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Overseas Geology Series

The hydrogeology of the Oju/Obi area, eastern Nigeria: Anyoga Eddi Adum East area data report

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Front cover illustration:
Test pumping borehole BGS36 at Anyoga Eddi Adum East using a whale pump.

Keyworth, Nottingham, British Geological Survey, 1998.

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PREFACE

Oju is a remote part of south-eastern Nigeria that suffers from severe water shortage during the annual dry season. From November to April, unprotected ponds, seepages and hollows are the primary source of domestic water. Unfortunately, these sources become less reliable towards the end of the dry season and many are contaminated. As a consequence, much of the population of Oju (300 000 approx.) is badly affected by a variety of water related illnesses, of which guinea worm and malaria are endemic; outbreaks of cholera, typhoid and dysentery are also common. In response, DFID have commissioned WaterAid to provide improved village level, year round water sources, primarily utilising the limited groundwater resources of the area.

Due to the complex hydrogeology, WaterAid have asked the British Geological Survey (BGS) to assist with the project. BGS are applying the results of TDR projects undertaken within other parts of the world to study these marginal groundwater resources.

The groundwater investigations by BGS started in September 1996. There are three main aims of the research: (1) to assess the potential of the Oju area for sustainable groundwater supplies; (2) to develop appropriate methods for siting wells or boreholes in the Oju environment; and (3) to recommend appropriate methods and designs for exploiting groundwater.

This report forms one of a series of data reports designed to complement the summary assessment of the hydrogeology of the Oju/Obi area and the Groundwater Development Map. The data presented were collected on five separate trips, August-September 1996, November-December 1996, February-March 1997, October-December 1997 and January-April 1998.

EXECUTIVE SUMMARY

The groundwater potential of the Makurdi sandstone was investigated at Anyoga Eddi Adum East during February-March 1998. Fifteen hundred meters of EM34-3 surveying was undertaken, using a 20 m inter-coil spacing, as were two resistivity soundings. Three boreholes were drilled: two deep exploratory boreholes and one shallow cored observation borehole. Two boreholes (BGS 36 and BGS 37) were completed with screen and casing; BGS 38 contained little water and was therefore back-filled. BGS36 and BGS 37 were test pumped; during these exercises water samples were obtained for hydrochemical analysis. The following conclusions are made from the results obtained:

- The Makurdi Sandstone at Anyoga Eddi Adum East comprises interbedded sandstones and mudstones. Sandstone layers up to 4 m thick are present.

- The sandstones are fine to medium grained, well cemented, feldspathic and frequently bioturbated. The sandstones contain interbedded thin mudstone beds that often show load casting features. The mudstone can be soft and is often shaley and carbonaceous. Thin sandstone, siltstone and limestone layers occur interbedded within the mudstone sequence.

- Where sandstone occurs at shallow depths, it has been weathered. Within the top few metres, feldspar has been leached increasing the inter-granular permeability and porosity; kaolinite clay is also present. At slightly greater depths, secondary silicate deposition is present, which produces very hard and dense siliceous sandstone layers with negligible inter-granular permeability.

- Where predominately mudstone is present at shallow depths, it has been weathered to olive-green illite-smectite rich clay (similar to Edumoga).

- The aquifer properties of the Makurdi Sandstone at Anyoga are disappointing. Groundwater was only found where significant sandstone occurred within the weathered zone. The inter-granular permeability of the sandstone is low, the majority of the water found in the two successful boreholes (BGS 36 and BGS 37) came from a fracture zone at about 11.5 m depth. This fracture is probably supplied by slow seepage from the sandstone.

- The yield from neither borehole is sufficient to sustain a hand pump. A hand dug well constructed through the weathered zone to the fractures below would be the most appropriate technology for abstracting groundwater.

- The storage coefficient at Anyoga was typical of a confined aquifer (1×10^{-4}). The exploratory boreholes could be kept open to routinely measure water levels within the aquifer to monitor the sustainability.

- The electrical conductivity measured using the EM34-3 varied from 10-30 mmhos/m. The lower measurements were associated with sandstone in the weathered zone, while the higher measurements indicated more mudstone within the weathered zone. Therefore, low EM34-3 readings are the best targets for groundwater. Resistivity soundings could also distinguish the sandstone from the mudstone.

- It is recommended that a more detailed study is made of the weathered zone of the sandstone to discover more about how and where the hard siliceous layers are likely to occur (e.g. in valleys or on ridges). A diamond-coring bit would be required to obtain samples.

1. BACKGROUND INFORMATION

The groundwater development potential of the Makurdi Sandstone was evaluated at Anyoga Eddi Adum East (see Figure 1). Several other boreholes have been drilled into the Makurdi Sandstone for investigation purposes within the Oju/Obi area (MacDonald and Davies 1998; Davies and MacDonald 1998). Several shallow traditional wells have been constructed within the village. These contain useful quantities of water during the rainy season, but their sides are prone to collapse. Community members have identified the presence of a hard rock layer 3-4 m below the ground surface that stopped them digging any deeper. A 9 m deep borehole located at the eastern end of the village has a very low yield; only one or two buckets of water can be pumped at one time, even during the rainy season. At Adum East village, less than a kilometre to the north, there are a borehole and a hand dug well, both high yielding.

The geology map shows that the Makurdi Sandstone underlies Anyoga Eddi Adum East. The Makurdi Sandstone forms a fluvial deltaic sandstone facies interbedded within the shallow marine pro-delta sediments of the Eze Aku group. The sandstone bands dip to the north-west, becoming thicker and coarser grained upward within the sequence, the highest sandstone band forming a prominent north-east – south-west trending ridge to the north of Adum East. Anyoga Eddi Adum East village is located in a densely vegetated and faulted valley; several streams flow through the village. Adum East to the north is situated on a small ridge. To the south of the village is a pronounced dambo like feature, such topographic features being frequent and well developed along strike fault lineations along the outcrop of the Makurdi Sandstone. Part of the village obtains domestic water from small seepages within the dambo. As the dry season progresses, seepages are dug further down-stream along the dambo. Figures 2 and 3 show the available map data for the area and also the locations of geophysical surveys and test boreholes. Table 1 list maps and aerial photographic coverage available for the Anyoga Eddi Adum East area.

Table 1. Available map information for Anyoga Eddi Adum East.

Data type	Source
Aerial Photographs	Sheet 289, run 2, 37-41
Topographic maps	1:50,000 Sheet 289NE Ejekwe NE
Geology map	Ogoja Area, Map No. 73, Scale 1:250,000

2. GEOPHYSICS

Several geophysical surveys were undertaken at Anyoga Eddi Adum East. Short EM34-3 surveys were carried out through the village and along the dambo to the south. Two resistivity soundings were then taken at points within the village. Table 2 gives a summary of the various traverses and soundings undertaken. Survey data collected are presented in Appendix 2.

Several observations can be made from analysis of the geophysics data. (Figure 4 shows an EM34-3 survey):

- Electrical conductivity varies from about 10 to 30 mmhos/m; the soundings tended to be noisy.
- There is a pronounced negative anomaly at 90 – 130 m on AE 1.

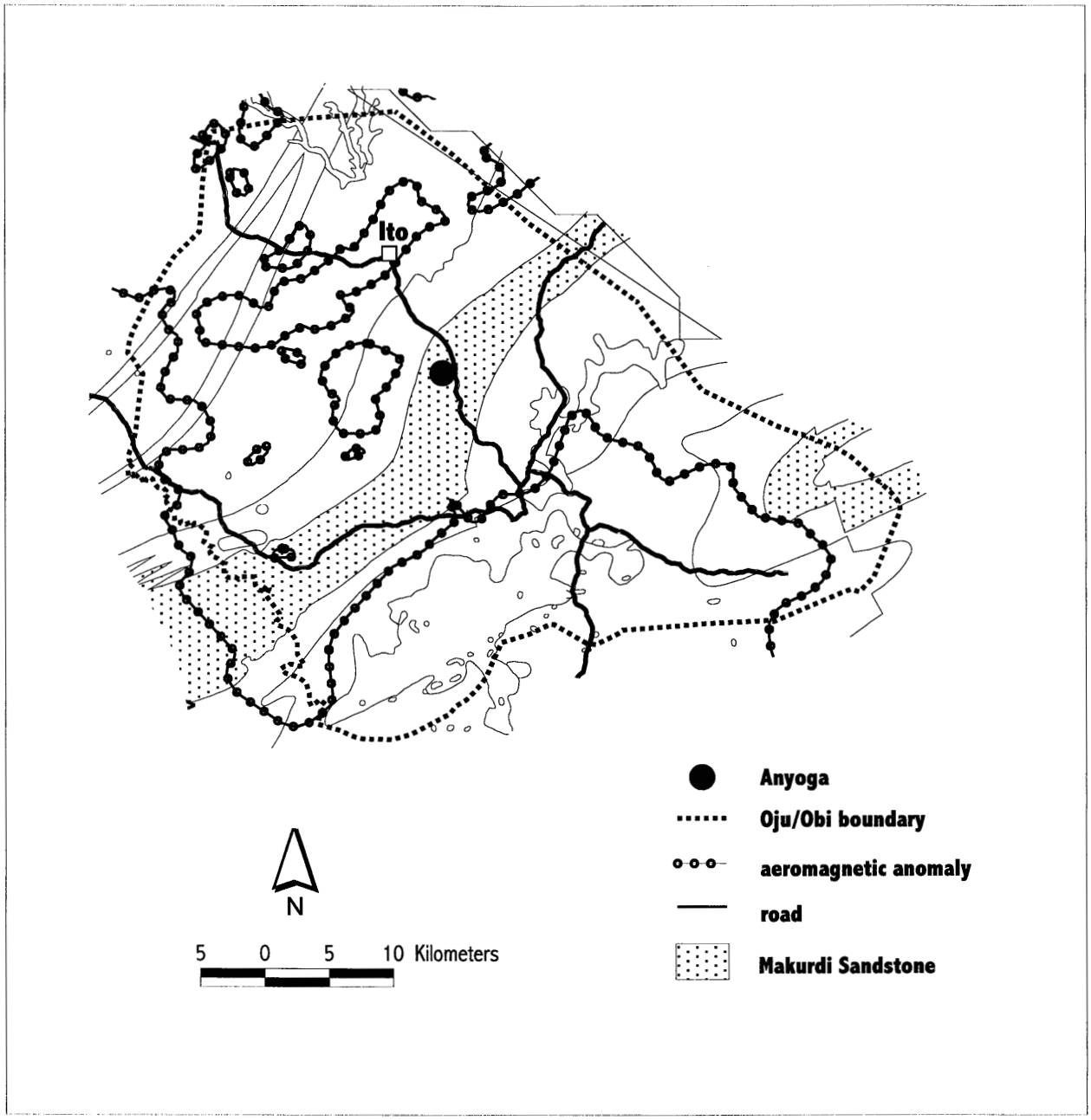

Figure 1. The location of Anyoga Eddi Adum East and the outcrop of the Makurdi Sandstone.

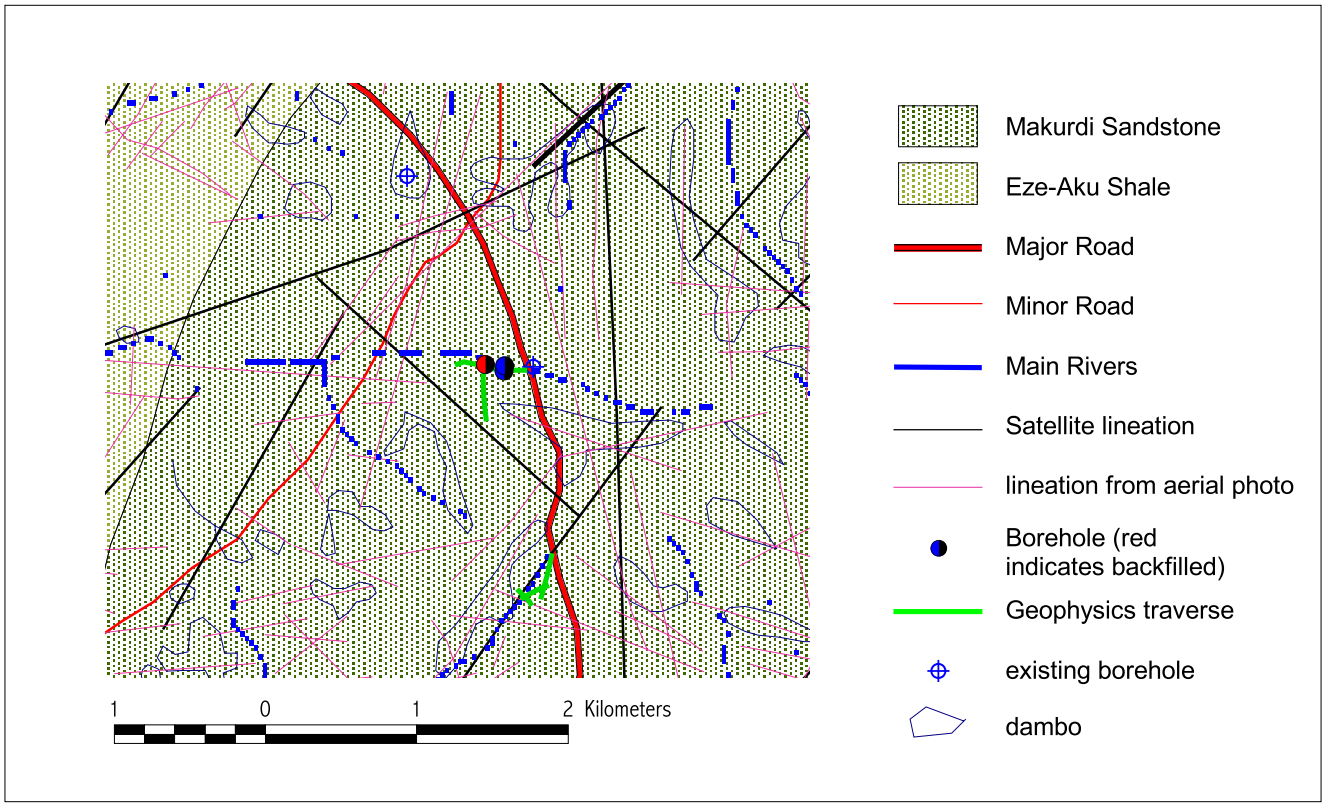

Figure 2. Available map information for Anyoga Eddi Adum East and location of boreholes and geophysical traverses.

