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Overseas Geology Series

The hydrogeology of the Oju/Obi area, eastern Nigeria: Odubwo area data report

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Test pumping borehole BGS2 at Odubwo.

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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 development potential of the Asu River Group sediments was investigated at Odubwo village and the WaterAid compound. Investigations that included seven kilometres of EM34-3 surveys (using various inter-coil spacings), three kilometres of magnetic profiling and two resistivity soundings were undertaken during November 1996, November 1997 and March-April 1998.. Four boreholes were drilled: a deep production borehole and three shallow observation boreholes. Of these BGS 1, BGS 2 and BGS 2b were completed as production boreholes with screen and casing; BGS2a was back-filled. These boreholes were test pumped and water samples obtained for hydrochemical analysis. The following conclusions can be made from the test site.

- The Asu River group rocks investigated were moderately hard splintery mudstones with a slatey cleavage, which have undergone a degree of burial diagenesis. Disseminated pyrite is present. The top few metres of the mudstone are weathered and contain some kaolinite clay. Thin fersiallitic soils have been developed.
- Below 10-15 m the mudstone contains many fractures; many of which have been filled with calcite. These fractures contain significant quantities of groundwater – water-bearing fractures have been detected to 60 m.
- Test pumping indicated a transmissivity of 4 m^2/d at Odubwo. Test pumping of the shallow (11.8 m) borehole at the WaterAid compound gave a transmissivity of only 0.27 m^2/d – a deeper borehole drilled at this site would probably have been comparable to those at Odubwo. The storage coefficient at Odubwo was typical of a confined aquifer (5×10^{-4}).
- The sustainability of groundwater supplies from the Asu river group is unknown. Since the only source of water is from thin fractures, there may be only be a limited amount of water stored within the aquifer. Therefore, the abstraction of water supplies from the Asu River Group should be closely monitored.
- The quality of groundwater from the Asu River group is generally good. The groundwater is of calcium bicarbonate type with occasional high iron or sulphate. The ionic contents of the groundwater samples analysed are all within the WHO recommended drinking water guidelines.
- At present, there is insufficient information to give guidelines for identifying specific borehole or well sites using geophysics in the Asu River group. All conductivity values tend to be low (<30 mmhos/m). Higher values within this range may represent greater weathering and therefore more groundwater, but at present, there are no data to substantiate this. Likewise with resistivity soundings.
- Due to the depth of the water-bearing zone and the comparative hardness of the rock, boreholes are the most appropriate technology for the Asu River Group

RECOMMENDATIONS:

1. Boreholes can probably be sited anywhere within the area underlain by Asu River Group rocks, where the electrical conductivity is below about 30 mmhos/m (indicating that the mudstone has been metamorphosed). More EM34-3 and resistivity data should be collected prior to drilling new boreholes to help create better guidelines for siting boreholes.

2. Water levels should be routinely monitored in the observation borehole at Odubwo to check the sustainability of the groundwater resource.

1. BACKGROUND INFORMATION

The groundwater potential of the Asu River Group was investigated at two locations: Odubwo village (in eastern Oju) and the WaterAid compound (see Figure 1). In Odubwo there are several shallow wells that contain water during the wet season. During the dry season, water is collected from shallow dugouts in the Ugbodum River, 2-3 km away. These seepages were investigated as part of the initial investigations in Oju/Obi (MacDonald and Davies 1997). As the dry season progresses, these seepages dry up and water has to be obtained from further downstream. Odubwo village is located on a small hill with a thickly vegetated valley to the north. The WaterAid compound is located to the north east of Oju Town centre.

The geology map shows that Odubwo is underlain by the Asu River group. Investigation of Asu River sediments exposed along the course of the Ugbodum River indicate a series of slumped limestones, shaley mudstones and sandstones deposited under marine conditions within a deep seismically active basin. The presence of thick turbidite sandstones, seismites, slumped mudstones and fault zones indicate syn-sedimentary tectonism within an active part of the Benue Rift system. Rapid deposition of sediments occurred, a thick sequence of mudstones and sandstones more than 2000 m thick forming. According to the geological map the WaterAid compound is located on the boundary between Asu River Group and Eze-Aku Shale where the environment of deposition changes from deep water marine to shallow shelf marine. The convoluted nature of the mudstones cored in borehole BGS1 indicate that the area was still seismically active at the time of deposition. Just south of the WaterAid compound occurs the scarp of a prominent thick palaeo-laterite remnant, upon which the OJU LGA offices are located. Figures 2 and 3 show the available map data for the area and also the locations of the geophysical surveys and test boreholes. Table 1 shows the appropriate maps and aerial photographs for Odubwo and the WaterAid compound.

Table 1. Available map information for Odubwo and the WaterAid compound.

Data type	Source
Aerial Photographs	Odubwo: Sheet 289, run 4, 86 Sheet 290, run 4, 119-120
	WaterAid: Sheet 289, run 4, 83-86
Topographic maps	1:50,000 Sheet 289NE Ejekwe NE
Geology map	Ogoja Area, Map No. 73, Scale 1:250,000

2. GEOPHYSICS

Seven kilometres of EM34-3 surveys were carried out at Odubwo and about 500 m at the WaterAid compound. These surveys were undertaken along main roads using a 20 m coil separation, although a variety of other coil spacings were also used over parts of the traverses. Both horizontal and vertical dipole measurements were taken. Some magnetic surveys were also carried out. Two resistivity surveys were undertaken, one at Odubwo and another at the WaterAid compound. Table 2 gives a summary of the various traverses and soundings. Data are presented in Annex 1.

Several observations can be made from analysis of the geophysical data produced. (Figure 4 shows much of the EM34-3 data for Odubwo):

