2/d
Water quality:	Date of test:	Temperature (^0C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production 1965
Out production 1966
Blocked screen failed to clear

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 133.0 m asl (Geol Survey) 133.7 m amsl (PEWC)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
25.4.1964	3.45 m					

Reference No: 28 (Geol Survey 4)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: 1637 m^3/d
Contractor:	Drawdown: 0.91 m
Depth: 29.87 m (28.35 m in 22.1.78)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 23 cm diameter	Pump capacity:
Screen: Very small slots from 13.72 m	

Transmissivity: Coefficient of storage: Specific capacity: 1799 m^2/d

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production 1965
Out production 1966
Blocked screen failed to clear

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 131 m asl (Geol Survey) 133 m a msl (PEWC) Casing 0.60 m agl

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
25.4.1964	3.79 m			22.1.78	1300	
22.1.1978	10.655 m					

Reference No: 29 (Geol Survey 5).	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: 1637 m^3/d
Contractor:	Drawdown: 0.88 m
Depth: 31.39 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 23 cm diameter	Pump capacity:

Screen: Very small slotts from 15.24 m

Transmissivity:	Coefficient of storage:	Specific capacity: 1860 m^2/d
Water quality:	Date of test:	Temperature (^0C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production 1965
Out of production 1966
Cleaned with no effect

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 139.0 m asl (Geol Survey) 139.5 m amsl (PEWC)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
25.4.1964	5.73					

Reference No: 30 (Geol Survey 6)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: 764 m^3/d
Contractor:	Drawdown:
Depth: 30.48 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 26 cm diameter	Pump capacity:

Screen: Very small slotts from 15.24 m

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production 1965
Out production 1965
Blocked screen, not cleaned

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 128 m asl (Geol Survey) 131 m amsl (PEWC)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
25.4.1964	5.34 m					

Reference No: 31 (Geol Survey 7)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1963/64	Yield: 764 m^3/d
Contractor:	Drawdown:
Depth: 26.52 m (26.60 m on 22.1.78)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:
Screen: Very small slotts from 12.19 m	

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

Not put into production Screens blocked

Ca, Mg, Na, K — HCO_3, SO_4, Cl, NO_3

Scale p.p.m. 0

Surface datum: 126.0 m asl (Geol Survey) 127.9 m amsl (PEWC) Casing 0.17 m agl

Lithology:

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
25.4.1964	5.19 m			22.1.1978	2500	
22.1.1978	8.38 m					

Reference No: 32 (Geol Survey 1)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 Geol Survey)	Yield: 327 m^3/d
Contractor: RWC	Drawdown:
Depth: 24.69 m (16.90 m on 22.1.78)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:

Screen: Very small slotts from 22.25 m

Transmissivity: Coefficient of storage: Specific capacity: 61 m^2/d

Water quality: Date of test: Temperature (^{0}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

Not put into production

Ca — HCO_3
Mg — SO_4
Na — Cl
K — NO_3

Scale p.p.m. 0

Surface datum: 131.0 m asl (Geol Survey) Casing 0.50 m agl

Lithology: 0-16.76 m crushed boulder and gravel which is cemented with few clay and coarse sand 16.76-21.34 m Weathered basement complex 21.34-24.69 m Crushed fresh basement complex

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
25.4.1964?	4.27 m			22.1.1978	1600	
22.1.1978	8.70 m					

Reference No: 33 (Geol survey ?)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 (Geol Survey)	Yield: low
Contractor: RWC	Drawdown:
Depth: 24.99 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:
Screen: Very small slotts from 22.86 m	

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^0C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

Well not put in production too saline

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 138.0 m asl (Geol Survey)

Lithology: 0-15.24 m boulders and gravel. 15.24-18.29 m brown sandy clay with pebbles 18.29-21.34 m weathered basement complex: 21.34-24.38 m fresh basement complex