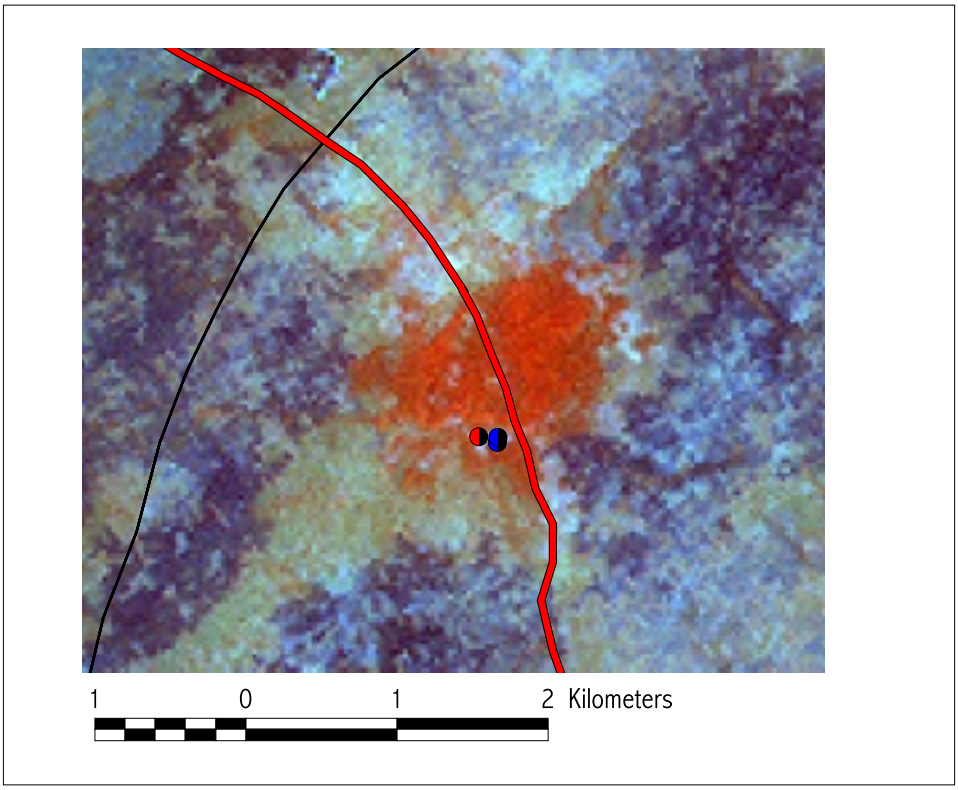

Figure 3. Satellite image for Anyoga Eddi Adum East.

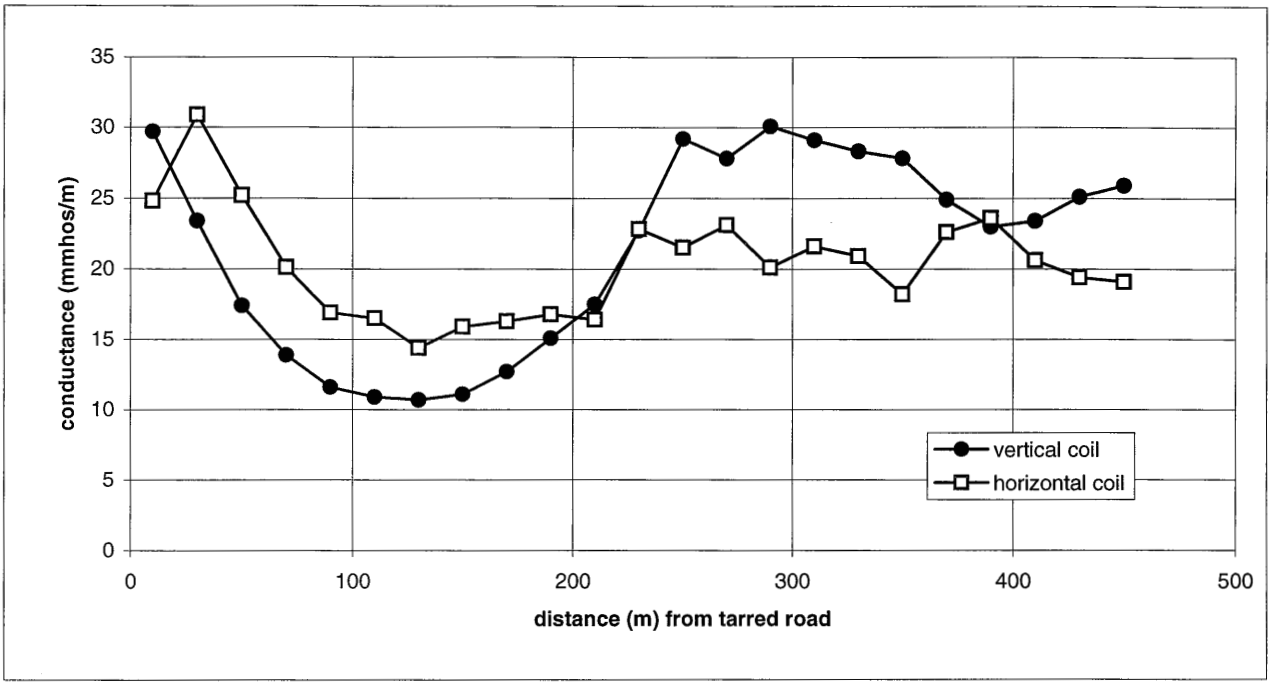

Figure 4. EM34-3 survey AE 1 for Anyoga Eddi Adum East. The centre point of the resistivity sounding sh in Figure 5 is located at 150 m.

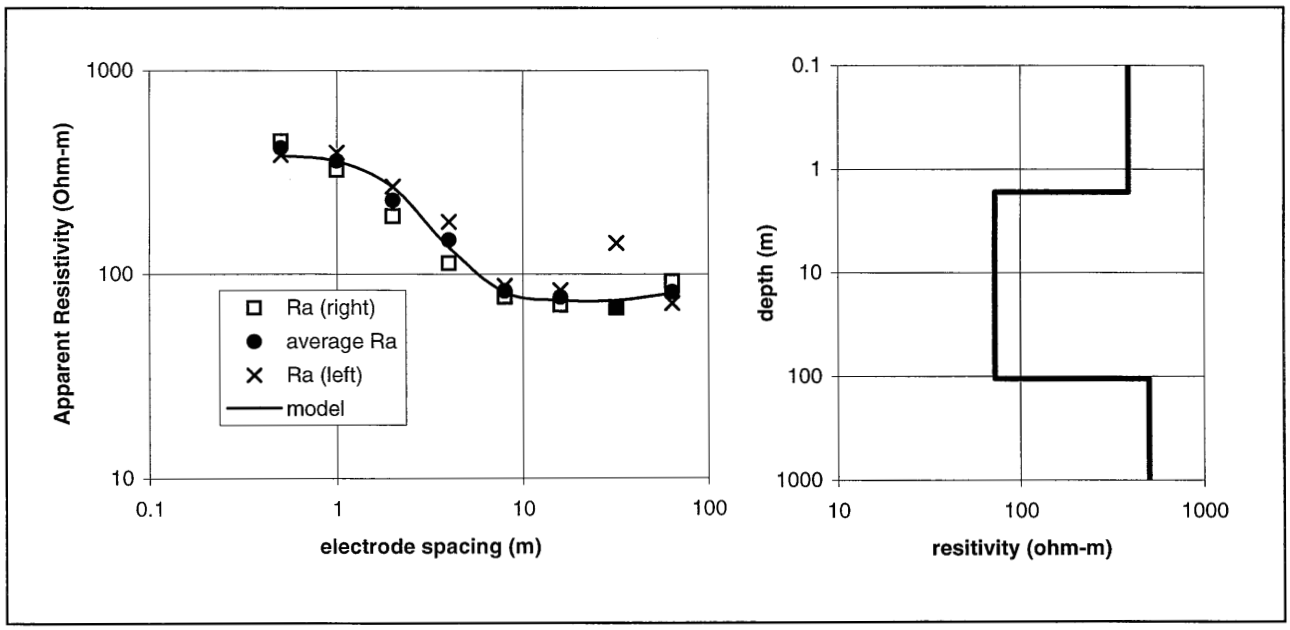

Figure 5. Resistivity sounding and interpretation for AE 6 at Anyoga Eddi Adum East. Both BGS36 and BGS37 were drilled at this location.

- Vertical and horizontal coil readings are broadly similar for 20 m spacings; however, where the conductivity was low, the horizontal coil measurements tended to be higher than those taken with the vertical coil.

- Conductivity measurements increase within the dambo.

- Two resistivity soundings were taken on traverse AE1; one where the conductivity was low (10 mmhos/m) and another where conductivity was high (30 mmhos/m). The first sounding showed a 1-2 m resistive soil overlying moderately resistive (65 – 80 ohm/m) bedrock (Figure 5). The second sounding gave 1-2 m resistive soil overlying a 20 m low resistivity layer (20-30 ohm-m) followed by 40 – 80 ohm-m bedrock.

Table 2. Main Geophysical Surveys carried out at Anyoga Eddi Adum East (data in Annex 1).

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
AE 1	6° 57.18' 8° 22.13'	0.5 km	20 m	EM34-3 (20 m)	From tarred road through village to new well
AE 2		0.4 km	20 m	EM34-3 (20 m)	From stream by okpaga tree to small shrine
AE 3	6° 56.477' 8° 22.223'	0.3 km	20 m	EM34-3 (20 m)	From culvert on tarred road along path past seepage
AE 4		0.2 km	20 m	EM34-3 (20 m)	Passed seepage accros dambo to start of channel
AE 5		0.1 km	20 m	EM34-3 (20 m)	Perpendicular to AE 4 across valley
AE 6			0.5 – 64 m	Offset Wenner	Located on orange tree 140 m along AE 1
AE 7			0.5 – 64 m	Offset Wenner	Located on okpaga tree 300 m along AE 1

Two sites were chosen for investigation at Anyoga Eddi Adum East, at the locations of the resistivity soundings. BGS 36 and BGS 37 were drilled on the low conductivity anomaly 150 m along AE 1. BGS38 was drilled on relatively high conductivity ground, approximately 300 m along AE 1.

3. DRILLING

Three boreholes were drilled within Anyoga Eddi Adum East village: two deep boreholes and one shallow observation borehole. BGS36 and BGS37 were drilled 11.4 m apart and were close to the well constructed by the RUSAFIYA project but abandoned when hard rock was encountered at about 4 m. Lithological chip and core samples obtained during drilling of the boreholes were logged and analysed. Summary data describing the boreholes is given in Table 3; further details are provided in Annex 2.

The sandstone lithology varies within the weathered zone with very hard siliceous sandstone layers occurring at 4-5 m and 9-9.5 m within a sequence of soft friable sandstone. At BGS 37, the quartz cemented sandstones proved to be too abrasive for the tungsten-carbide core bits used, only short cores could be obtained. In the future, a diamond impregnated core bit would be required to obtain core samples of all parts of the Makurdi sandstone sequence.

Table 3. Summary details of drilling. Full details given in Annex 2.

Bh ID	Location	Date completed	Total depth	Drilled diameter	Section cored	Main water strikes	Casing above gl	Comments
BGS 36	6° 57.168' 8° 22.041'	16/3/98	41.5 m	165 mm	39.3 – 41.3	15.5 m 21.5 m	0 m	11.4 m away from BGS 37
BGS 37	6° 57.168' 8° 22.041'	18/3/98	18.5 m	165 mm	8.5 – 8.8 9.95 – 11.6	11.4 m	0.25 m	Very hard – wore out several core bits
BGS 38	6° 57.143' 8° 21.946'	18/3/98	41.7 m	165 mm	39.6 – 41.7	9.5 m damp	none	

The following sections give a brief summary of the lithological logs. Full details are given in Annex 3. Figure 6 shows a schematic of the borehole logs.

Summary lithological log: BGS 36

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 4.0	Clayey very weathered horizon
4.0 - 4.5	Hard to friable fine grained sandstone, fairly weathered
4.5 - 5.0	Hard fine grained silicified sandstone
5.0 - 9.0	Soft friable fine to medium grained sandstone, fairly weathered
9.0 - 9.5	Hard quartzitic fine grained sandstone
9.5 - 11.5	Fine to medium grained sandstone
11.5 - 12.0	Carbonaceous mudstone
12.0 - 17.5	Fine grained sandstone
17.5 - 19.0	Interbedded carbonaceous mudstones, siltstone, hard sandstone and limestone
19.0 - 21.5	Mudstone
21.5 - 26.5	Carbonaceous shaley mudstone
26.5 - 27.5	Fine grained sandstone and mudstone
27.5 - 29.5	Carbonaceous mudstones and fine grained sandstone
29.5 - 31.5	Fine grained sandstone with mudstone partings
31.5 - 33.5	Carbonaceous mudstone and fine grained sandstone
33.5 - 34.0	Fine grained sandstone
34.0 - 35.0	Carbonaceous mudstone and hard fine grained sandstone
35.0 - 36.0	Carbonaceous siltstone
36.0 - 36.5	Fine grained sandstone
36.5 - 37.5	Carbonaceous mudstone
37.5 - 39.5	Fine grained sandstone and carbonaceous mudstone
39.30 - 39.47	Interbedded muddy fine-grained sandstone and silty mudstone
39.47 - 39.62	Carbonaceous mudstones
39.62 - 40.12	Muddy fine grained sandstone, bioturbated
40.12 - 40.74	Interbedded shaley mudstones and fine grained sandstones
40.74 - 40.76	Fine to medium grained micaceous sandstone
40.76 - 40.90	Silty mudstone and fine grained sandstone
40.90 - 41.30	Carbonaceous mudstone and dense limestone

Summary lithological log: BGS 37

0.0 - 2.0	Soil/ferricrete horizon
2.0 - 3.5	Clayey, very weathered silts and fine grained sandstones
3.5 - 5.0	Weathered friable fine to medium silty sandstones

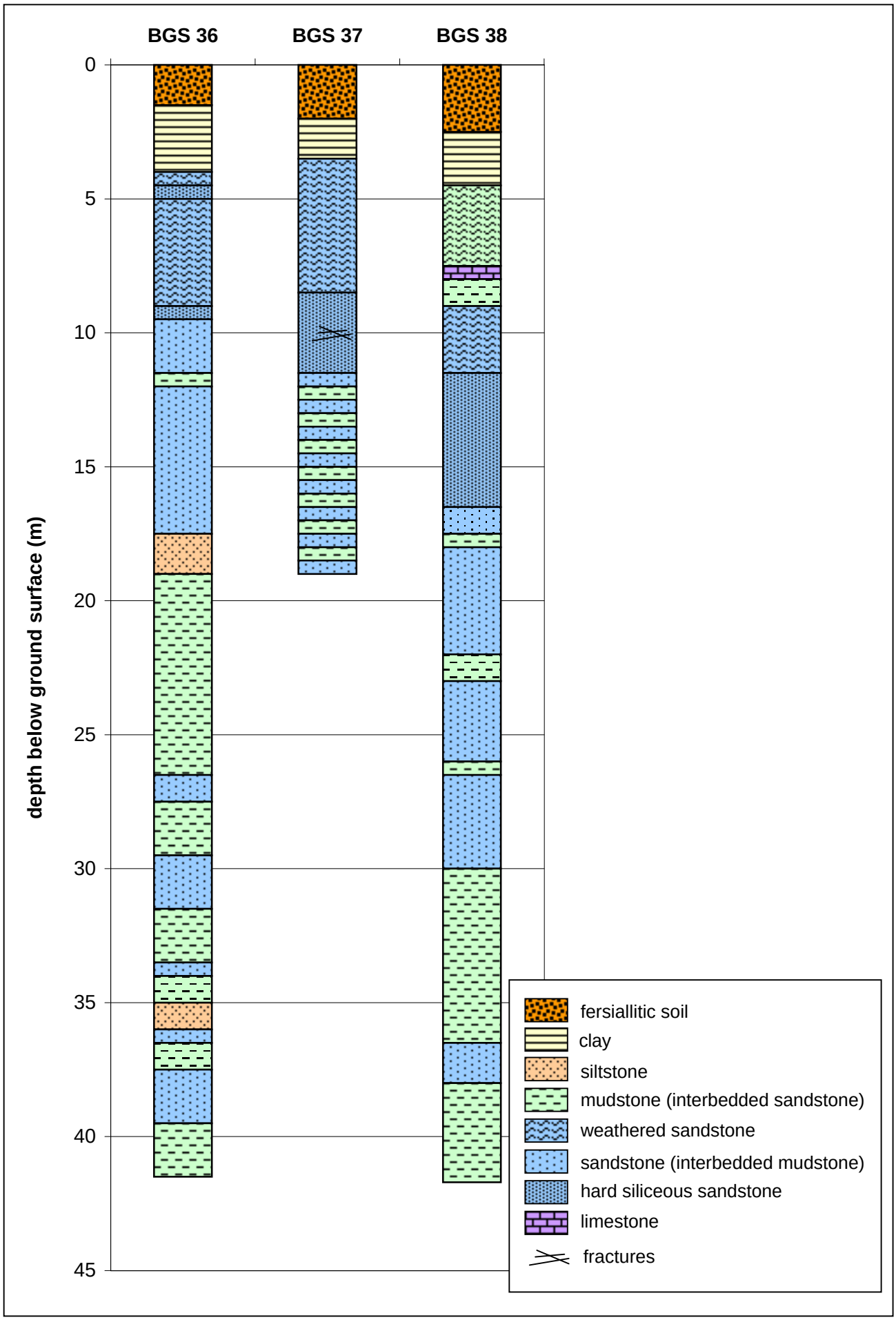

Figure 6. Simplified lithological logs for Anyoga Eddi Adum East (horizontal axis not to scale).