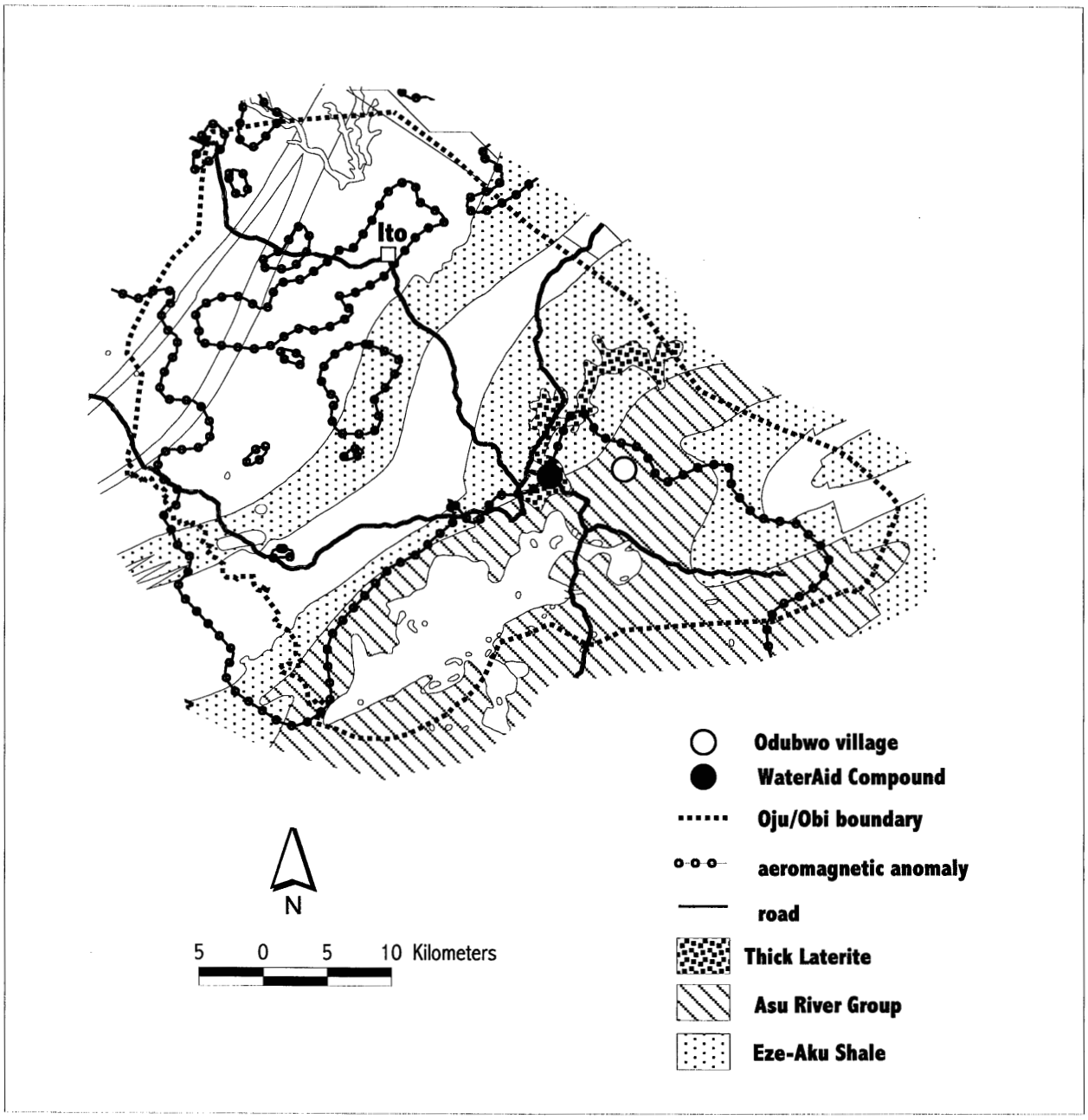

Figure 1. The location of Odubwo and the WaterAid compound.

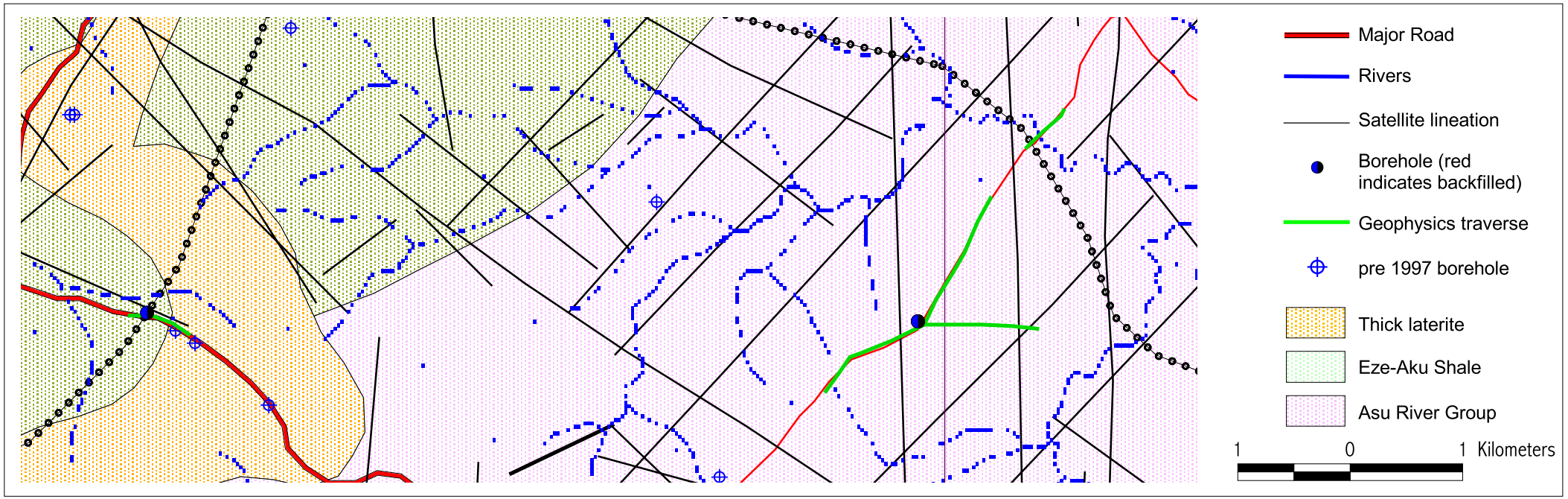

Figure 2. Available map information for Odubwo and the WaterAid Compound. The location of boreholes and geophysical traverses are also shown.