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
1966	6.40 m					

Reference No: 34 (Geol Survey 3)	Grid Reference:
Name: Obs point No 4 (RWC)	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 Geol Survey)	Yield: 655 m^3/d
Contractor: RWC	Drawdown: 2.90 m
Depth: 25.60 m (25.60 m 16.1.78)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:
Screen: Slotted from 21.34 m	

Transmissivity: 2121 m^2/d (source Geol Survey)	Coefficient of storage: 0.0008	Specific capacity: 226 m^2/d
Water quality:	Date of test: 28.1.72	Temperature (^0C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production Aug 1966
Out production June 1967
Screens blocked unable to clear

Ca, Mg, Na, K — HCO_3, SO_4, Cl, NO_3

0

Scale p.p.m.

Surface datum: 140.0 m asl (Geol Survey) Casing 0.61 m agl

Lithology:

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
Aug 1966	6.58 m			16.1.1978	4250	
16.1.78	8.95 m					
July 1976	9.88 m					
Aug	9.00 m					
Sept	9.01 m					
Oct	8.68 m					
Nov	8.85 m					
Dec	8.03 m					
Jan 1977	8.35 m					
Feb	8.89 m					
March	8.96 m					
April	9.36 m					
May	9.46 m					
June	9.08 m					

WATER LEVEL OBSERVATIONS FOR WELL NO 34

KHOR ARBAAT

Source Geological Survey Bulletin 28

Date	SWL	Date	SWL
7.12.71	5.90	25.10.72	7.40
14.12.71	6.00	13.11.72	7.60
21.12.71	6.00	21.11.72	7.80
28.12.71	6.10	28.11.72	7.92
14. 1.72	6.18	5.12.72	7.94
18. 1.72	6.30	12.12.72	–
24. 1.72	6.35	17.12.72	–
10. 2.72	7.45	26.12.72	7.90
21. 2.72	–	30.12.72	7.90
24. 2.72	7.50	3. 1.73	7.02
6. 3.72	7.55	10. 1.73	7.94
15. 3.72	7.60	21. 1.73	8.00
20. 3.72	7.60	27. 1.73	8.00
27. 3.72	7.80	6. 2.73	–
3. 4.72	7.80	12. 2.73	7.95
8. 4.72	–	24. 2.73	8.05
27. 4.72	–	6. 3.73	7.12
6. 5.72	8.30	14. 3.73	8.33
13. 5.72	8.50	26. 3.73	7.24
20. 5.72	–	5. 4.73	8.95
10. 6.72	–	17. 4.73	–
17. 6.72	–	6. 5.73	12.50
2. 7.72	7.36	15. 5.73	10.70
10. 7.72	7.30	23 5.73	11.10
19. 7.72	7.27	5. 6.73	11.20
26. 7.72	7.26	13. 6.73	–
2. 8.72	6.31	19. 6.73	[illegible]
16. 8.72	7.10	26. 6.73	–
20. 8.72	7.10	19. 7.73	[illegible]
30. 8.72	6.90	22. 7.73	[illegible]
4. 9.72	7.10	2. 8.73	–
12. 9.72	7.20	9. 8.73	9.70
20. 9.72	7.20	25. 8.73	[illegible]
27. 9.72	–	1. 9.73	
4.10.72	7.40	1.10.73	10.60
11.10.72	7.50	16.10.73	[illegible]
18.10.72	7.60	5.11.73	8.61

Reference No: 35 (Geol Survey 4)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 Geol Survey)	Yield: 1091 m^3/d
Contractor: RWC	Drawdown: 1.65 m
Depth: 25.91 m (26.10 m silt bottom)	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:

Screen: Very small slots - now enlarged from 21.95 m

Transmissivity: | Coefficient of storage: | Specific capacity: 661 m^2/d

Water quality: | Date of test: | Temperature (^0C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production Aug 1966
Slots have been enlarged
Not in production 1978