5.0 - 6.5	Hard to friable medium to fine grained fairly weathered sandstones, water bearing in parts
6.5 - 8.0	Hard to friable fissile micaceous medium to fine sandstone
8.0 - 8.69	Hard to very soft medium to fine grained sandstones, fairly weathered, with water bearing fractures
8.69 - 11.60	Hard compact siliceous medium to fine grained sandstones
11.60 - 18.5	Massive shaley mudstones and fine grained sandstones

Summary lithological log: BGS 38

0.0 - 2.5	Soil/ferricrete horizon
2.5 - 4.5	Clayey very weathered zone
4.5 - 7.5	Weathered sandstones, siltstones and mudstones
7.5 - 8.0	Limestone
8.0 - 9.0	Unweathered massive sandstones and mudstones
9.0 - 11.5	Fairly weathered friable fine grained sandstones - some dampness
16.5 - 18.0	Unweathered medium and fine grained sandstones and shales
18.0 - 19.5	Massive fine grained sandstones
19.5 - 21.5	Hard to friable fine to medium sandstones
21.5 - 25.5	Friable fine grained sandstone with shale
25.5 - 26.5	Friable to hard fine grained sandstones with interbedded shales
26.5 - 30.0	Massive friable fine grained sandstones
30.0 - 33.5	Massive interbedded fine grained sandstones, siltstones and mudstones
33.5 - 36.5	Massive interbedded fine grained sandstones and shaley siltstones
36.5 - 38.0	Hard fine grained sandstones with shaley partings sandstones and mudstones, chaotically bedded and bioturbated

4. PUMPING TESTS

Several pumping tests were carried out at Anyoga Eddi Adum East. Since BGS 36 and BGS 37 were close together, it was possible to use one as an observation borehole when the other was being test pumped with a Whale pump system, to obtain an estimate of aquifer storage coefficient. A bailer test was also carried out on each borehole. The pumping tests carried out are summarised in Table 4. Data and analyses are presented in Annex 4. The test results were analysed using methods described by Barker (1989) and in Kruseman and de Ridder (1990).

The test pumping of BGS36 and BGS37 produced similar results. Water levels fell gradually in the abstraction borehole until between 11 and 12 m, where the drawdown increases markedly. This corresponds to a decrease in drawdown in the observation borehole "This breakaway" indicates that primary inflow fracture has been de-watered. From analysing the drawdown curves it appears that about two thirds of the water flow into the borehole during testing is from this one fracture.

The yield of neither borehole is sufficient for a hand pump. A hand dug well constructed adjacent to the boreholes would be the preferred groundwater development option. Storage capacity and seepage area could thereby be maximised to ensure that water levels did not drop to below the 11 m inflow level. Within the village, approximately 20 m along AE 1, there is an existing borehole with a much lower yield than boreholes BGS36 or BGS37.

Table 4. Summary of pumping tests carried out at Anyoga Eddi Adum East. (Annex 4 contains data and analyses).

Borehole and Test	Date	Casing (magl)	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m^2/d)
BGS 36						
Bailer test	27/3/98	0.1 m	6.545 m	4.03 mins	0.28 l/s	Barker: T = 1.6 m^2/d Theis recovery: T = 1.3 m^2/d
Whale Test	20/3/98	0.1 m	5.41 m	192 mins	0.14 l/s	Jacob: abh early 0.8 m^2/d abh late 0.3 m^2/d obh T = 0.9 m^2/d S = 0.0001 Theis recovery: Abh early T = 0.58 m^2/d Abh late T = 0.8 m^2/d
BGS 37						
Bailer test	27/3/98	0.32 m	7.025 m	9:43 mins	0.23 l/s	Barker: T = 1.1 m^2/d Theis recovery T = 1.1 m^2/d
Whale test	27/3/98	0.32 m	5.829 m	200 mins	0.14 l/s	Jacob: abh early 0.61 m^2/d abh late 0.2 m^2/d obh T = 0.85 m^2/d S = 0.00013 Theis recovery: Abh T = 0.7 m^2/d Obh T = 0.85 m^2/d

Water samples for hydrochemical analysis were taken from boreholes BGS36 and BGS37. Parameters measured in the field are shown in Table 5. All the available chemistry data are given in Annex 5. The water in both boreholes is more highly mineralised than other waters from the Makurdi Sandstone (e.g at Adum East or Ochingingi). The deeper borehole has considerably higher mineral content than the shallow borehole. However, the water is within the WHO recommended guidelines for drinking water.

Table 5. Chemistry samples taken from Anyoga Eddi Adum East.

ID No	Sample No	date	Conductivity (µS/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	HCO3 titr (50ml 1.6M)	Comments
BGS 36	221	20/3/98	1510	755	7.55	29	425	Sample taken after 2 hours pumping
BGS 37	226	27/3/98	965	484	7.26	28	255	Sample taken after 1.5 hours pumping

5. SUMMARY AND CONCLUSIONS

The groundwater potential of the Makurdi Sandstone was investigated at Anyoga Eddi Adum East.. Various geophysical surveys were carried out and a series of boreholes drilled and tested. The following work was undertaken:

- 1.5 km of EM34-3 surveys
- 2 resistivity VES
- Three boreholes were drilled and several metres of core taken
- chip and core samples from each borehole were logged and analysed
- two boreholes, BGS 36 and BGS 37 were screened and cased
- short bailer tests were carried out on BGS 36 and BGS 37
- longer (3-4 hour) pumping tests were also carried out and drawdown measured in both abstraction and observation boreholes
- water samples were obtained for hydrochemical analysis.

The geophysical surveys highlighted the following:

1. The electrical conductivity measured using the EM34-3 varied from 10-30 mmhos/m. The lower measurements were associated with sandstone in the weathered zone, while the higher measurements indicated more mudstone within the weathered zone.

2. Vertical and horizontal coil readings are broadly similar for 20 m spacings. However, where the conductivity was low, the horizontal coil measurements tended to be higher than those taken with the vertical coil. This is probably because the sandstone does not have highly conductive clays within the weathered zone so there is no shallow conductive layer. The higher conductivity at depth (shown by the higher horizontal coil measurements) may be accounted for by the saturated sandstone, but could also be affected by the increase in mudstone with depth.

3. The negative anomaly in the EM34-3 is due to a sandstone layer and not a fracture zone.

4. Two resistivity soundings were run: one at BGS36 where sandstone was near to the surface and the other at BGS38 where a mudstone layer was close to the surface. At BGS36 the VES showed resistive soil overlying 65 – 80 ohm/m bedrock; the VES at BGS38 gave resistive soil followed by 20 m low resistivity (20 – 30 ohm/m) followed by 40-80 ohm-m bedrock. These results correlate with the geological logs.

5. Although geophysical surveys were carried out within the dambo, no drilling was undertaken to help interpret the surveys. Conductivity increased from about 10 mmhos/m at the edge of the dambo to 25 mmhos-m in the centre of the dambo at the start of the stream channel. This is likely to be due to an increase in clay content within the dambo (Carruthers and Smith (1992) found similar results in Zimbabwe)

Analysis of the rock and chip samples and test pumping indicated the following:

- The Makurdi Sandstone at Anyoga Eddi Adum East comprises interbedded sandstone and mudstone. Sandstone layers up to 4 m thick are present.

- The sandstone comprises fine to medium grained well cemented feldspathic sandstone with frequent thin mudstone beds often showing bioturbation and load casts.

- The mudstone can be soft and is often shaley and carbonaceous. Thin sandstone, siltstone and

limestone layers can be present.

- Within the weathered zone, feldspar grains have been leached by weathering enhancing inter-granular permeability and porosity.

- Secondary silicate deposition is recognised at discrete levels within the weathered zone (5-15 m). Several very hard siliceous sandstone layers with negligible inter-granular permeability have been formed.
- Boreholes drilled into mudstone layers within the weathered zone usually produced little groundwater. Conversely, where sandstone was present at shallow depths there was often sufficient groundwater to support a hand dug well.

- Although the sandstone has inter-granual porosity, the inter-granual permeability (below the first few metres where feldspar has been removed) is low.

- About two thirds of the flow from the two successful boreholes came from a fracture zone at about 11.5 m depth. This fracture is probably supplied by slow seepage from the sandstone.

- The storage coefficient at Anyoga Eddi Adum East was typical of a confined aquifer (1×10^{-4}). The sustainability of any wells dug within the village should be monitored. The exploratory boreholes could be kept open to routinely measure water levels within the aquifer.

- The quality of groundwater from the Makurdi Sandstone is generally good. The deeper borehole produced groundwater with a higher mineral content than the shallow borehole

The aquifer properties measured at Anyoga Eddi Adum East are disappointing. The sandstone has low inter-granular permeability, which has been further reduced by secondary silicate and iron oxide cementation. There are a large number of mudstone layers that reduce the groundwater reservoir capacity of the 'Makurdi Sandstone at Anyoga Eddi Adum East. Groundwater was only found where sandstone was present at shallow depths (>15 m). The main targets for groundwater are fractures within the sandstone at the base of the weathered zone. Hand dug wells constructed through the hard silcrete layer to about 15 m are the best option for water supply.

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Annex 1: Geophysical data

Anyoga Eddi Adum East

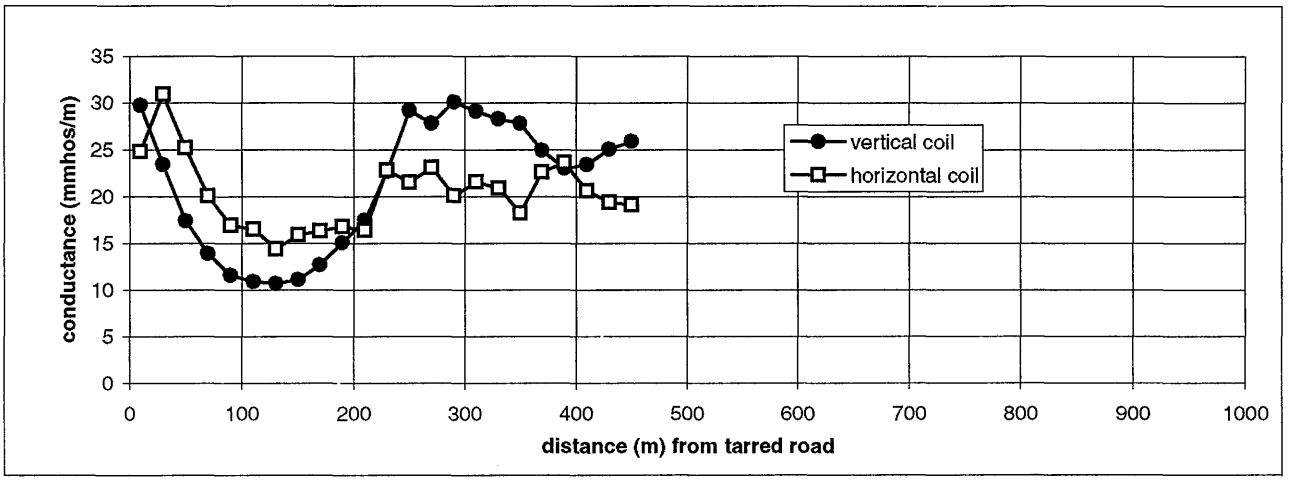
AE 1-2

GPS start: 6 degs 57.18; 8 degs 22.130
GPS finish
Date and time: 13/02/98 9:00 - 15:00
Survey: AE 1 from tarred road through village to new hand duug wel
AE 2 from dugout near stream, passed okatopo tree towards depression

AE1:

position (m)	strike (deg)
0	258
200	266
240	278
280	290
300	309
340	306
360	276

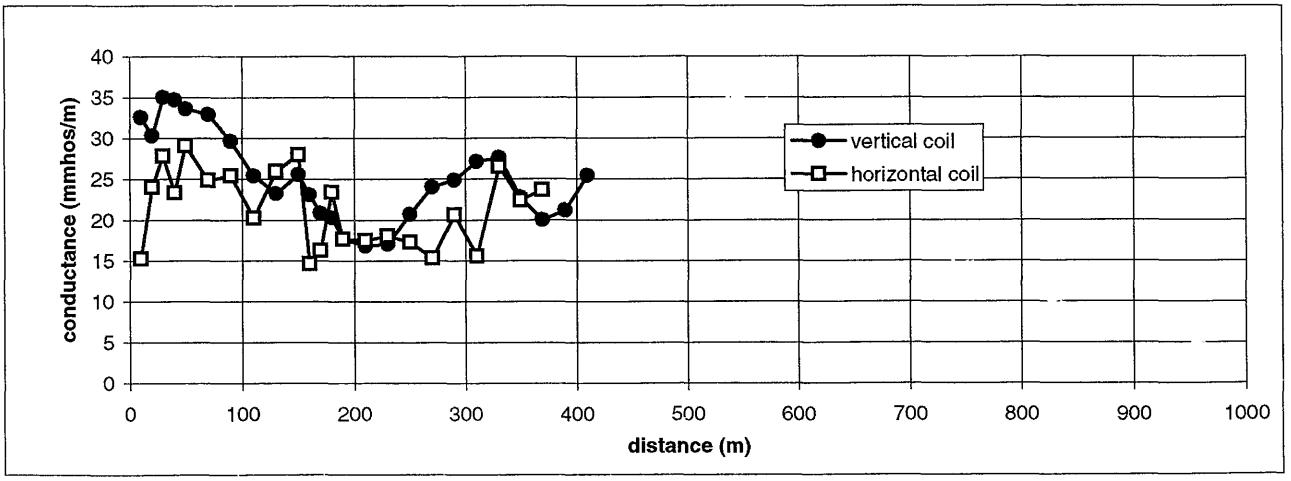
position (m)	comments
0	tarmac road
20	borehole
60	goal posts
140	orange tree left
200	grass bathroom
300	Okatopa tree
370	palm tree
460	new well



AE2:

position (m	strike (deg)
0	181
20	209
40	200
160	160
200	128
220	166
240	180
320	200
360	160

position (m)	comments
0	pond
100	by okatopo tree
170	R by small pole right
205	Y junction
295	small stream
340	path left to shrine
400	small path left