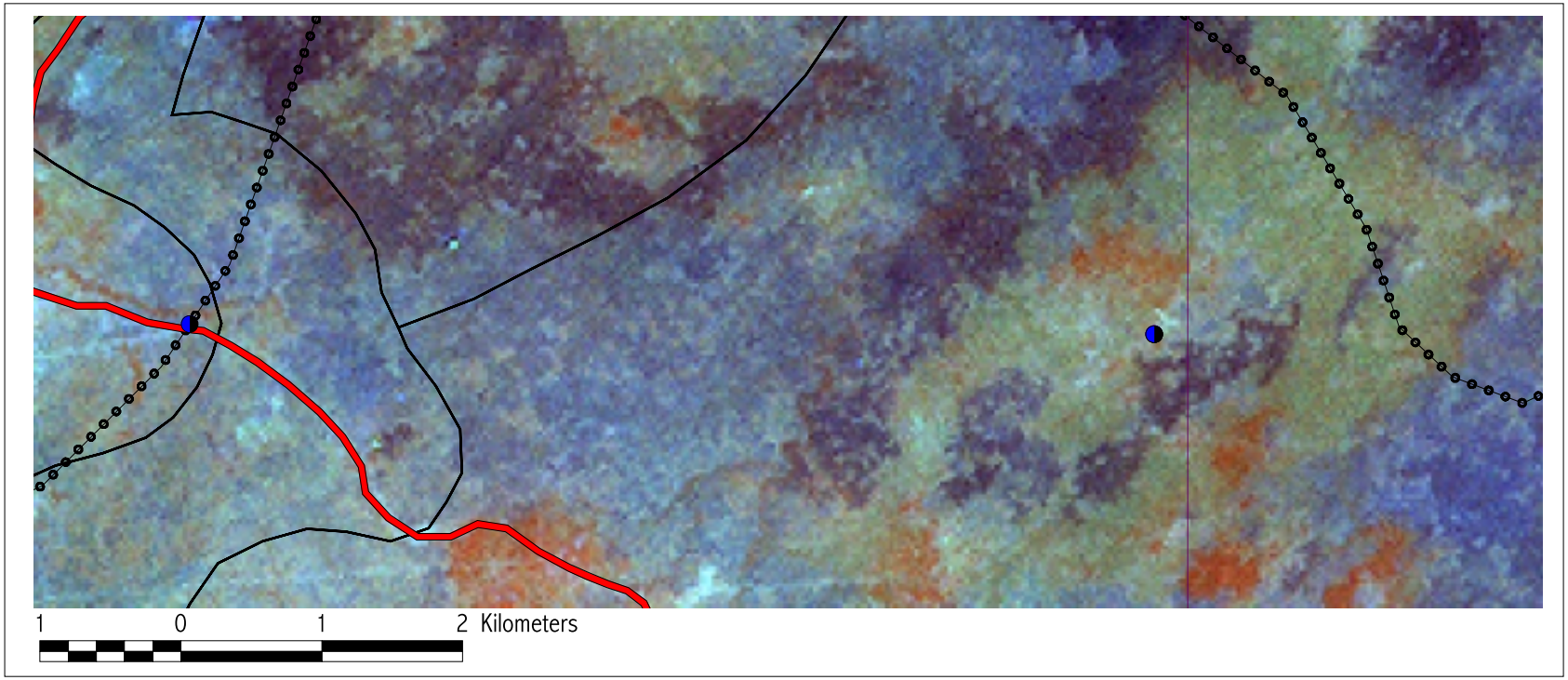

Figure 3. Satellite image for Odubwo and WaterAid compound.

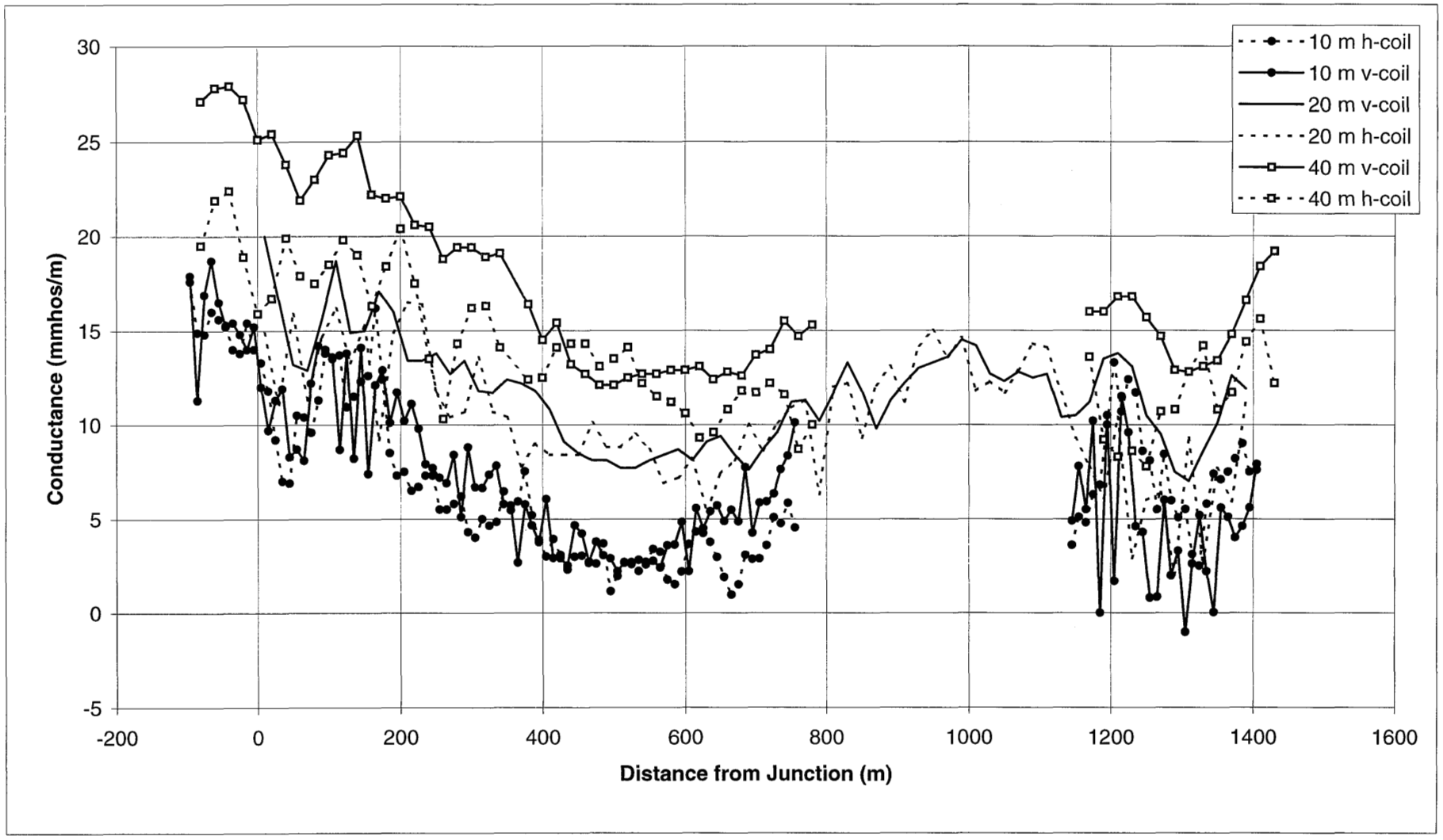

Figure 4 EM34-3 surveys at Odubwo for 10 m, 20 m and 40 m coil separations

1. Electrical conductivity varies from about 5 to 30 mmhos/m – measurements (especially with the horizontal coils) show many short wavelength anomalies.

2. The measured electrical conductivity increases with inter-coil spacing. This trend is most pronounced with the vertical coils, but is also observed with the horizontal coils.