Ca | Mg | Na | K — HCO_3 | SO_4 | Cl | NO_3

Scale p.p.m. 0

Surface datum: 143.0 m asl (Geol Survey) Casing 0.57 m agl

Lithology: 0-22.86 m Boulders, gravel cemented beds and small clay. 22.86-24.38 m Weathered basement complex. 24.38-25.91 m Basement complex

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
1966	8.44 m			16.1.78	1400	
16.1.1978	10.225 m					

Reference No: 36 (Geol Survey 5)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 Geol Survey)	Yield: 1855 m^3/d
Contractor: RWC	Drawdown: 0.76 m
Depth: 25.3 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:

Screen: Enlarged slotts from 21.34 m

Transmissivity:	Coefficient of storage:	Specific capacity: 2441 m^2/d
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production Aug 1966 to date

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 145.0 m asl (Geol Survey)

Lithology: 0-23.47 m boulders and gravel. 23.47-24.38 weather basement complex 24.38-25.30 fresh basement complex

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
1965?	9.51 m			16.1.1978	1300	

Reference No: 37 (Geol Survey 6)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66 (1964/65 Geol Survey)	Yield: 1855 m^3/d
Contractor: RWC	Drawdown: 0.76 m
Depth: 24.99 m	Length of Test:
Diameter:	Pump setting:
Casing: Mild steel 27 cm diameter	Pump capacity:
Screen: Enlarged slotts from 21.34 m	

Transmissivity:	Coefficient of storage:	Specific capacity: 2441 m^2/d
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production August 1966 to date

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 144.0 m asl (Geol Survey)

Lithology: 0-23.47 boulders and gravel. 23.47-24.38 weathered basement complex. 24.38-24.99 m fresh basement complex

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
Aug 1966	8.23 m			16.1.1978	1400	

Reference No: 38	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1965/66	Yield: 1027 m^3/d
Contractor:	Drawdown: 1.74 m
Depth: (14 m on 16.1.78)	Length of Test: 3 hrs
Diameter: Hand dug 3.1 m	Pump setting:
Casing:	Pump capacity:
Screen:	

Transmissivity: 200 m^2/d (source Geol Survey)	Coefficient of storage:	Specific capacity: 590 m^2/d
Water quality:	Date of test: 28.1.1972	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production

Pump test data from Geol Survey Bulletin No 28

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 140.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
16.1.1978	DWL 12.6 m			16.1.1978	1300	

Reference No: 39	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 1966/67	Yield:
Contractor:	Drawdown:
Depth:	Length of Test:
Diameter:	Pump setting:
Casing:	Pump capacity:

Screen:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{0}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

Hand dug well blocked with silt to ground level

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: 138.0 m asl (Geol Survey)

Lithology:

Date	SWL (BSD)	Date	SWL (BSD)	Date	μmhos	pH

Reference No: 40	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1966/67	Yield:
Contractor:	Drawdown:
Depth: 9.0 m	Length of test:
Diameter: 1.90 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.40 m agl 133.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	Dry					

Reference No: 41	Grid Reference:
Name:	Location: KHOR ARBAAT PORD SUDAN
Date Constructed: 1967/68	Yield:
Contractor:	Drawdown:
Depth: 14.40 m	Length of test:
Diameter: 3.0 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production
Jan 1978
∿ 1 m^3/1.5 mins
Drawing air

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.10 m agl 132.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	DWL 13.30m			22.1.78	1500	

Reference No: 42	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1967/68	Yield:
Contractor:	Drawdown:
Depth: 12.05 m	Length of test:
Diameter: 2.80 m	Pump setting:
Casing:	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 3.0 m agl 132.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	11.30 m			22.1.78	1600	

Reference No: 43	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1968/69	Yield:
Contractor:	Drawdown:
Depth: 10.60 m	Length of test:
Diameter: 1.95 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.45 m agl 128.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
22.1.78	Dry					