Anyoga Eddi Adum East

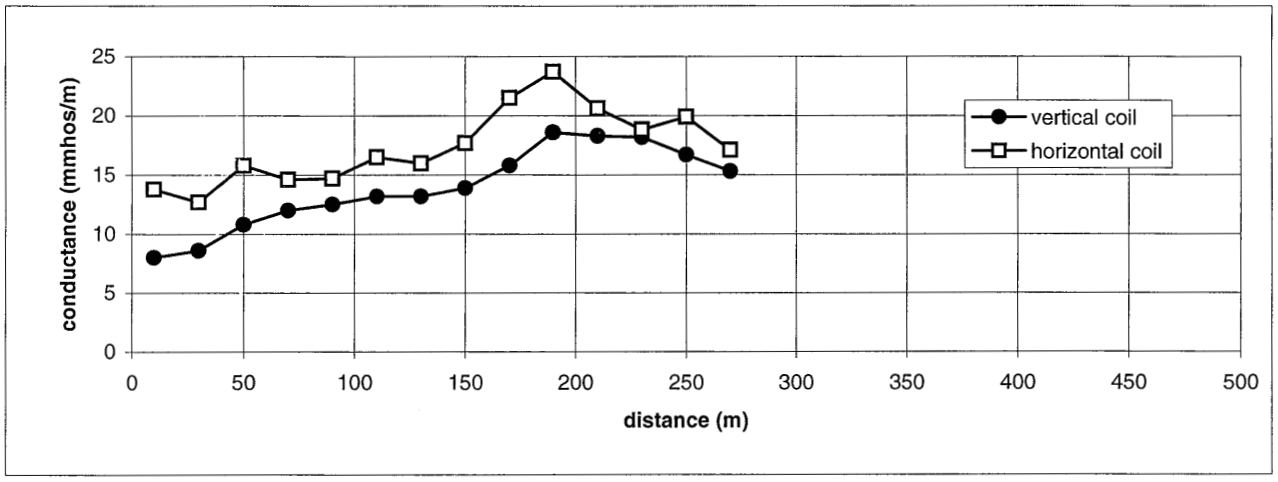
AE 3-5

GPS start: 6 degs 56.477' 8 degs 22.223
GPS finish
Date and time: 13/02/98
Survey: AE 3 staring at culvert along small pathin dambo to seepage
AE 4 from large tree up from seepage, past seepageto stream channel
AE 5 from Agba tree end A4 perpendicular across channel

AE 3

position (m)	strike (deg)
0	169
40	189
160	184

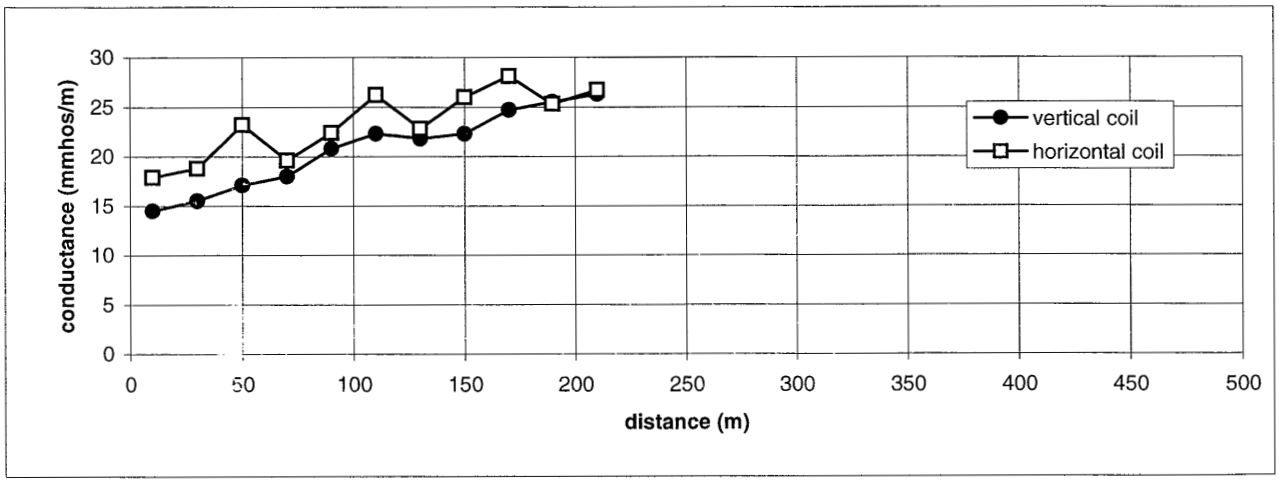
position (m)	comments
0	side of valley
100	small tree left
180	seepage
200	up small
250	large tree



AE 4

position (m)	strike (deg)
0	244
60	256
160	233

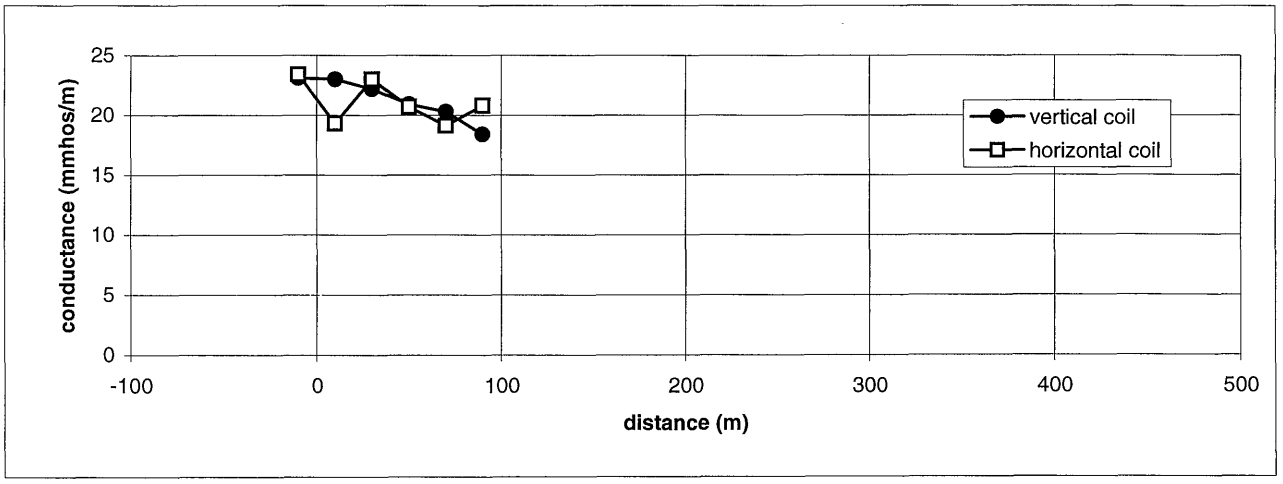
position (m)	comments
0	down
10	large tree
60	seepage
100	flat
120	trees
200	start of stream channel
220	Agba tree



AE 5

position (m)	strike (deg)
0	143

position (m)	comments
0	Agba tree
20	midpoint valley
40	up
80	another agba tree

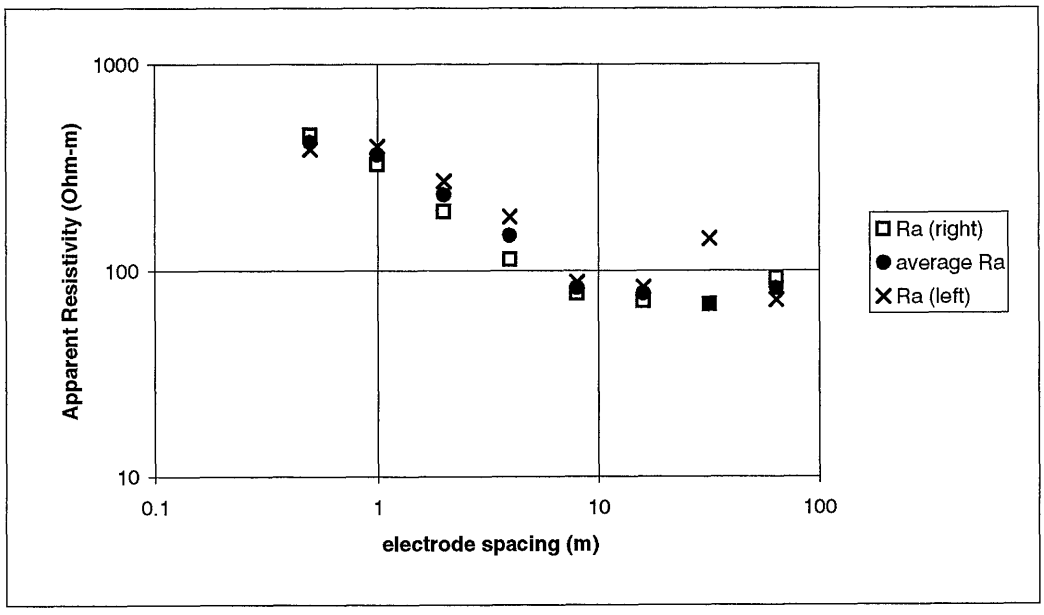


Anyoga

AE 6

Resistivity Survey 1
Located on orange tree - 140 m AE1
Offset Wenner left to tarmac road
strike 74 degs
13/02/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	122.7	143.7	385.278	451.218	418.248
1	63	51.8	395.64	325.304	360.472
2	21.5	15.31	270.04	192.2936	231.1668
4	7.22	4.51	181.3664	113.2912	147.3288
8	1.744	1.542	87.61856	77.47008	82.54432
16	0.828	0.704	83.19744	70.73792	76.96768
32	0.707	0.34	142.0787	68.3264	68.3264
64	0.179	0.228	71.94368	91.63776	81.79072



DATA SET: AE 6

CLIENT: Water Aid DATE: Feb 1998
LOCATION: Anyoga SOUNDING: 1
COUNTY: Oju/Obi Local GOvernmant AZIMUTH: 74 degs
PROJECT: Water and Sanitation EQUIPMENT: BGS128
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Offset Wenner Configuration

FITTING ERROR: 7.759 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	387.9	1.67	-1.67	0.00431	648.0
2	72.84	105.5	-107.2	1.44	7692.2
3	503.6				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	351.580	387.925	433.889
	2	66.975	72.846	81.724
	3	58.725	503.622	1108.120
THICK	1	1.410	1.671	1.924
	2	55.798	105.596	1514.990
DEPTH	1	1.410	1.671	1.924
	2	57.503	107.266	1516.525

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	418.0	383.2	8.30
2	1.00	360.0	358.8	0.306
3	2.00	231.0	267.7	-15.92
4	4.00	147.0	135.5	7.78
5	8.00	82.50	81.38	1.35
6	16.00	77.00	74.43	3.33

* BRITISH GEOLOGICAL SURVEY *

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	68.30	74.34	-8.84
8	64.00	81.80	80.62	1.43

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.02		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	-0.15	0.00	0.95
	P 1	P 2	P 3	T 1	T 2

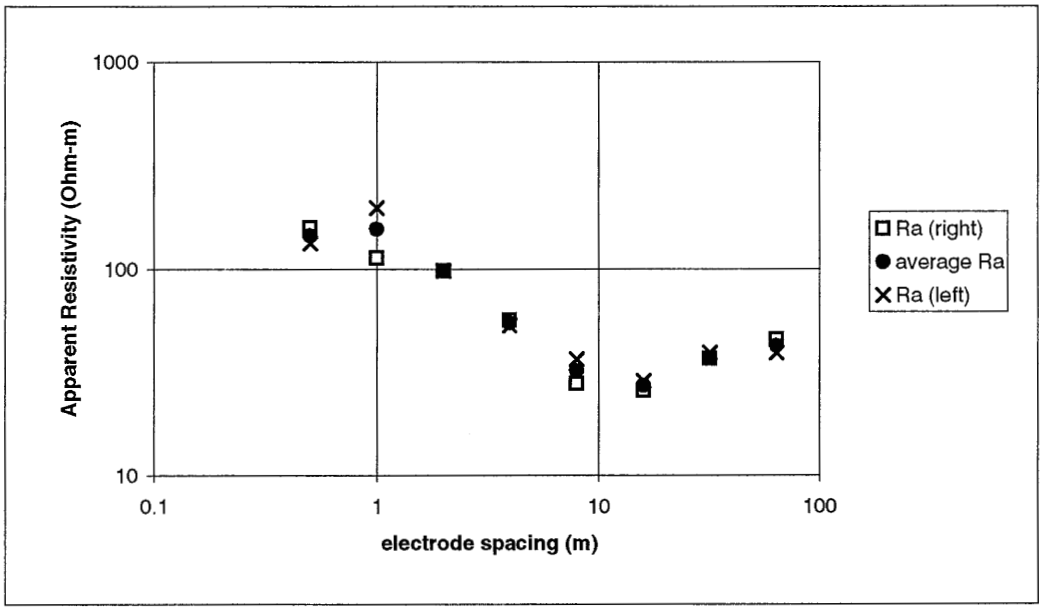
* BRITISH GEOLOGICAL SURVEY *

Anyoga

AE 7

Resistivity Survey 2
Located on okpaga tree - 300 m AE1 6 degs 57.143 8 degs 21.946
Offset Wenner left to tarmac road
strike 114 degs
13/02/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	42.3	50.1	132.822	157.314	145.068
1	31.4	17.92	197.192	112.5376	154.8648
2	7.76	7.76	97.4656	97.4656	97.4656
4	2.11	2.23	53.0032	56.0176	54.5104
8	0.723	0.551	36.32352	27.68224	32.00288
16	0.283	0.254	28.43584	25.52192	26.97888
32	0.1943	0.182	39.04653	36.57472	36.57472
64	0.0972	0.113	39.06662	45.41696	42.24179



DATA SET: AE7

CLIENT: Water Aid DATE: Feb 1998
LOCATION: Anyoga SOUNDING: 2
COUNTY: Oju/Obi Local GOvernmant AZIMUTH: 114 degs
PROJECT: Water and Sanitation EQUIPMENT: BGS128
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Offset Wenner Configuration

FITTING ERROR: 6.404 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	151.2	1.73	-1.73	0.0114	262.9
2	26.51	19.37	-21.11	0.730	513.8
3	53.30				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	139.081	151.266	165.738
	2	23.244	26.516	30.098
	3	41.582	53.302	78.764
THICK	1	1.527	1.738	1.973
	2	10.853	19.378	39.511
DEPTH	1	1.527	1.738	1.973
	2	12.740	21.116	41.192

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	145.0	149.6	-3.18
2	1.00	155.0	140.7	9.19
3	2.00	97.40	106.3	-9.17
4	4.00	54.50	53.30	2.18
5	8.00	32.00	30.51	4.65
6	16.00	27.00	29.38	-8.83

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	36.60	34.75	5.05
8	64.00	42.20	42.83	-1.49

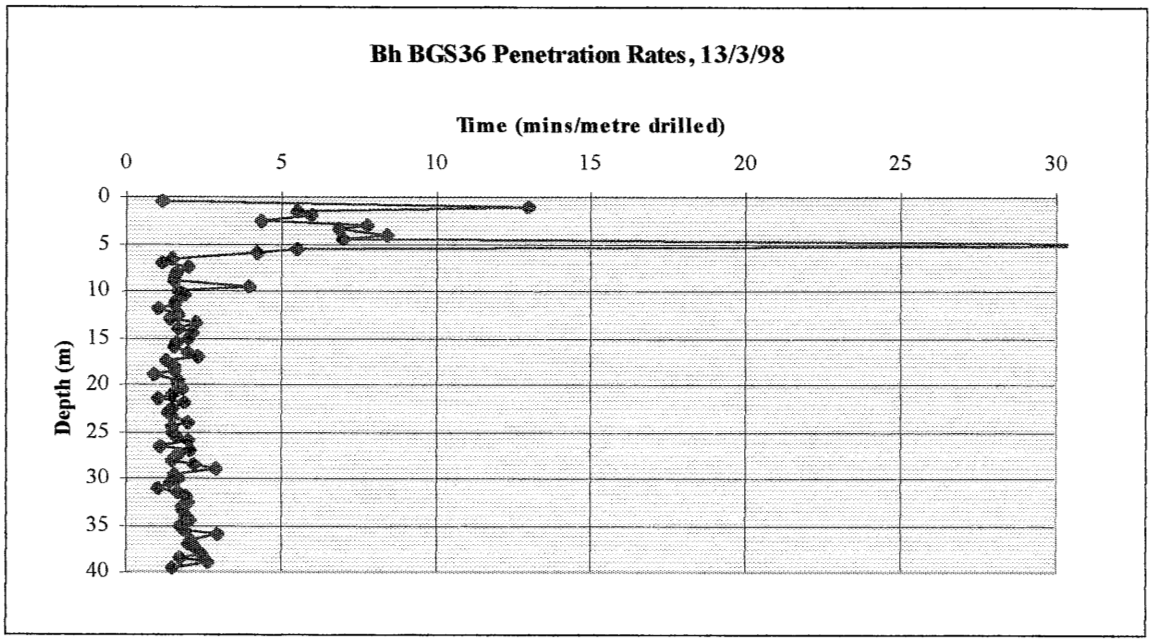
PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.99		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	-0.01	-0.02	0.00	0.95
	P 1	P 2	P 3	T 1	T 2