3. Vertical and horizontal coil readings are broadly similar for 10 and 20 m spacings; using 40 m coil separation, horizontal readings are consistently lower.

4. Resistivity soundings gave broadly similar profiles: resistive soil overlying a 10-20 m thick moderately resistive (40-70 ohm-m) layer, overlying more resistive bedrock. The sounding carried out at Odubwo indicated a lower resistive weathered layer and bedrock than at the WaterAid compound.

5. The magnetic soundings indicated several anomalies superimposed on the background diurnal variations. The most pronounced anomaly was recorded at the river, which according to the satellite image and aerial photographs is structurally controlled.

Only one site was chosen for exploration in Odubwo village. The site (0 m along OD1, OD3, OD5) was next to the primary school where the EM34-3 survey showed high readings (20 mmhos/m). At the WaterAid compound, space is limited so the borehole had to be located 100 m along WA1, where the electrical conductivity was low.

Table 2. Main Geophysical Surveys carried out at Odubwo and the WaterAid compound (data in Annex 1)

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
OD1	6° 52.27' 8° 29.87'	1.1 km	20 m	EM34-3 (20 m)	From junction near school along road past dugouts
OD2	6° 52.27' 8° 29.87'	1.1 km	10 m	magnetic	As OD1
OD3	6° 52.27' 8° 29.87'	1.5 km	20 m	EM34-3 (20 m)	From junction near school along road to river
OD4	6° 52.27' 8° 29.87'	1.4 km	10 m	magnetic	As OD3
OD5	6° 53.091' 8° 30.405'	0.5 km	20 m	EM34-3 (20 m)	Across river
OD6	6° 53.091' 8° 30.405'	0.5 km	10 m	magnetic	As OD5
OD7	6° 52.27' 8° 29.87'	1 km	20 m	EM34-3 (20 m)	From junction near school along road through village
OD8	6° 52.27' 8° 29.87'	1 km	10 m	magnetic	As OD7
OD9	6° 52.201' 8° 29.847'	0.5 km	20 m	EM34-3 (20 m)	From 100 m OD7 to 350 m OD3
OD10	6° 52.201' 8° 29.847'	0.5 km	20 m	EM34-3 (40 m)	As OD9 – 40 m coil separation
OD11	6° 52.201' 8° 29.847'	0.5 km	10 m	EM34-3 (10 m)	As OD9 – 10 m coil separation
OD12	6° 52.288' 8° 29.963'	0.4 km	20 m	EM34-3 (40 m)	From end OD11 towards river
OD13	6° 52.288' 8° 29.963'	0.4 km	10 m	EM34-3 (10 m)	As OD12
OD14	6° 52.768' 8° 30.161'	0.3 km	20 m	EM34-3 (40 m)	From 1.2 km along OD3 – 40 m coils
OD15	6° 52.768' 8° 30.161'	0.3 km	10 m	EM34-3 (10 m)	As OD 14 – 10 m separation
OD16	6° 52.27' 8° 29.87'		0.5 – 64 m	Offset Wenner	At junction near school (beginning OD1, OD3, OD5)
WA 1	6° 52.310' 8° 26.152'	0.6 km	20 m	EM34-3 (20 m)	From culvert, past WaterAid compound
WA 2	6° 52.310' 8° 26.152'		0.5 – 64 m	Offset Wenner	At WaterAid compound – BGS 1

3. Drilling

Three boreholes were drilled at Odubwo: one deep production borehole, a shallow observation borehole and a cored exploration hole that was subsequently back-filled. Samples from the boreholes were logged and analysed. One cored borehole was drilled in the WaterAid compound. This borehole was drilled primarily to test that the drilling rig was operating correctly, and act as a monitoring borehole adjacent to the main production well in the compound. Summary information on the boreholes is given in Table 3. More details on construction etc. are given in Annex 2.

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

Borehole ID	Location	Date completed	Total depth	Drilled diameter	Section cored	Main Water Strikes	Casing above gl	Comments
BGS 1	6° 52.27' 8° 29.87'	17/11/97	11.8	165 mm	0 – 11.8 m	damp	0.3 m	shallow
BGS 2	6° 52.27' 8° 29.87'	20/11/97	63.7 m	165 mm	No core	19.7, 51.7	0.26 m	
BGS 2a	6° 52.27' 8° 29.87'	22/11/97	20.8 m	100 mm	0 – 20.8 m	12 m		back-filled
BGS 2b	6° 52.310' 8° 26.152'	23/11/97	19.5 m	165 mm	No core	Not recorded		Drilled next to BGS2a – 12.5 m away from BGS2

BGS 2a was drilled 12.25 m away from the production borehole BGS 2. During the drilling of BGS 2a, water and air suddenly starting issuing from BGS2 – thus proving direct fracture connection between BGS 2 and BGS 2a at 11.5 m depth.

The following sections give a brief summary of the lithological logs. Full details are given in Annex 3. Figure 5 shows a schematic of the borehole logs.

Summary lithological log: BGS 1

0.0 - 3.0	Red nodular ferricrete
3.0 - 4.5	Grey, brown and orange silty clay
4.5 - 11.8	Dark grey jointed hard metamorphosed slatey mudstones, convoluted

Summary lithological log: BGS 2

0.0 - 2.5	Soil/ferricrete zone
2.5 - 5.7	Clayey very weathered zone
5.7 - 8.7	Weathered mudstones
8.7 - 13.7	Non-weathered massive mudstones - water bearing sapprolite
13.7 - 16.7	Massive hard mudstones with calcite veining - water producing zone
16.7 - 18.7	Weathered mudstone zone
18.7 - 23.7	Fairly weathered mudstones with calcite veining - water producing zone
23.7 - 28.7	Massive fairly weathered mudstones
28.7 - 35.7	Massive shaley mudstones with calcite veining - water producing zone
35.7 - 40.7	Massive shaley mudstones
40.7 - 45.7	Massive fairly weathered shaley mudstones - some pyrite
45.7 - 54.7	Massive shaley mudstones with calcite veining - water producing zone