Reference No: 45	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1968/69	Yield:
Contractor:	Drawdown:
Depth: 10.60 m	Length of test:
Diameter: 2.95 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.80 m agl 131.41 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	Dry					

Reference No: 46	Grid Reference:
Name: Obs point No 2 (RWC)	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1969/70	Yield:
Contractor:	Drawdown:
Depth: 19.56 m (silty)	Length of test:
Diameter: (Geol Survey say open well)	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 1.0 m agl 132.15 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
22.1.78	10.72 m			22.1.78	1500	
July 1976	9.53					
Aug	9.45					
Sept	8.80					
Oct	8.85					
Nov	8.78					
Dec	8.05					
Jan 1977	8.35					
Feb	8.47					
March	8.85					
April	8.51					
May	8.70					
June	9.00					

Reference No: 47	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1969/70	Yield:
Contractor:	Drawdown:
Depth: 10.20 m	Length of test:
Diameter: 3.10 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.80 m agl 132.32 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	Dry					

Reference No: 48	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN.
Date Constructed: 1970/71	Yield:
Contractor:	Drawdown:
Depth: 13.29 m	Length of test:
Diameter: ~ 3 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Damaged by floods

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 2.25 m agl 129.97 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	12.31 m			22.1.78	1600	

Reference No: 49	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1970/71	Yield:
Contractor:	Drawdown:
Depth: 13.53 m	Length of test:
Diameter: 3.33 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 1.27 m agl 129.59 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	11.33 m			22.1.78	1700	

Reference No: 50	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: PEWC	Drawdown:
Depth:	Length of test:
Diameter: Hand dug	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 139.98 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
				16.1.78	1500	

Reference No: 51	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72 (Geol Survey)	Yield:
Contractor:	Drawdown:
Depth:	Length of test:
Diameter: ∿ 3 m (Borehole according to Geol Survey)	Pump setting:
Casing:	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Badly washed away hand dug well

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 132.54 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
22.1.78	∿ 11.17 m			22.1.78	1500	

Reference No: 52	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: PEWC	Drawdown:
Depth: 14.55 m	Length of test:
Diameter: 2.0 m	Pump setting:
Casing:	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Datum 1.3 m agl 121.0 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	11.33 m			22.1.78	1700	

Reference No: 54	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth: 20.75 m	Length of test:
Diameter: 20 cm	Pump setting:
Casing: Mild steel	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.9 m agl 132.63 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
22.1.78	10.40 m			22.1.78	1600	

Reference No: 55	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature ($^{\circ}C$):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production
Jan 1978
∿ 1 m^3/2.5 mins
drawing air

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 131.45 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH

Reference No: 56	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth: 21.50 m	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 21 cm diam	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^{o}C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 0.61 m agl 128.58 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	10.48 m			22.1.78	1300	

Reference No: 57	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth: 21.90 m	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 1.13 m agl 135.68 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
22.1.78	10.31 m			22.1.78	1800	

Reference No: 58	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production Jan 1978

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 137-63 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH

Reference No: 59	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1971/72	Yield:
Contractor: RWC	Drawdown:
Depth:	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (^oC):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: 140.38 m asl (Geol Survey)

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
				16.1.78	1700	

Reference No: 61	Grid Reference:
Name:	Location: KHOR ARBAAT, PORT SUDAN
Date Constructed: 11.10.73	Yield: 393 m^3/d
Contractor: Water Drilling and Engineering Co	Drawdown:
Depth: 23 m	Length of Test:
Diameter: 55 cm gravel packed	Pump setting:
Casing: 16 m of 10" (25 cm) mild steel	Pump capacity:
Screen: 8 m of 10" galvanised Bridgestone	

Transmissivity:	Coefficient of storage:	Specific capacity:
Water quality:	Date of test:	Temperature (^0C):

Total dissolved solids: 985 ppm	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production from 1973 to time of visit 1978

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum:

Lithology: Drilled to basement (?)