Annex 2: Drilling and borehole construction data

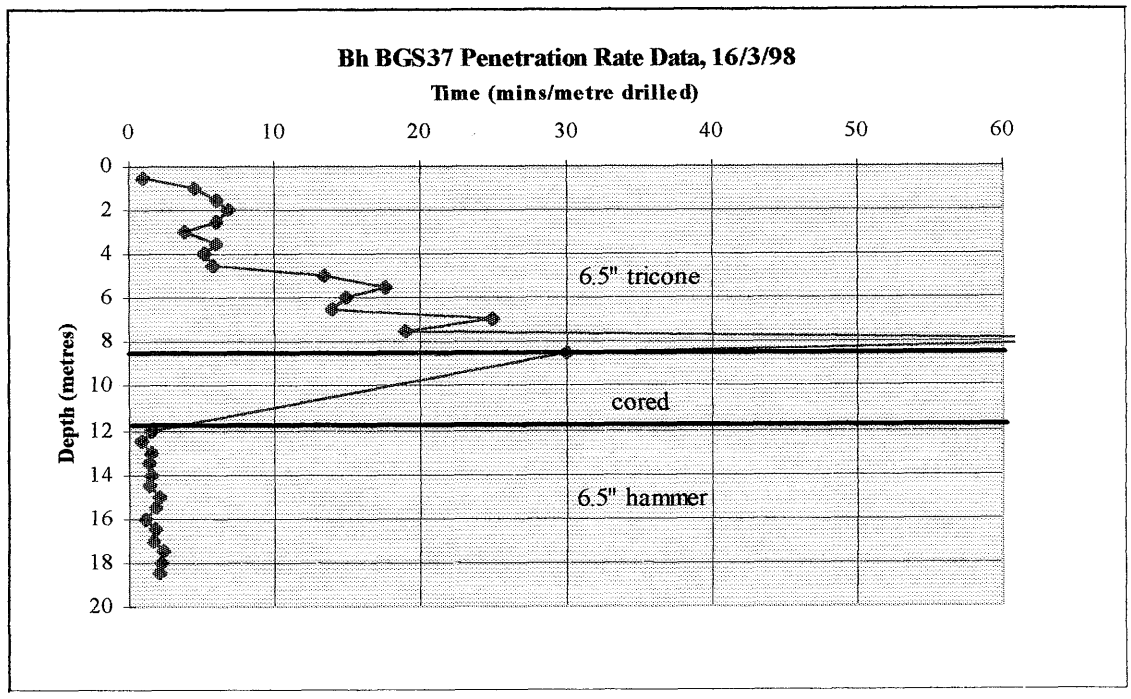
Borehole BGS36

Borehole Drilling/Construction Details	
Date drilling started	13/3/98
Date drilling completed	16/3/98
13/3/98 - Drilled with 6.5" tricone	0.00 - 6.0m
13/3/98 - Drilled with 6.5" hammer	6.0 - 39.3m
13/3/98 - Cored at 3"	39.3 - 41.3m
Depths water struck	15.5, 21.5,
Depth of borehole on completion	41.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x5.8mx125mm casing
	2x5.8mx125mm screen
	8x2.9mx125mm screen
Original top of casing above ground level	0.0m
Total length of casing/screen	40.6m
Amount of casing removed	0.0m
Rest water level below casing top	5.77m



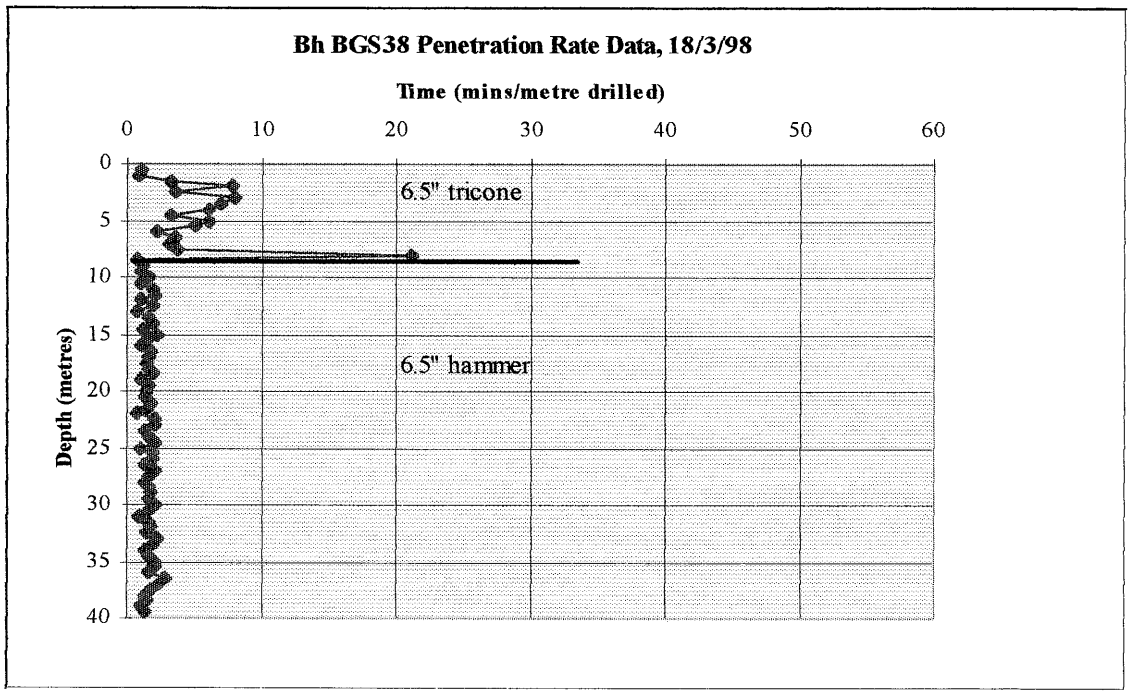
Borehole BGS37

Borehole Drilling/Construction Details	
Date drilling started	16/3/98
Date drilling completed	18/3/98
16/3/98 - Drilled with 6.5" tricone	0.00 - 8.5m
16/3/98 - Cored at 3"	8.5 - 8.8m
16/3/98 - Drilled with 6.5" hammer	8.5 - 9.95m
16/3/98 - Cored at 3"	9.95 - 11.6m
16/3/98 - Drilled with 6.5" hammer	11.6 - 18.5m
Depths water struck	8.2, 11.2, 11.4 (flowing),
Depth of borehole on completion	18.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	2x5.8mx125mm casing
	3x2.9mx125mm screen
Original top of casing above ground level	1.05m
Total length of casing/screen	20.1m
Amount of casing removed	0.80m
Top of casing above ground level	0.25m
Rest water level below casing top	6.19m



Borehole BGS38

Borehole Drilling/Construction Details	
Date drilling started	17/3/98
Date drilling completed	18/3/98
17/3/98 - Drilled with 6.5" tricone	0.00 - 7.5m
17/3/98 - Drilled with 6.5" hammer	7.5 - 39.6m
18/3/98 - Cored at 3"	39.6 - 41.7m
Depths water struck	9.5 (damp)
Depth of borehole on completion	41.7mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	none
Rest water level below GS	38.40m



Annex 3: Lithological Logs

Lithological Log: BGS 36

Soil/ferrecrete horizon	
0.0 - 0.5	Light brown 7.5YR6/4 to yellowish red 5YR5/6 silty sand
0.5 - 1.0	Yellowish red 5YR4/6 clayey silt with dark red and black nodules of ferrecrete
1.0 - 1.5	Purple red and black nodular ferrecrete with red 2.5YR4/6 silty matrix
Clayey very weathered horizon	
1.5 - 2.0	Red 2.5YR4/8 and very brown 10YR7/4 mottled lateritic clay
2.0 - 2.5	Red 10R4/8 to red 2.5YR4/8 and very pale brown 10YR8/4 silty lateritic clay with some pale grey kaolin
2.5 - 3.0	Mottled yellowish red 5YR6/8 sandstone and 7/10Y light greenish grey clay with red 2.5YR4/8 silts, damp
3.0 - 3.5	Reddish yellow 5YR6/8 silts to 3.2m then white kaloinitic clay with orange streaks
3.5 - 4.0	White kaolin clay above weathered orange/brown fine to medium friable to hard Makurdi sandstone
Hard to friable fine grained sandstone, fairly weathered	
4.0 - 4.5	Very pale brown 10YR7/4 hard to friable fine grained sandstone, some mica, with reddish yellow 7.5YR6/8 specks
Hard fine grained silicified sandstone	
4.5 - 5.0	Hard light brown grey fine grained sandstone, siliceous in parts
Soft friable fine to medium grained sandstone, fairly weathered	
5.0 - 5.5	Softer friable brown grey fine to medium grained fairly muddy in parts sandstones and interbedded dark grey shaley siltstones, some hard cherty fragments.
5.5 - 6.0	Light greyish white with orange specks fine grained sandstones, brown grey thinly bedded fine to medium grained sandstoneswith grey silty shales
6.0 - 6.5	Friable grey brown fine grained sandstones
6.5 - 7.0	Dark grey friable medium grained sandstones
7.0 - 7.5	Light fawn brown fine grained sandstone
7.5 - 8.0	Soft friable brown fine grained sandstone
8.0 - 8.5	Dark grey mudstones interbedded with grey fine grained sandstones
8.5 - 9.0	Soft friable light grey fine grained sandstones
Hard quartzitic fine grained sandstone	
9.0 - 9.5	Very hard light grey quartzitic fine grained sandstones with some black organic partings
Fine to medium grained sandstone	
9.5 - 10.0	Soft whitish grey fine grained sandstone - damp
10.0 - 10.5	Friable light grey fine grained sandstone
10.5 - 11.0	Soft brownish grey fine to medium grained sandstone, damp
11.0 - 11.5	Grey fine grained sandstones with dark grey mudstones
Carbonaceous mudstone	
11.5 - 12.0	Black carbonaceous mudstones
Fine grained sandstone	
12.0 - 12.5	Greyish white fine to medium grained sandstones with hard bands, damp
12.5 - 13.0	Greyish white fine grained sandstones with hard and soft bands
13.0 - 13.5	Greyish white fine grained sandstones with hard and soft bands
13.5 - 14.0	Light grey friable fine grained sandstone
14.0 - 14.5	Light grey fine grained sandstones, damp
14.5 - 15.0	Light grey fine grained sandstones, damp
15.0 - 15.5	Soft light grey fine grained sandstones
15.5 - 16.0	Light grey fine grained sandstones
16.0 - 16.5	Light grey fine grained sandstones
16.5 - 17.0	Soft and friable light grey fine grained sandstones
17.0 - 17.5	Light grey fine grained sandstones and dark grey mudstones
Interbedded carbonaceous mudstones, siltstone, hard sandstone and limestone	
17.5 - 18.0	Dark grey blocky carbonaceous mudstones
18.0 - 18.5	Dark grey silty mudstones with thin hard sandstone or limestone
18.5 - 19.0	Dark grey sandy siltstones

Mudstone	
19.0 - 19.5	Dark grey mudstones
19.5 - 20.0	Dark grey mudstones
20.0 - 20.5	Dark grey mudstones
20.5 - 21.0	Dark grey mudstones
21.0 - 21.5	Dark grey mudstones
Carbonaceous shaley mudstone	
21.5 - 22.0	Brownish black carbonaceous shaley mudstone
22.0 - 22.5	Brownish black carbonaceous shaley mudstone
22.5 - 23.0	Brownish black carbonaceous shaley mudstone
23.0 - 23.5	Brownish black carbonaceous shaley mudstone
23.5 - 24.0	Brownish black carbonaceous shaley mudstone
24.0 - 24.5	Brownish black carbonaceous shaley mudstone
24.5 - 25.0	Brownish black carbonaceous shaley mudstone
25.0 - 25.5	Brownish black carbonaceous shaley mudstone
25.5 - 26.0	Brownish black carbonaceous shaley mudstone with thin hard bands
26.0 - 26.5	Black carbonaceous mudstones
Fine grained sandstone and mudstone	
26.5 - 27.0	Black fine grained sandstones to black mudstones
27.0 - 27.5	Dark grey friable fine grained sandstones
Carbonaceous mudstones and fine grained sandstone	
27.5 - 28.0	Black carbonaceous mudstones with thin fine grained sandstones
28.0 - 28.5	Dark grey black fine grained muddy sandstones and black carbonaceous mudstones
28.5 - 29.0	Hard light grey to grey fine grained sandstones
29.0 - 29.5	Thin alternations of black carboaceous mudstones and thin fine grained sandstones
Fine grained sandstone with mudstone partings	
29.5 - 30.0	Thinnly bedded dark grey to grey fine grained sandstones
30.0 - 30.5	Thin light grey fine grained sandstones with dark grey carbonaceous mudstone partings
30.5 - 31.0	Thin soft grey fine grained sandstones
31.0 - 31.5	Thin grey fine grained sandstones and shales
Carbonaceous mudstone and fine grained sandstone	
31.5 - 32.0	Black carbonaceous mudstones with thin dark grey fine grained sandstones
32.0 - 32.5	Black carbonaceous mudstones with thin dark grey fine grained sandstones
32.5 - 33.0	Black carbonaceous mudstones with thin dark grey fine grained sandstones
33.0 - 33.5	Black carbonaceous mudstones with black carbonaceous fine grained sandstones
Fine grained sandstone	
33.5 - 34.0	Dark grey fine grained sandstones
Carbonaceous mudstone and hard fine grained sandstone	
34.0 - 34.5	Black carbonaceous mudstones with thin dark grey fine grained sandstones
34.5 - 35.0	Black carbonaceous mudstones with some hard grey fine grained sandstone bands
Carbonaceous siltstone	
35.0 - 35.5	Black carbonaceous siltstones
35.5 - 36.0	Black carbonaceous siltstones
Fine grained sandstone	
36.0 - 36.5	Black to dark grey fine grained sandstones
Carbonaceous mudstone	
36.5 - 37.0	Black carbonaceous mudstones with thin hard bands
37.0 - 37.5	Black carbonaceous mudstones with thin hard bands
Fine grained sandstone and carbonaceous mudstone	
37.5 - 38.0	Dark grey fine grained sandstones and black carbonaceous mudstones
38.0 - 38.5	Dark grey fine grained sandstones and black carbonaceous mudstones
38.5 - 39.0	Hard dark grey fine grained sandstones and black carbonaceous mudstones
39.0 - 39.5	Dark grey fine grained sandstones and black carbonaceous mudstones
Interbedded muddy fine grained sandstone and silty mudstone	
39.30 - 39.47	Interbedded grey muddy sandstones, dark grey silty mudstones and thinly bedded greenish grey fine grained sandstones. Some bioturbation and load cast structures.