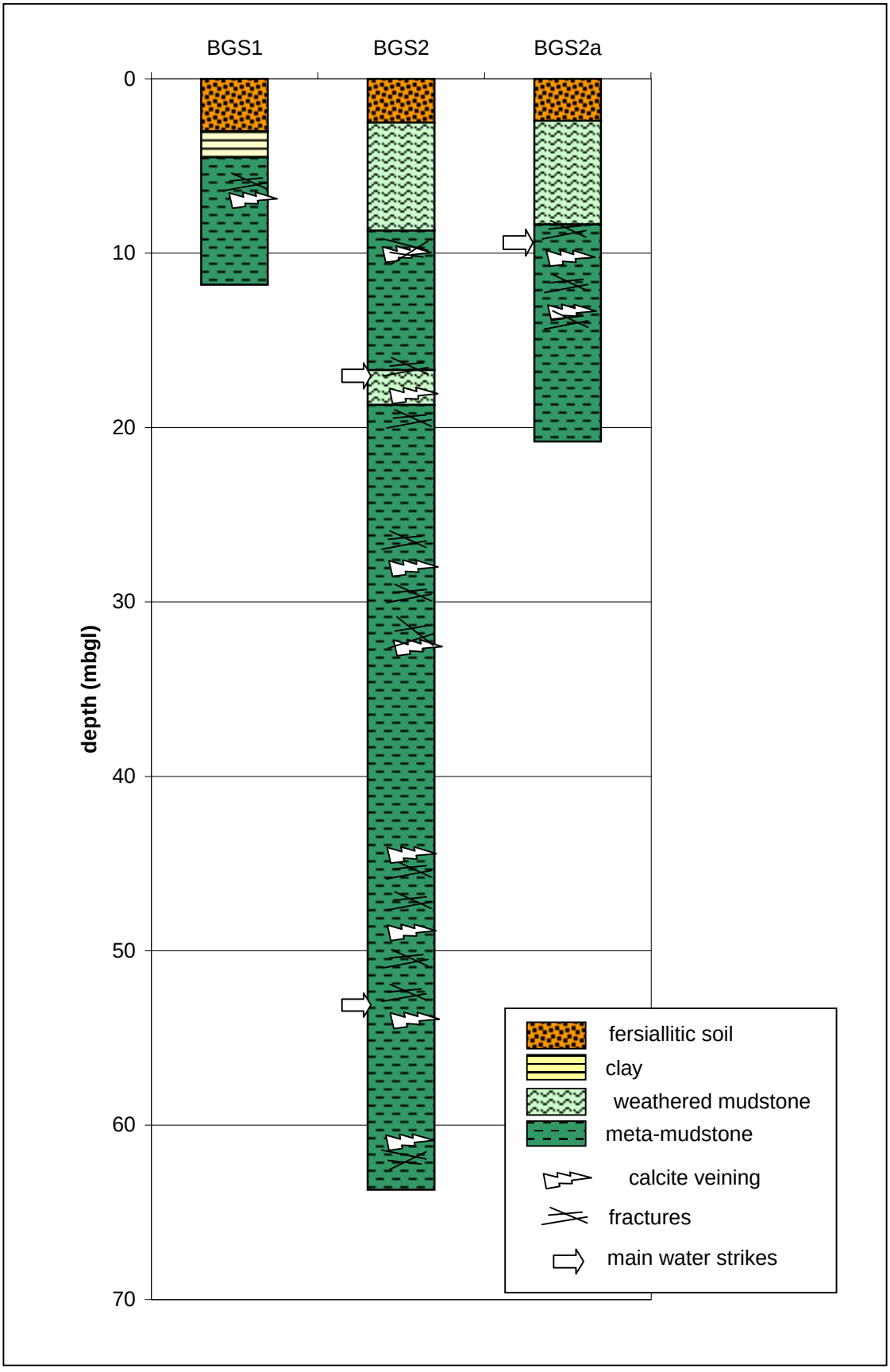

Figure 5. Lithological logs for boreholes drilled at the WaterAid compound and Odubwo village. (Horizontal axis not to scale).

54.7 - 59.7 Massive shaley mudstones
59.7 - 63.7 Fractured shaley mudstones with calcite veining - water producing zone

Summary lithological log: BGS 2a

0.00 - 2.40 Soil/ferricrete horizon
2.40 - 5.60 Clayey very weathered horizon
5.60 - 8.35 Weathered mudstones
8.35 - 11.85 Non-weathered massive mudstones, some calcite veining
11.85 - 17.90 Hard massive mudstones with calcite veining - water producing zone
17.90 - 20.80 Massive hard slatey mudstones

No samples were taken from BGS 2b since it was drilled less than a metre from BGS 2a.

4. PUMPING TESTS

Several pumping tests were carried out at Odubwo. Since the two boreholes were close together, it was possible to measure drawdown in the borehole that was not pumping, and therefore derive an estimate of aquifer storage coefficient. Both the deep production borehole and the shallow observation borehole were test pumped. The yield from the borehole drilled in the WaterAid compound was low, therefore a bailer test was undertaken. The BERWASSA pump test unit was used to test BGS 2. This unit had been borrowed from BERWASSA in a bad state of repair. Peter Rastal (driller) managed, with considerable effort, to get it to work, but unfortunately, this was the only pumping test successfully completed using the unit. The pump test unit proved to be very unreliable and was therefore returned to BERWASSA. A summary of test pumping carried out at Odubwo and the WaterAid compound is given in Table 4. Data and analyses are presented in Annex 4. The tests were analysed using various methods (Barker 1989, Kruseman and de Ridder 1990).

Table 4. Summary of pumping tests carried out at Odubwo and the WaterAid compound. (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 1							
Bailer test	7/4/98	0.28 m	3.254 m	6:50 mins	0.305 l/s	Barker:	T = 0.27 m^2/d
BGS 2							
Berwassa test pump	7/3/98	0.3 m	BGS2: 6.65 m BGS2b: 6.6 m	240 mins	1.25 l/s	Jacob: abh Obh Theis Rec: abh Obh	T = 4.1 m^2/d T = 4.1 m^2/d S = 0.0005 T = 4.1 m^2/d T = 3.4 m^2/d
BGS 2b Bailer test	28/3/98	0.3 m	7.365 m	10:11	0.32 l/s	Barker: Theis Rec:	4.9 m^2/d 2.6 m^2/d
Whale pump	28/3/98	0.3 m	BGS2b: 7.32 BGS2: 7.47	200 mins	0.15 l/s	Jacob: abh Obh Theis Rec: abh Obh	T = 3.6 m^2/d T = 5 m^2/d S = 0.00047 T = 3.2 m^2/d T = 3.6m^2/d

The test pumping carried out at Odubwo show that the Asu River Group shales have transmissivity of 4 m^2/d, sufficient to support a handpump. The storage coefficient is typical for a confined aquifer. The aquifer properties measured from the two boreholes (both shallow and deep) were identical. Two explanations are possible: (1) the majority of the water bearing fractures are in the upper 20 m of the boreholes; or (2) the two boreholes are effectively joined through the fracture connection at 11.8 m. The second explanation is probably more appropriate since there is a marked break in slope of both drawdown and recovery once the water-levels pass about 12 m. BGS2 was equipped with a hand pump.