Date	SWL (BSD)	Date	SWL (BSD)	Date	μmhos	pH
17.10.73	8.73 m			22.1.78	1900	

Reference No: 62	Grid Reference:
Name:	Location: KHOR ARBAAT, PORT SUDAN
Date Constructed: 6.9.73	Yield: 1091 m^3/d
Contractor: Water Drilling & Engineering Co	Drawdown: 11.25 m
Depth: 19 m (13.60 m 16.1.78, silt base)	Length of Test:
Diameter: 22" gravel pack	Pump setting:
Casing: 10" mild steel 12 m	Pump capacity:

Screen: 10" galvanised Bridgestone 8 m

Transmissivity:	Coefficient of storage:	Specific capacity: 96 m^2/d
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids: 1050 ppm	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum:

Lithology: Drilled to basement (?) Casing 0.85 m agl

Date	SWL (BSD)	Date	SWL (BSD)	Date	μmhos	pH
11.9.73	8.65 m					
16.1.78	10.80 m			16.1.78	1400	

Reference No: 63	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 19.2.74	Yield: 764 m^3/d) 768 m^3/d) Geol
Contractor: Water drilling & engineering co	Drawdown: 9.05 m } PEWC 9.06 m } Survey
Depth: 26.70 m (26.35 cm 16.1.78)	Length of test: 3½ hrs 3½ hrs) Bal 28
Diameter: 22, 20, 16"	Pump setting:
Casing: 20 m of 10" mild steel	Pump capacity:

Transmissivity: 24 m^2/d (PEWC) 28 m^2/d (Geol) Coefficient of storage: Specific capacity 84 m^2/d

Screen: 8 m of 10" galvanised Bridgestone screen

Water quality: Date of test: Temperature (°C):

Total dissolved solids: 1250 ppm	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production			
Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum: Casing 1.03 m agl

Lithology: see next page

Date	SWL(BSD)	Date	SWL(BSD)	Date	μmhos	pH
26.2.74	11.66 m					
16.1.78	11.81 m			16.1.78	1700	

GEOLOGICAL DESCRIPTION OF BH 63

Depth (m) From	Depth (m) To	Description of Strata
0	1	Coarse, medium and fine sand with minor amounts of silts. The grains are volcanic fragments, quartz and feldspathic grains.
1	2	Gravels, minor amounts of coarse sand, medium and fine sand with minor amounts of silt. The gravels are mainly subangular volcanic fragments with few metamorphic.
2	3	Gravels, coarse and medium sand. The gravels are subrounded to subangular volcanic fragments.
3	4	Mainly pebbles with minor amounts of sand.
4	5	Mainly pebbles with minor amounts of sand and clays.
5	6	Same as 4 - 5.
6	7	Same as above (4-5 and 5-6).
7	8	Cobbles, pebbles, gravels, coarse, medium and fine sand.
8	9	Pebbles, gravels with minor amounts of sand.
9	10	Same as 8-9.
10	11	Gravels, coarse sand with minor amounts of medium and fine sand.
11	12	Boulders, coarse sand. The boulders are subangular-subrounded volcanics (Rhyolite).
12	13	Gravels, minor amounts of sand and silt.
13	14	Cobbles, pebbles, gravels. These are subangular to subrounded fragments cemented together with fine material, mainly clays. The formation is in an unconsolidated condition.
14	23	The formations decribed above (13-14) continues.
23	24	Boulders of biotitegranite . The fragments shows lines of weakneas on the boulder (joints).
[illegible]	26.70	Weathered biotite granite, ended with drilling biotite granite fresh.