	Light brown crystaline vein mineral along bedding planes and joint planes at base, muddy sandstones are fairly micaceous, no fossils
Carbonaceous mudstones	
39.47 - 39.62	Dark grey fine grained carbonaceous mudstones, some brown vein material along joints and cracks, no fossils
Muddy fine grained sandstone, bioturbated	
39.62 - 40.12	Hard interbedded muddy carbonaceous sandstones and greenish grey fine grained sandstones. Thinly bedded, much bioturbation, very sand between 39.95 - 40.06
Interbedded shaley mudstones and fine grained sandstones	
40.12 - 40.74	Dark grey silty shaley thinly bedded mudstones with interbedded thin greenish grey fine sandstone bands. Some load casts associated with sands sinking into muds
Fine to medium grained micaceous sandstone	
40.74 - 40.76	Hard band of grey white fine to medium sandstone, much mica and black organics
Silty mudstone and fine grained sandstone	
40.76 - 40.90	Dark grey silty mudstone with thin white fine grained sandstone bands, no fossils
Carbonaceous mudstone and dense limestone	
40.90 - 41.30	Sub-parallel thinly bedded alternations of carbonaceous mudstones and thin white **calcite** bands, convoluted bedding, sharp boundary between overlying mudstones, some recrystalisation at top of limestone band, probably a thick algal limestone deposit.

Lithological Log: BGS 37

Soil/ferrecrete horizon	
0.0 - 0.5	Light brown (7.5YR6/4) fine grained soil
0.5 - 1.0	Light brown (7.5YR6/4) fine grained soil
1.0 - 1.5	Black and dark red ferrecrete nodules within orange red sandy martix
1.5 - 2.0	Dark red and light brownish grey clayey fine grained sands with some dark red and black ferrecrete nodules
Clayey, very weathered silts and fine grained sandstones	
2.0 - 2.5	Light bluish grey to light greenish grey clay within much red and yellow clayey fine grained sandstones
2.5 - 3.0	Light bluish grey clay and orange and brown silts
3.0 - 3.5	Grey black mudstones with weathered light grey clay and light orange red silty fine sands, with light fawn grey fine sandstone
Weathered friable fine to medium silty sandstones	
3.5 - 4.0	Light brown grey friable fine grained sandstones with orange and light grey clayey layers
4.0 - 4.5	Fawn fine to medium grained sandstones weathered soft with hard bands
4.5 - 5.0	Friable grey to grey brown medium to fine grained micaceous sandstones with grey siltstones
Hard to friable medium to fine grained fairly weathered sandstones, water bearing in parts	
5.0 - 5.5	Grey medium to fine micaceous sandstones, weathered orange in parts, with silcretised hard bands as at 5.0-5.2m and 5.4-5.5m
5.5 - 6.0	Fairly hard grey medium to fine sandstone, some orange weathering
6.0 - 6.5	Fairly hard to friable white medium to fine grained sandstone with orange specs, some thin grey shale bands
Hard to friable fissile micaceous medium to fine sandstone	
6.5 - 7.0	Dark to light white grey friable sandstone, hard to soft, fine to medum grained, feldspathic 6.5-6.7m, grey shaley micaceous siltstone 6.7-6.8m and sandstone 6.8-7.0m
7.0 - 7.5	White to light grey fine to medium micaceous fissile and fractured sandstones with grey clay mud drapes
7.5 - 8.0	Interbedded light grey to white medium to fine fissile sandstone with very hard light brown and grey fine grained quartzite
Hard to very soft medium to fine grained sandstones, fairly weathered, with water bearing fractures	
8.0 - 8.5	Light grey and grey medium to fine sandstones with limonitic brown specks, some organic carbon and grey shaley partings, sandstones are friable and micaceous in parts. Very soft below 8.2m in very damp brown grey medium grained sandstones interbedded with thin dark grey shaley mudstones
8.65 - 8.69	Light brown grey very hard quartzite, light brown colouration due to iron oxide staining along small water bearing crack
Hard compact siliceous medium to fine grained sandstones	
8.69 - 8.95	Light greyish white homogenous fine to medium grained sandstone, some mica. Bedding not readily discernable, siliceous cement
9.0 - 9.5	no sample
9.5 - 10.0	no sample
10.0 - 10.5	no sample
10.54 - 10.60	Compact hard light greyish white medium to fine grained sandstone with silica cement
10.60 - 10.61	Grey compact medium to finegrained sandstone with siliceous cement
10.61 - 10.89	Compact hard light greyish white medium to fine grained sandstone with siliceous cement, thickly bedded.
10.89 - 10.93	Compact hard light greyish white medium to fine grained sandstone with siliceous cement. Some intermittent dark grey black muddy intercalations
10.93 - 11.37	Compact hard light greyish white medium to fine grained sandstone with siliceous cement, rippled base

11.04 - 11.07	Light grey septarian nodule of calcareously cemented sandstone
11.37 - 11.60	White cross bedded medium grained sandstone with black organic and micaceous partings
11.44 - 11.46	Joint planes with orange brown surfaces, water bearing fracture
Massive shaley mudstones and fine grained sandstones	
11.5 - 12.0	Black carbonaceous shaley mudstone with dark grey sandstones
12.0 - 12.5	Black carbonaceous shaley mudstone with dark grey sandstones
12.5 - 13.0	Black carbonaceous shaley mudstone with dark grey sandstones
13.0 - 13.5	Black carbonaceous shaley mudstone with dark grey sandstones
13.5 - 14.0	Black carbonaceous shaley mudstone with dark grey sandstones
14.0 - 14.5	Black carbonaceous shaley mudstone with dark grey sandstones
14.5 - 15.0	Black carbonaceous shaley mudstone with dark grey sandstones
15.0 - 15.5	Black carbonaceous shaley mudstone with dark grey sandstones
15.5 - 16.0	Black carbonaceous shaley mudstone with dark grey sandstones
16.0 - 16.5	Black carbonaceous shaley mudstone with dark grey sandstones
16.5 - 17.0	Black carbonaceous shaley mudstone with dark grey sandstones
17.0 - 17.5	Black carbonaceous shaley mudstone with dark grey sandstones
17.5 - 18.0	Black carbonaceous shaley mudstone with dark grey sandstones
18.0 - 18.5	Black carbonaceous shaley mudstone with dark grey sandstones

Lithological Log: BGS38

Soil ferecrete horizon	
0.0 - 0.5	Brown 5YR4/3 loamy soil
0.5 - 1.0	Brown 5YR4/3 loamy soil with black carbonised wood fragments
1.0 - 1.5	Brown 5YR4/3 loamy soil with black carbonised wood fragments
1.5 - 2.0	Brown 5YR4/3 loamy soil with black carbonised wood fragments to 1.8m, with ferricrete to 2.0m
2.0 - 2.5	Dark red and black very nodular ferricrete in reddish yellow matrix with some mottled orange and yellow clays
Clayey very weathered zone	
2.5 - 3.0	Reddish yellow 7.5YR6/8 to yellowish red 5YR5/8 mottled clays
3.0 - 3.5	Yellow 10YR7/8 to brownish yellow 10YR6/8 fine sand with light greenish grey 8/5BG clay
3.5 - 4.0	Yellow 10YR7/8 to brownish yellow 10YR6/8 fine sand with light greenish grey 8/5BG clay, with some fragments of weathered medium to fine grained sandstones
4.0 - 4.5	Yellowish brown 10YR5/8 weathered sandstone with much interbedded light greenish grey 8/5BG clay
Weathered sandstones, siltstones and mudstones	
4.5 - 5.0	Weathered olive green grey silty sandstones and light blue grey clay
5.0 - 5.5	Olive green to dark grey brown weathered shaley mudstones
5.5 - 6.0	Grey to brown grey weathered carbonaceous shaley mudstones
6.0 - 6.5	Dark grey to dark brown grey shaley mudstones
6.5 - 7.0	Dark grey to olive green weathered sandy mudstones
7.0 - 7.5	Dark brown grey very fine grained mudstones with light blue grey and bright orange clay along weathered horizons, with thin orange grey fine grained sandstone bands
Limestone	
7.5 - 8.0	Very hard grey limestone
Unweathered massive sandstones and mudstones	
8.0 - 8.5	Dark grey interbedded sandstones and mudstones
8.5 - 9.0	Dark grey interbedded sandstones and mudstones
Fairly weathered friable fine grained sandstones - some dampness	
9.0 - 9.5	Light brown fine sandstones, DAMP
9.5 - 10.0	Light grey fine grained sandstones with hard and soft bands
10.0 - 10.5	Light grey fine grained sandstones
10.5 - 11.0	Grey to white friable fine grained sandstones
11.0 - 11.5	Light grey friable fine grained sandstone with brown limonitic specks
Unweathered hard fine grained sandstone to quartzite	
11.5 - 12.0	Grey quartzitic fine grained sandstones with brown specs
12.0 - 12.5	Harder grey quartzitic fine grained sandstone
12.5 - 13.0	Hard light grey quartzite
13.0 - 13.5	Hard white to light grey fine sandstone
13.5 - 14.0	Hard white to light grey fine sandstone
14.0 - 14.5	Hard white to light grey well bedded fine sandstone
14.5 - 15.0	Hard white to light grey fine sandstone with harder bands of quartzite
15.0 - 15.5	Hard white to light grey fine sandstone
15.5 - 16.0	Hard white to light grey fine sandstone
16.0 - 16.5	Hard white to light grey fine sandstone
Unweathered medium and fine grained sandstones and shales	
16.5 - 17.0	Light grey medium grained sandstone, some grey shales and some softer fine grained sandstone
17.0 - 17.5	Light grey medium grained sandstone, some grey shales and some softer fine grained sandstone
17.5 - 18.0	Interbedded light grey shales and white thinly bedded fine grained sandstones
Massive fine grained sandstones	
18.0 - 18.5	Hard white to light grey fine grained sandstone, thickly bedded
18.5 - 19.0	Friable thickly bedded grey fine grained sandstones

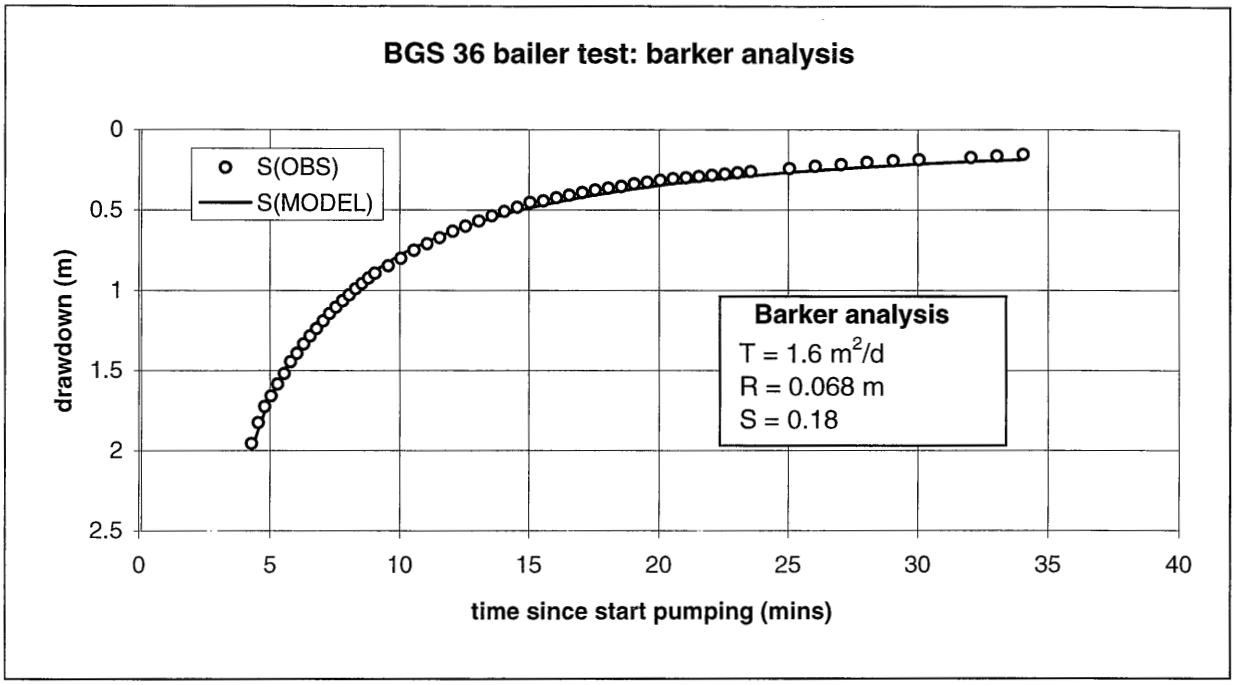
19.0 - 19.5	Friable thickly bedded grey fine grained sandstones
Hard to friable fine to medium sandstones	
19.5 - 20.0	Hard white fine grained quartzitic sandstones
20.0 - 20.5	Friable light grey/white fine to medium grained sandstones
20.5 - 21.0	Friable light grey/white fine to medium grained sandstones
21.0 - 21.5	Grey medium grained micaceous sandstone
Friable fine grained sandstone with shale	
21.5 - 22.0	Light grey to white friable fine grained sandstone
22.0 - 22.5	Light grey to white friable fine grained sandstone white grey shaley partings
22.5 - 23.0	Light grey to white friable fine grained sandstone white grey shaley partings
23.0 - 23.5	Light grey to white friable fine grained sandstone
23.5 - 24.0	Light grey to white friable fine grained sandstone
24.0 - 24.5	Light grey fine grained sandstone, hard in parts with grey shaley partings
24.5 - 25.0	White to light grey fine grained friable sandstone
25.0 - 25.5	Harder light grey to white fine grained sandstone
Friable to hard fine grained sandstones with interbedded shales	
25.5 - 26.0	Friable thinly bedded white to light grey fine grained sandstone with grey shaley partings and bands of hard white quartzite
26.0 - 26.5	Interbedded dark grey shales and bands of white fine grained friable to hard fine grained sandstone
Massive friable fine grained sandstones	
26.5 - 27.0	Soft white friable fine grained sandstones
27.0 - 27.5	Hard white fine grained thickly bedded sandstones
27.5 - 28.0	White to light grey fine grained friable sandstones with thin grey shale bands
28.0 - 28.5	White fine grained sandstone
28.5 - 29.0	White fine grained sandstone, thinly bedded
29.0 - 29.5	White thickly bedded harder fine grained sandstone
29.5 - 30.0	Light grey white fine grained sandstone
Massive interbedded fine grained sandstones, siltstones and mudstones	
30.0 - 30.5	Dark grey to black shaley fine to medium grained sandstones
30.5 - 31.0	Black carbonaceous muddy siltstones
31.0 - 31.5	Dark grey to black fairly hard carbonaceous muddy siltstones
31.5 - 32.0	Dark grey black silty mudstones
32.0 - 32.5	Dark grey siltstones and hard grey fine grained sandstones
32.5 - 33.0	Dark grey shaley siltstones and thin muddy grey fine sandstones
33.0 - 33.5	Dark grey shaley siltstones and thinly bedded mudstones
Massive interbedded fine grained sandstones and shaley siltstones	
33.5 - 34.0	Dark grey thinly bedded fine grained sandstones and shaley siltstones
34.0 - 34.5	Dark grey thinly bedded fine grained sandstones and shaley siltstones
34.5 - 35.0	Dark grey thinly bedded fine grained sandstones and shaley siltstones
35.0 - 35.5	Dark grey thinly bedded fine grained sandstones and shaley siltstones
35.5 - 36.0	Dark grey thinly bedded fine grained sandstones and shaley siltstones
36.0 - 36.5	Black carbonaceous shaley mudstones above hard white fine to medium grained sandstones
Hard fine grained sandstones with shaley partings	
36.5 - 37.0	Hard white to grey fine grained quartzitic sandstone
37.0 - 37.5	Light greyish white friable to hard thinly bedded fine grained sandstones
37.5 - 38.0	Light grey thinly bedded fine grained sandstones with shaley partings
Muddy fine grained sandstones and mudstones, chaotically bedded and bioturbated	
38.0 - 38.5	Dark grey shaley fine grained sandstones
38.5 - 39.0	Dark grey to black carbonaceous mudstones, siltstones and grey hard thin sandstones
39.0 - 39.6	Black carbonaceous mudstones with thin grey fine grained sandstone bands
39.60 - 39.87	Grey bioturbated muddy fine grained silty sandstones
39.87 - 39.88	Dark grey mudstone with grey brown crystalline evaporite? top surface
39.88 - 39.93	Light grey bioturbated fine grained sandstones
39.93 - 39.96	Dark grey thinly bedded sandy mudstones
39.96 - 40.04	Interbedded white fine grained sandstonesand dark grey muddy fine grained sandstones