The sustainability of a groundwater source from Odubwo is uncertain. Groundwater flows through a limited number of fractures of limited storage. The village is also located on a hill several kilometres from the nearest source of recharge water. The water-levels in the observation borehole (BGS 2b) should be monitored to check that pumping from BGS 2 is sustainable in the long term.

The transmissivity measured from BGS 1 is low, 0.27 m^2/d. The borehole is shallow and was completed above the depth of the water-bearing horizons observed in BGS 2. It is possible that a deeper borehole drilled in the WaterAid compound would have a much greater yield. In fact, two deep boreholes have been drilled 200-400 m away from the compound and fitted with India MKII hand-pumps. These boreholes are heavily used during the dry season, indicating that water-bearing fractures are present at depth.

Water samples were taken for hydrochemical analysis from the boreholes at Odubwo and the WaterAid well (located about 5 m from BGS 1). Parameters measured in the field are shown in Table 5. All the available chemistry data are given in Annex 5. The chemistry of the two boreholes at Odubwo is similar to that determined from other boreholes in the Asu River Group sediments. The water is within the WHO recommended guidelines for drinking water. The sample shown for the WaterAid Well is also similar to Asu River Group waters. Samples taken at different times of the year, however, showed a marked difference in groundwater chemistry. Rainwater dilutes the deeper groundwater, which significantly reduces the salinity and pH.

Table 5. Chemistry samples taken from Odubwo and the WaterAid Compound.

ID No	Sample No	date	Conductivity (µS/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	HCO3 titr (50ml 1.6M)	Comments
BGS 2b	227	28/3/98	905	454	6.93	29	231	Sample taken after 2 hours pumping
BGS 2	259	3/4/98	915	457	7.05	29	249	Pumped for only a few minutes before sample
WaterAid Well	260	7/4/98	616	308	7.51	29	172	Samples show a marked variation throughout the year.

5. Summary and Conclusions

The groundwater potential of the Asu River group was investigated at Odubwo village and the WaterAid compound. Various geophysical surveys were carried out and a series of boreholes drilled and tested. The following work was undertaken:

- 7.5 km of EM34-3 surveys
- 3 km magnetic profiling
- 2 resistivity VES
- A deep (63 m) and a shallow (20 m) boreholes drilled and completed at Odubwo, and a 20 m deep cored borehole drilled and back-filled. A shallow (11.5 m) borehole was cored, reamed out and completed at the WaterAid compound.
- chip and core samples from most boreholes were logged and analysed
- three boreholes, BGS 1, BGS 2 and BGS 2b were screened and cased
- short bailer tests were carried out on BGS 1 and BGS 2b
- longer (4-5 hour) pumping tests were carried out on BGS 2 and BGS 2b
- water samples for hydrochemical analysis were taken from each borehole.

The geophysical surveys highlighted the following:

1. The electrical conductivity measured using the EM34-3 was low (5-30 mmhos/m) which reflects the fact that the mudstone has undergone some burial metamorphism and that there is little highly conductive clay present within the weathered zone.

2. Measured conductivity increased with inter-coil spacings. Vertical and horizontal coil readings are broadly similar for both 10 and 20 m spacings; using 40 m coil separation, horizontal readings are consistently lower than vertical readings.

3. Resistivity soundings gave fairly consistent profiles: resistive soil overlying a 10-20 m thick moderately resistive (40-70 ohm-m) layer, overlying more resistive bedrock. The low resistivity weathered zone is probably attributable to water filled fractures and clay content. A 20 m thick low resistivity layer would explain the variation in measured conductivity with inter-coil spacing and coil orientation.

4. At present, there is insufficient information to give guidelines for identifying specific borehole or well sites using geophysics in the Asu River group. All conductivity values tend to be low (<30 mmhos/m). Higher values within this range may represent greater weathering and therefore more groundwater, but at present, there are no data to substantiate this.

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

- The Asu River group comprises moderately hard splintery mudstones, which have undergone a degree of lithification due to low grade burial metamorphism. Much of the hardened mudstone has a distinct slatey cleavage. Disseminated pyrite is present. The mudstones are commonly convoluted due to slumping indicative of syn-sedimentary tectonic activity

- The top few metres of the mudstone are weathered and contain some kaolinite clay. Thin fersiallitic soils have also been developed.

- Below 10 m the mudstone contains many fractures, most of which have associated calcite deposits. Water bearing fractures have been detected as deep as 60 m. Such fractures may occur in distinct horizons being due to episodic natural hydro-fracturing of the mudstones due to

compaction and fluid release prior to lithification.

- Water is found only within the fractures, there is no inter-granular porosity or permeability. The main water bearing fractures were found to be from below about 10-15 m. Shallow wells or boreholes that do not penetrate these fractures have poor yields.

- Pumping tests indicated moderate transmissivity at Odubwo, 4 m^2/d. Tests in the shallow (11.8 m) borehole at the WaterAid compound gave a transmissivity of only 0.27 m^2/d – a deeper borehole at this site would probably have been comparable to those at Odubwo.

- The storage coefficient at Odubwo was typical of a confined aquifer (5×10^{-4}). However, since the only groundwater that is available is stored in fractures, the specific yield is likely to be low. Therefore, the sustainability of water supplies from this aquifer must be closely monitored.

- The quality of groundwater from the Asu River group is generally good. The groundwater is Calcium Bicarbonate type with occasional high iron or sulphate. The samples are all within the WHO recommended drinking water guidelines.

The groundwater potential of the Asu River Group is high. The mudstone has undergone metamorphism and is moderately hard. The main targets for groundwater are fractures from about 15 m to 30 m. Boreholes are therefore the most appropriate technology for the area, although hand dug wells would be sustainable if they were dug sufficiently deep.