Reference No: 64	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 2.4.1974	Yield: 546 m^3/d) Source 655 m^3/d) Geol
Contractor: Water drilling & engineering co	Drawdown: 8.6 m) PEWC 8.6 m) Survey
Depth: 21.70 m (20.85 m 16.1.1978)	Length of Test:6 hrs) 6 hrs)
Diameter: 22", 20" & 16"	Pump setting:
Casing: 14.7 m 10" mild steel	Pump capacity:

Screen: 8 m of 10" galvanised Bridgestone screen T = 26 m^2/d using Geol Survey data

Transmissivity: 21 m^2/d (29 m^2/d recovery)	Coefficient of storage:	Specific capacity: ∿ 69 m^2/d
Water quality:	Date of test: 11.4.74	Temperature (°C):

Total dissolved solids: 1670 ppm	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

Not in production

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum: Casing 0.9 m agl

Lithology: Drilled to basement complex see next page

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
4.1974	10.35 m			16.1.1978	1800	
16.1.1978	11.000 m					

GEOLOGICAL DESCRIPTION OF BH 64

Depth (m)		Description of Strata
From	To	
0	1	Gravel, coarse, medium and fine sand. The grains are volcanic and igneous subangular to subrounded fragments.
		Gravel, coarse, medium and fine sand, with minor amount of silt. The grains are volcanic, igneous and metamorphic fragments of various shapes.
	3	Mainly gravels, with minor amount of silt. The grains are metamorphic, igneous (granitic) and volcanic fragments. They are subanguler to subrounded with various shapes-bladed-elongated-to compact.
3		Gravels, coarse, medium and fine sand, with minor amount of silt. The grains are volcanic, igneous and metamorphic. Subangular to subrounded, with various shapes.
	5	Mainly gravels, with minor amounts of sands and silt. The grains are metamorphic, igneous and volcanic fragments of various shapes.
5	8	The formation is mainly gravel, coarse, medium and fine sand, with minor amount of silt. The amount of silts is greater than that of (4-5). The grains are metamorphic, igneous and volcanic fragments. They are subangular to subrounded, various shapes
8	10	Mainly pebbles, cobbles, gravels and minor amount of fine materials (fine sand and silt). The grains vary from subangular to subrounded igneous, volcanic and metamorphic fragments.
10	11	Mainly gravel with amounts of coarse sand and fine materials (fine sand silt). The grains are igneous, volcanic and metamorphic subangular to subrounded fragments.
1'	12	Pebbles, cobbles, gravels with minor amounts of fine sand and silt. The pebbles, cobbles and gravels are igneous and volcanic subangular to subrounded fragments.
12	13	Mainly pebbles, gravels, with minor amount of coarse sand. The fragments are igneous and volcanic subrounded and compact.
13	15	Pebbles, gravels and an equal amount of fine sand, and silt. The pebbles and gravelsare igneous and volcanic subangular to subrounded fragments.
15	16	Pebbles, gravels, sands and silt. Same as (13-15)
16	17	Angular fragments of diorite, gravels, sand and minor amount of silt.
17	18	Gravels, coarse sand, medium and fine sand with small amount of silt. The gravels and sand are subangular to subround, elongated, platty and compact varieties of igneous, volcanic and metamorphic fragments.
18	20	Angular fragments of diorite rock, gravels, sands and minor amount of silt.
20	21,7	Rock fragments of granodiorite, granite and diorite.

Reference No: 65	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 1976	Yield: 2304 m^3/d
Contractor: RWC	Drawdown:
Depth: 29.26 m	Length of test:
Diameter:	Pump setting:
Casing: Mild steel 25 cm diameter	Pump capacity:

Transmissivity: Coefficient of storage: Specific capacity:

Screen: 1 cm drilled holes

Water quality: Date of test: Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non carbonate hardness:	Free CO_2:

In production

Ca			HCO_3
Mg			SO_4
Na			Cl
K			NO_3

Scale e.p.m. 0

Surface datum:

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
				16.1.78	2500	

Reference No: 66 (RWC 7697)	Grid Reference:
Name:	Location: KHOR ARBAAT PORT SUDAN
Date Constructed: 9.4.77	Yield: 2400 m^3/d (bailer)
Contractor: RWC	Drawdown: 7.62 m
Depth: 23.16 m	Length of test:
Diameter: 25 cm	Pump setting:
Casing: Mild steel	Pump capacity:

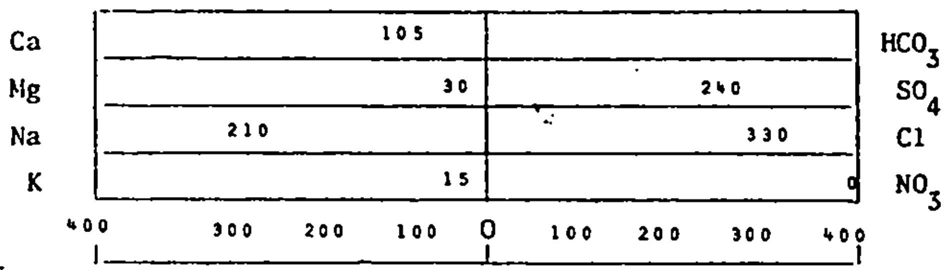
Transmissivity: Coefficient of storage: Specific capacity: 315 m^2/d

Screen: 12.5 - 23.16 m

Water quality: Date of test: Temperature (^oC):

Total dissolved solids: 1000 ppm	Conductivity:
Total hardness: as $CaCO_3$ 390 ppm	pH:
Carbonate hardness:	Alkalinity: 160
Non carbonate hardness:	Free CO_2:

In production Jan 1978



F 0.35 ppm
As Nil
Pb Nil
F Nil

Scale p.p.m.

Surface datum:

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
9.4.77	9.14 m			9.4.77	1400	7.7
Water encountered at 10.67 m				22.1.78	1600	

Reference No: 67 (RWC 7698)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 6.6.77	Yield: 2400 m^3/d
Contractor: RWC	Drawdown: 4.27 m
Depth: 19.81 m	Length of Test:
Diameter: 25 cm	Pump setting:
Casing: Mild steel	Pump capacity:

Screen: 12.19 - 19.81 m

Transmissivity:	Coefficient of storage:	Specific capacity: 562 m^2/d
Water quality:	Date of test:	Temperature (°C):

Total dissolved solids:	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

In production
Jan 1978

Ca		HCO_3
Mg		SO_4
Na		Cl
K		NO_3

Scale p.p.m. 0

Surface datum:

Lithology:

Date	SWL(BSD)	Date	SWL(BSD)	Date	µmhos	pH
6.6.77	10.36 m			22.1.78	1600	
Water encountered at 10.67 m						

Reference No: 68 (RWC 7699)	Grid Reference:
Name:	Location: Khor Arbaat Port Sudan
Date Constructed: 5.8.1977	Yield: 122 m^3/d
Contractor: RWC	Drawdown: 0 m
Depth: 22.40 m (21.34 m RWC)	Length of Test:
Diameter: 25 cm	Pump setting:
Casing: Mild steel	Pump capacity:
Screen: 9.45 - 21.34 m	

Transmissivity: Coefficient of storage: Specific capacity:

Water quality: Date of test: Temperature (°C):

Total dissolved solids: 920 pmm	Conductivity:
Total hardness:	pH:
Carbonate hardness:	Alkalinity:
Non Carbonate hardness:	Free CO_2:

This well is not vertical and is not in production

Ca		HCO_3
Mg		SO_4
Na	similar to 7697 (RWC)	Cl
K		NO_3

Scale p.p.m. 0

Surface datum: Casing 1.35 m agl

Lithology:

Date	SWL (BSD)	Date	SWL (BSD)	Date	µmhos	pH
5.8.1977	12.19 m			5.8.1977	1250	7.7
22.1.1978	12.16 m			22.1.1978	1500	
Water encountered at 12.19 m						