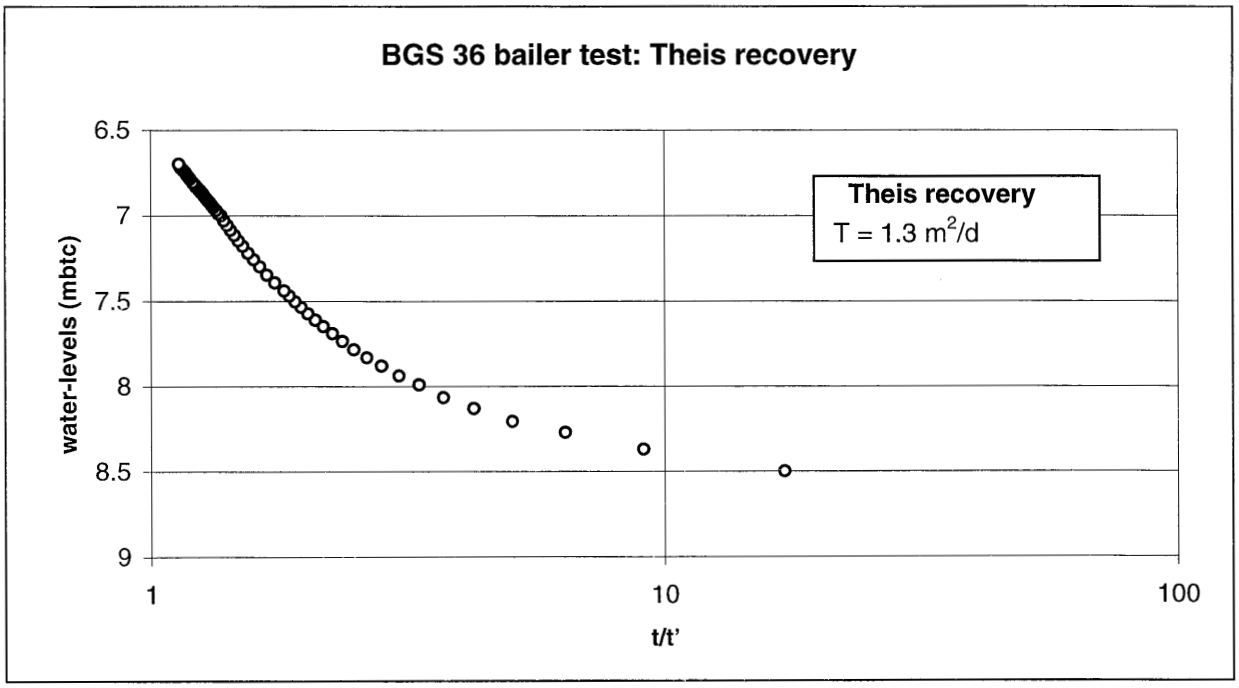
40.04 - 40.10	Dark grey thinly bedded muddy bioturbated fine grained sandstones
40.10 - 40.17	Light grey fine grained sandstones, slumped bedding with loadstructures above thin black to dark grey mudstones
40.17 - 40.28	Dark grey thinly bedded muddy sandstones
40.28 - 40.36	Light grey chaotically bedded fine grained sandstones
40.36 - 40.45	Dark grey thinly bedded muddy fine grained sandstones with some bioturbation
40.45 - 40.46	Dark grey thinly bedded mudstones
40.46 - 40.50	Dark grey thinly bedded muddy bioturbated fine sandstones
40.50 - 40.58	Light grey chaotically bedded/slumped fine to medium grained sandstones
40.58 - 40.64	Thinly bedded dark grey and light grey muddy sandstones, some load structures
40.64 - 40.79	Dark grey black shaley mudstones
40.79 - 40.90	Light grey bioturbated and slumped fine grained sandstones
40.90 - 40.93	Dark grey shaley very muddy fine grained thinly bedded sandstones
40.93 - 41.08	Light greyish white bioturbated and load slumped fine grained sandstones
41.08 - 41.33	Interbedded thinly bedded grey and dark grey muddy fine grained sandstones and sandy shaley, bioturbated in parts
41.33 - 41.42	Chaotically bedded and slumped rounded masses of white to light grey fine grained sandstone within a dark grey sandy mudstone matrix, flaser structures with muds forced upwards into sandstones due to compressive loading
41.42 - 41.49	Dark grey very muddy fine grained sandstones, some bioturbation
41.49 - 41.61	Light grey fragmented thinly bedded fine grained sandstones with interbedded dark grey thinly bedded muddy fine grained sandstones
41.61 - 41.65	Dark grey sandy mudstones
41.65 - 41.70	Dark grey bioturbated fine grained muddy sandstones with light grey fine grained sandstones in parts

Annex 4: Test Pumping Data

BGS 36

bailer test 27/03/98
rwl abh: 6.545
No of bails = 15
time pumping 4:03 mins
prate: 0.28 l/s = 24 m3/d





BGS 36: whale pump test

20/03/98

ABH BGS 36

rwl 5.41 m btc

height casing = 0.1 m agl distance between boreholes = 11.4 m

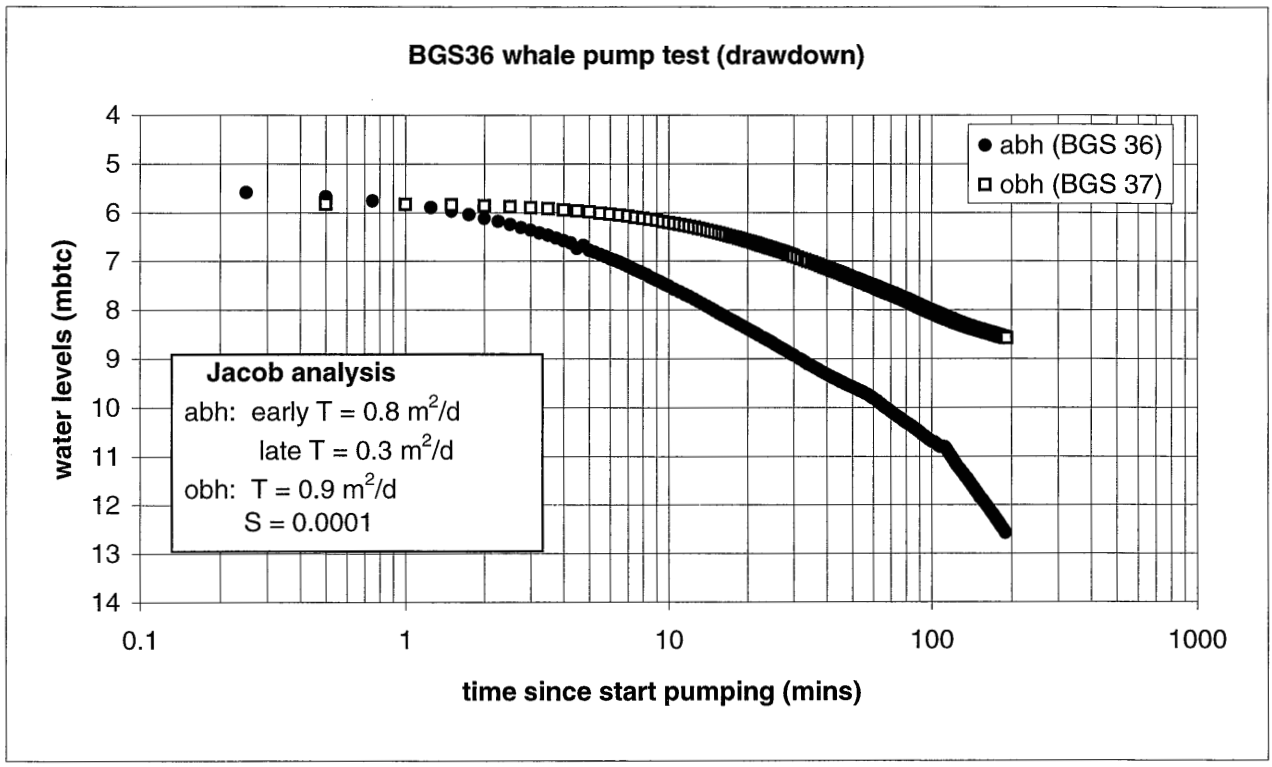
OBH (BGS 37)

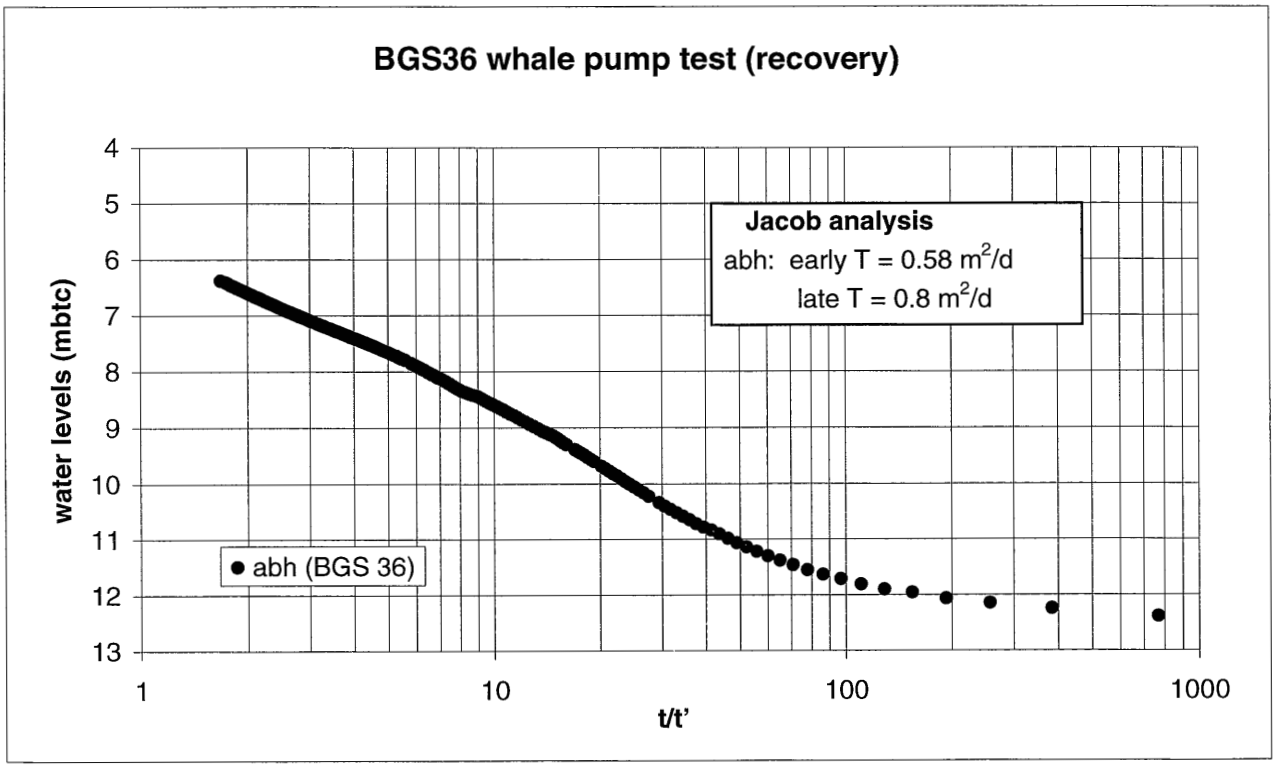
rwl 5.817 mbtc

height casing = 0.32 m agl

time 192 mins

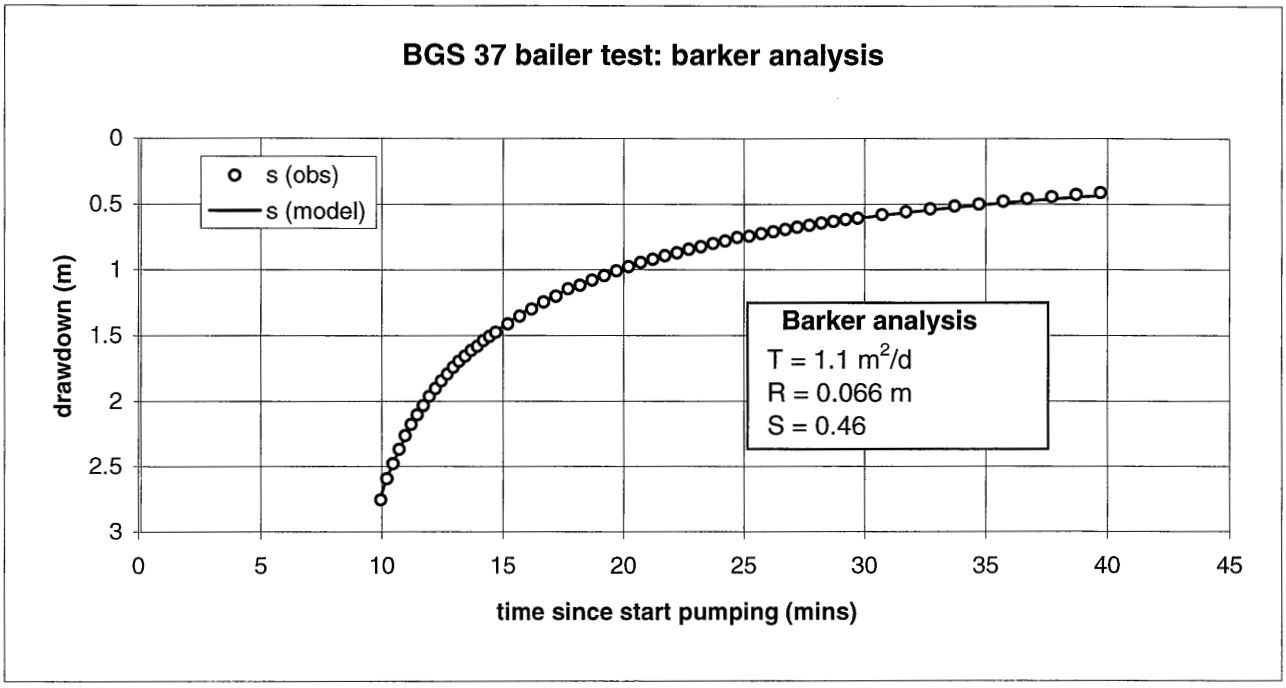
prate = 0.17 - 0.13 l/s; weighted average = 0.14 l/s 12.1 m3/d