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Annex 1: Geophysical data

Odubo

OD1/2

GPS start: 6 52.27 8 29.87
Date and time: 28/11/96 10:30 - 12:15
Survey: (OD1) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OD2) magnetic
From junction in the road past dug outs

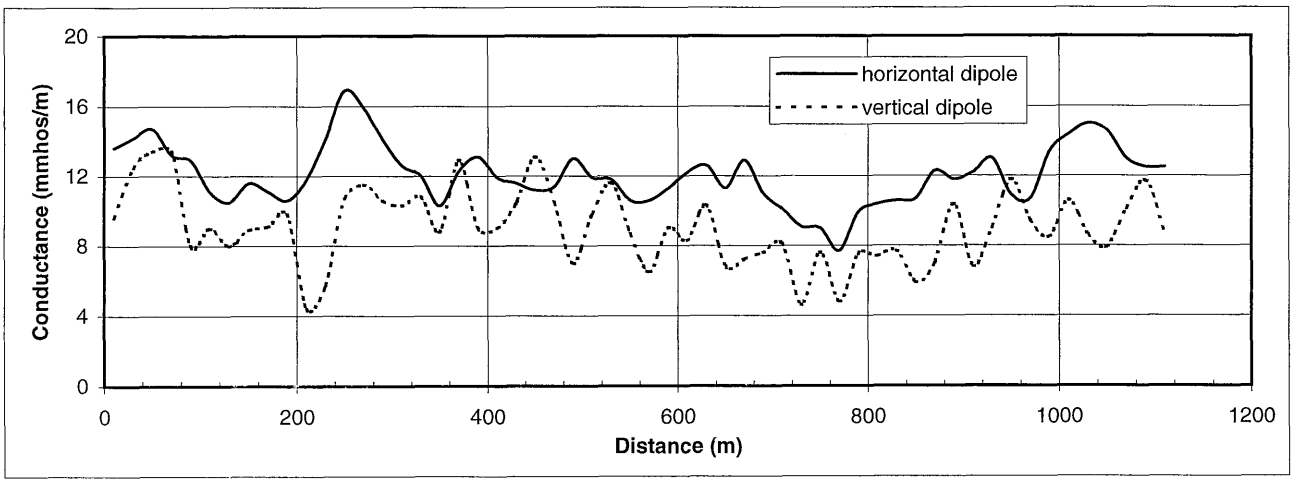
Strike:

position (m)	strike (deg)
0	99
250	91
510	86
730	91
810	98
910	94
1010	91

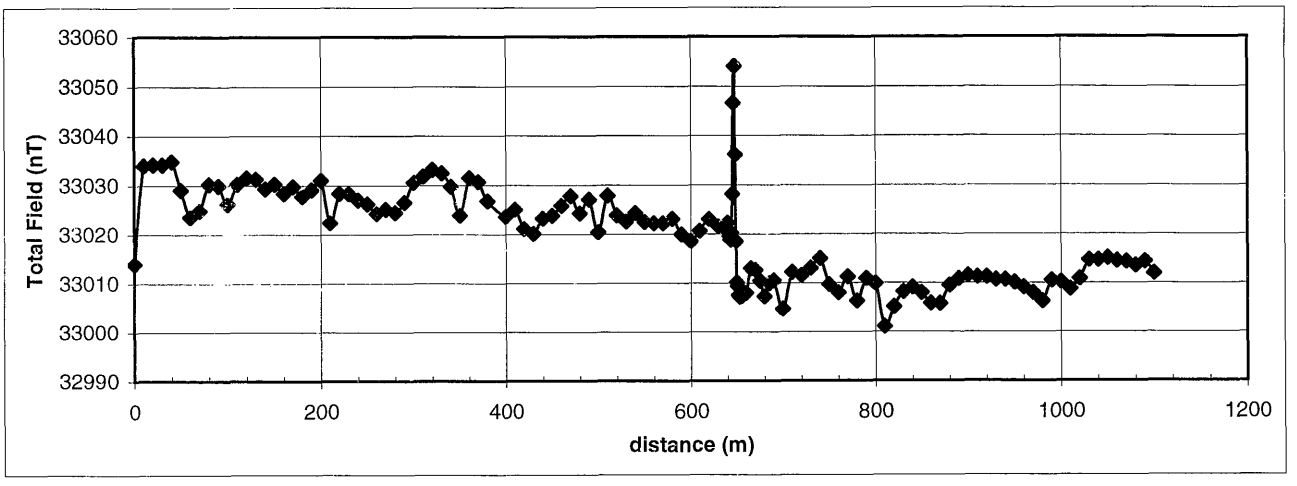
Comments:

position (m)	comments
0	metal sign
190	lip of depression
240	bottom depression
240	dug outs
500	yams

OD1 (EM survey):



OD2 (magnetic survey):



Odubo

OD3/4

GPS start: 6 52.27 8 29.87
Date and time: 28/11/96 10:30 - 12:15
Survey: (OD3) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OD4) magnetic
From junction in the road towards the river

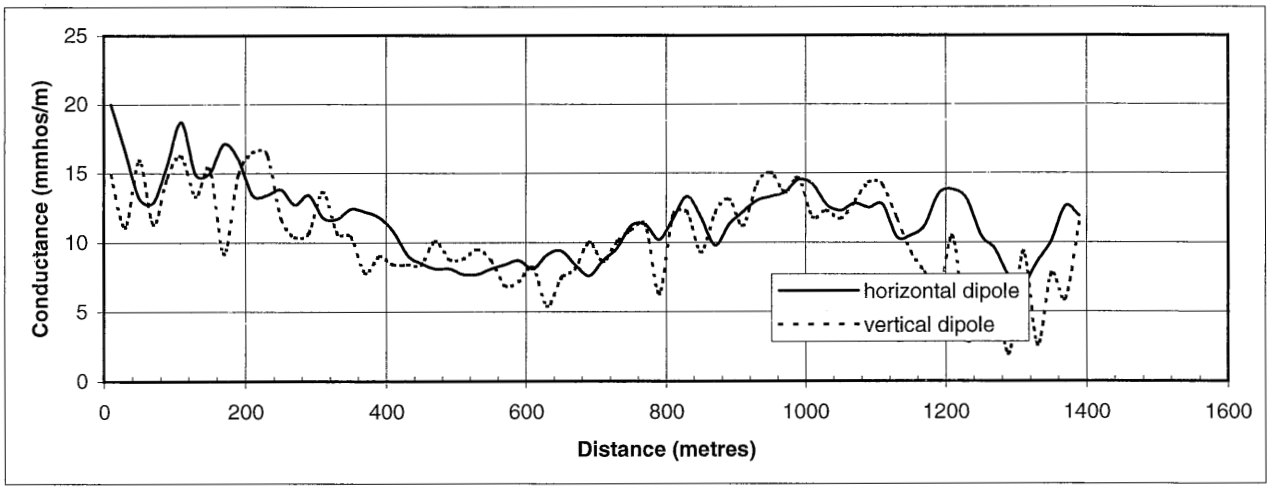
Strike:

position (m)	strike (deg)
0	39
130	35
230	26
350	19
470	30
630	28
810	29
930	33
1130	27
1290	39
1350	50