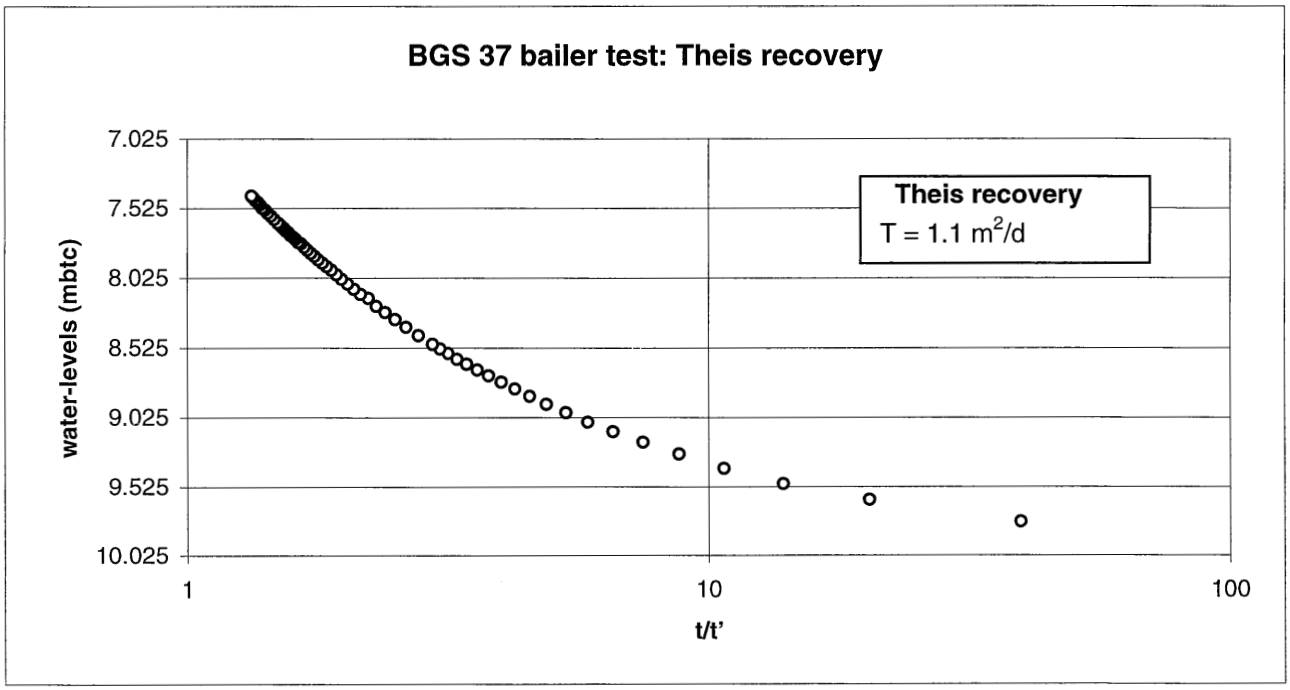




BGS 37: bailer test

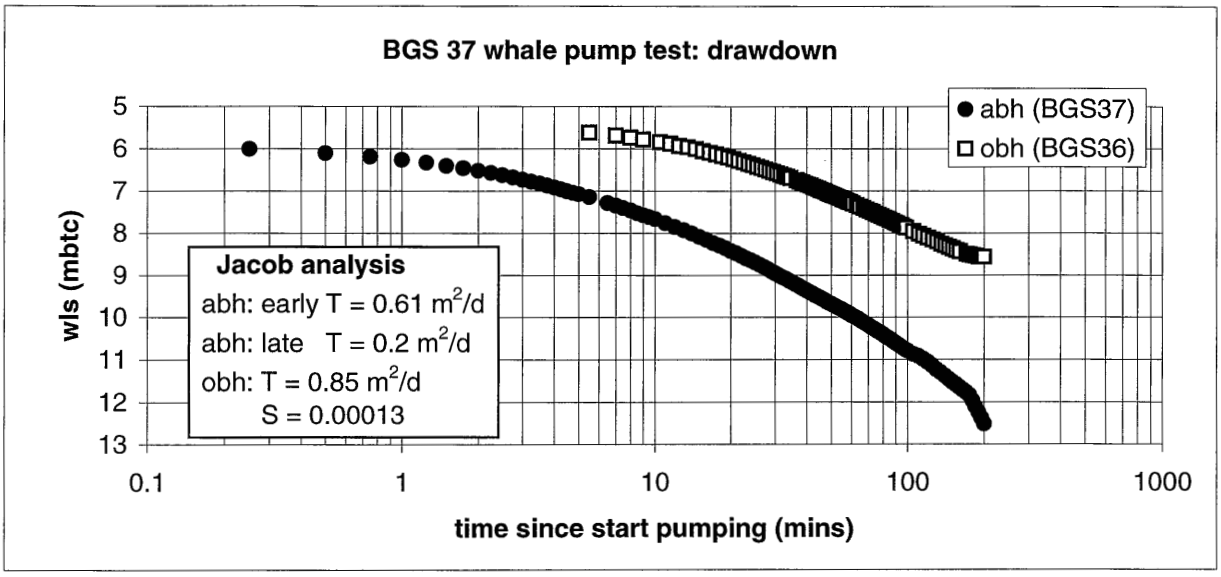
bailer test 27/03/98
rwl abh: 7.025 m
No of bails = 30
time pumping 9:43 mins
prate: 0.23 l/s = 20 m3/d

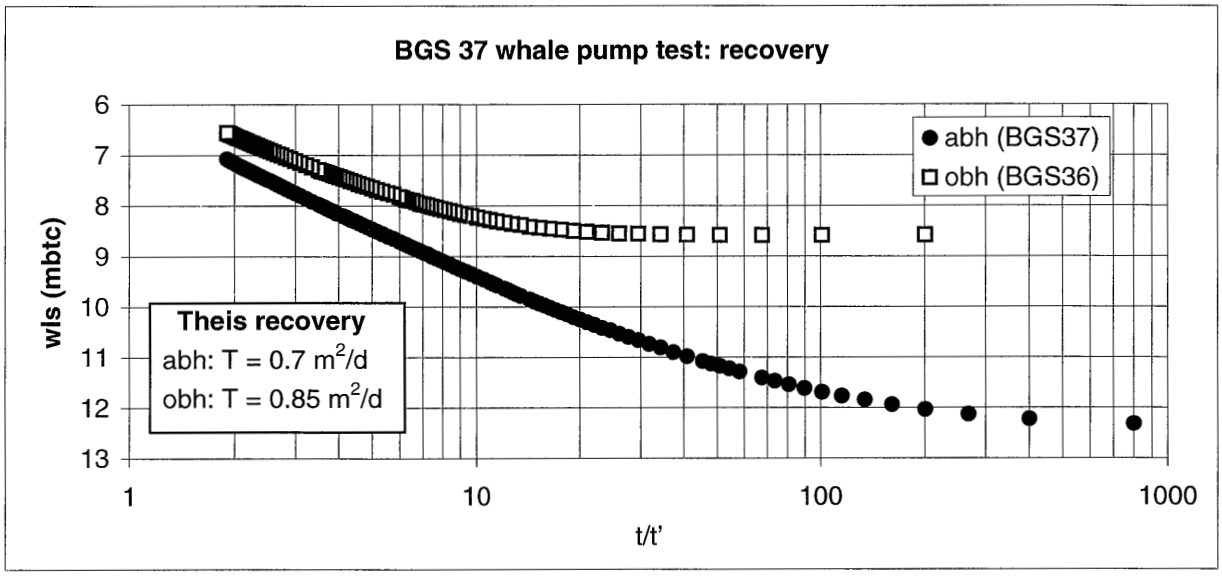


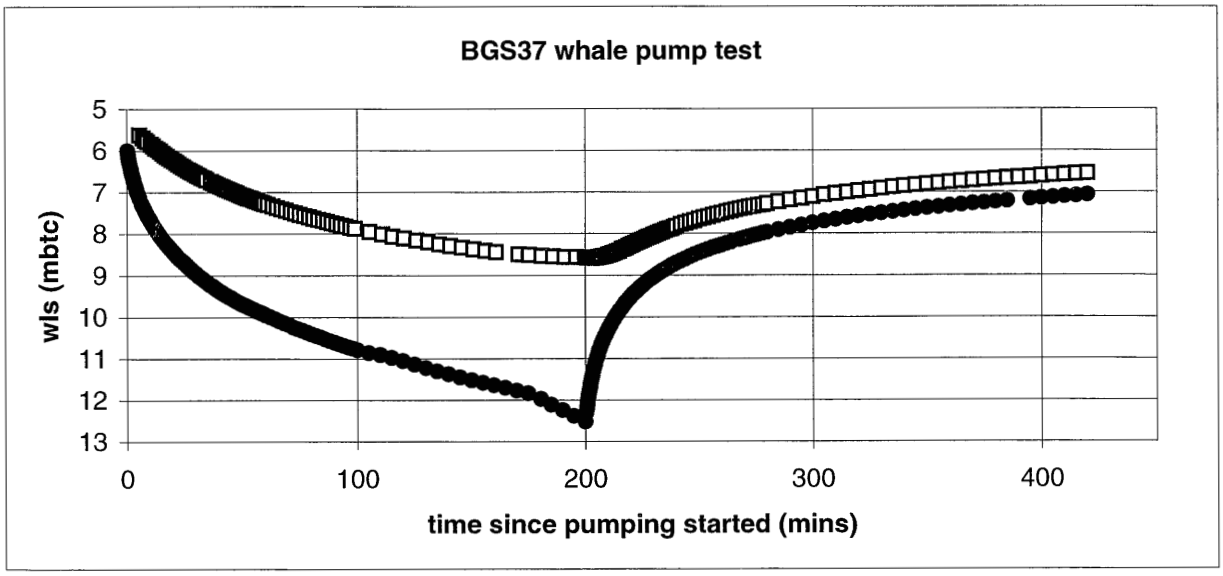


BGS 37: whale pump test

27/03/98
Abh (BGS 37) rwl = 5.829 m Obh (BGS 36) rwl = 5.442 m
height casing = 0.32 m agl (abh) 0.1 m (obh)
time pumping = 200 mins
prate = 0.17 l/s - 0.13 l/s; weighted average = 0.14 l/s

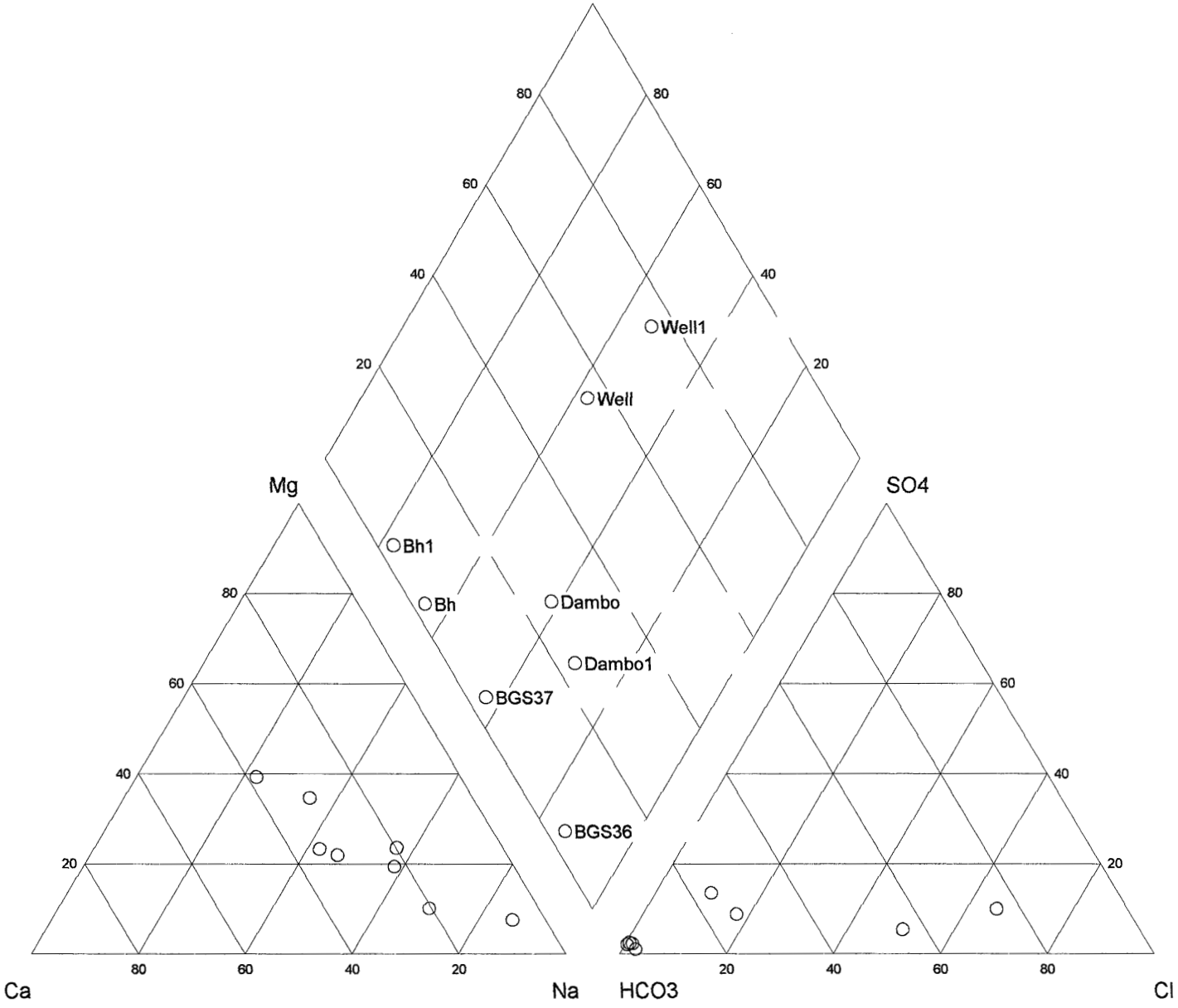






Annex 5: Water Quality Data

Groundwater Hydrochemistry - Adum East



Anyoga Eddi Adum East

Jan-Apr 1998

Easting	Northing	sample ID No	Bh No	pH	Temp DegC	Cond microS/cm	HCO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l
8.37	6.939	Oju30	dambo	5.5	28.3	30	10	3.9	0.9	1	0.3	1.4	0.8
8.363	6.963	Oju31	Well	6.4	29.4	164	9	10.4	5.1	6.2	2.6	2.9	14.1
8.362	6.964	Oju32	Bh	7.42	29.1	336	231	21.3	1.4	31.6	19.7	4.6	1
8.36735	6.9528	221	BGS36	7.55	29.1	1510	1040	360	4.3	22.4	16.7	8.5	
8.36735	6.9528	226	BGS37	7.26	28.6	965	622	141	3.5	43	31	11.6	
8.36287	6.96307	251	Well	7.51	31.8	241	23	11	4.8	7.78	3.2	2.2	
8.36198	6.96392	252	Bh	7.42	30.4	464	266	40.9	1.6	31.2	21.5	4.5	
8.37013	6.93938	253	Dambo	6.78	32.7	67.7	18	5.67	3.7	1.88	1	1.7	

sample ID No	NO3-N mg/l	Si mg/l	Sr mg/l	Ba mg/l	Li mg/l	B mg/l	Fe Total mg/l	Mn mg/l	I mg/l	F mg/l	Br mg/l
Oju30		9.3	0.014	0.016			0.21	0.016	0.0022	0.03	0.007
Oju31	5.9	6.2	0.059	0.16			0.15	0.02	0.0047	0.04	0.028
Oju32		27.3	0.126	0.287	0.037		0.17	0.007	0.009	0.23	0.006
221		11.3	0.127	0.287	0.106	0.07	0.58	0.063	0.0099		
226		16.2	0.214	0.389	0.057	0.04	0.13	0.169	0.0032		
251		9.7	0.068	0.186	-0.007	-0.03	0.19	0.035	0.0056		
252		25.4	0.126	0.292	0.037	-0.03	0.12	0.006	0.0105		
253		10.8	0.016	0.036	-0.007	-0.03	0.2	0.022	0.0017		