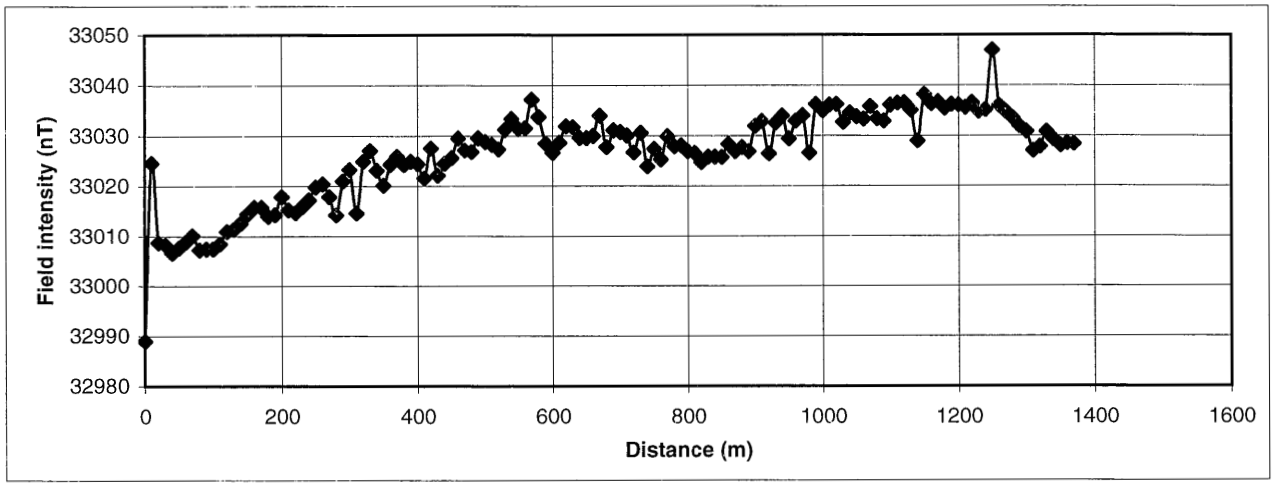
Comments:

position (m)	comments
0	metal sign
200	school 40 m NW
460	gentle down
640	gentle up
1250	bike that wouldn't be moved

OD3 (EM34):



OD4 (magnetic):



Odubo

OD5/6

GPS start: 6 53.091, 8 30.405
Date and time: 29/11/1996 10:15 - 11:15
Survey: (OD5) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OD6) magnetic
Across river

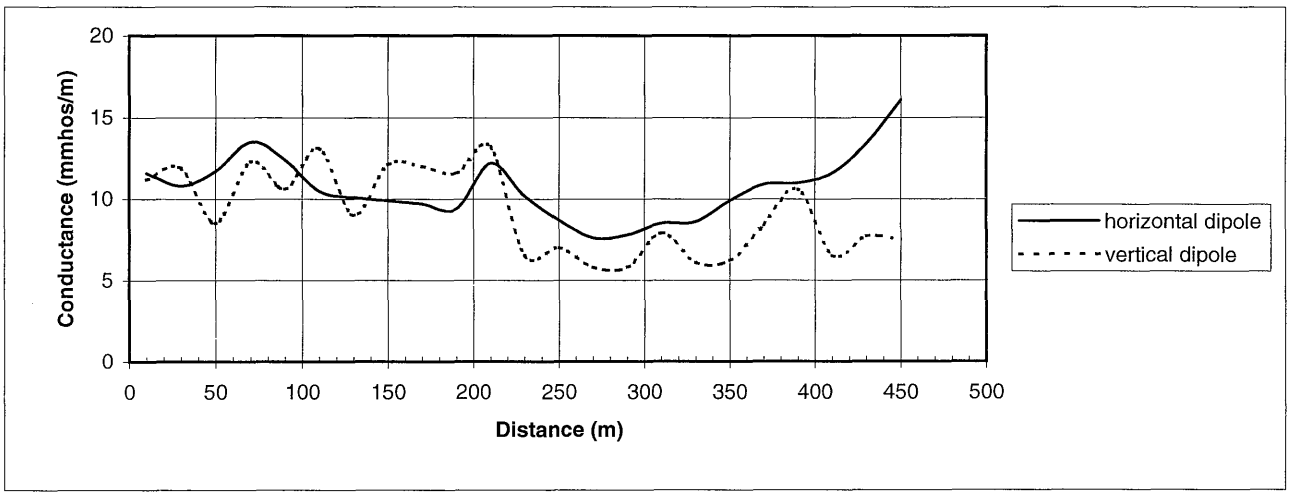
Strike:

position (m)	strike (deg)
0	30
260	19
350	24
450	54

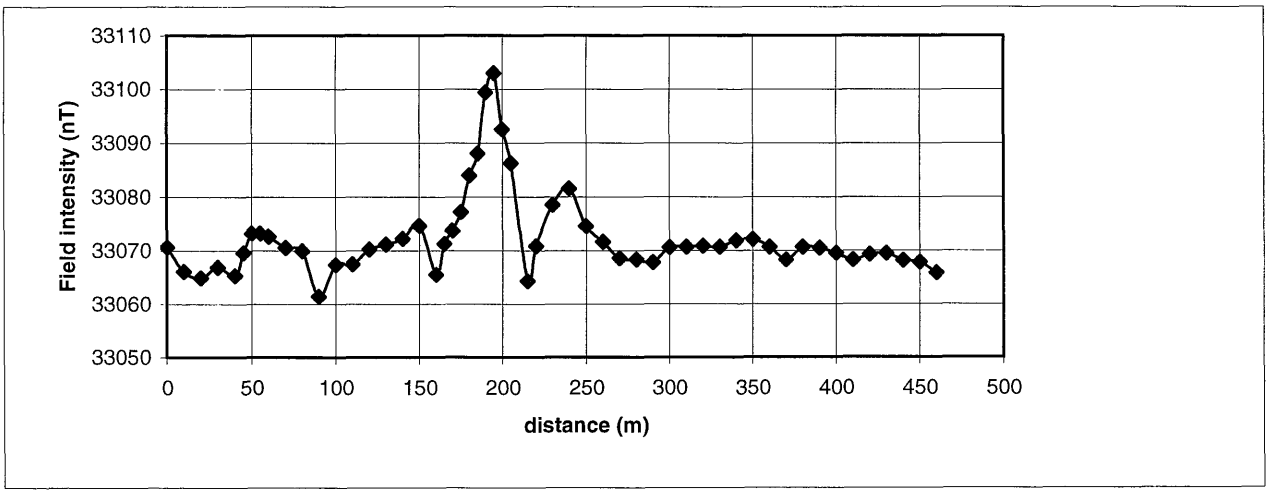
Comments:

position (m)	comments
160	basins 4 m
195	lip of channel
	entranched channel 2 - 5 m sides
210	river
260	top of rise

OD5 (EM34):



OD6 (magnetic):



Odubo OD7/8

GPS start: 6 52.27 8 29.87
Date and time: 29/11/1996 11:30-13:00
Survey: (OD7) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OD8) magnetic
Same startpoint as OD1-4: this time traversing through the village

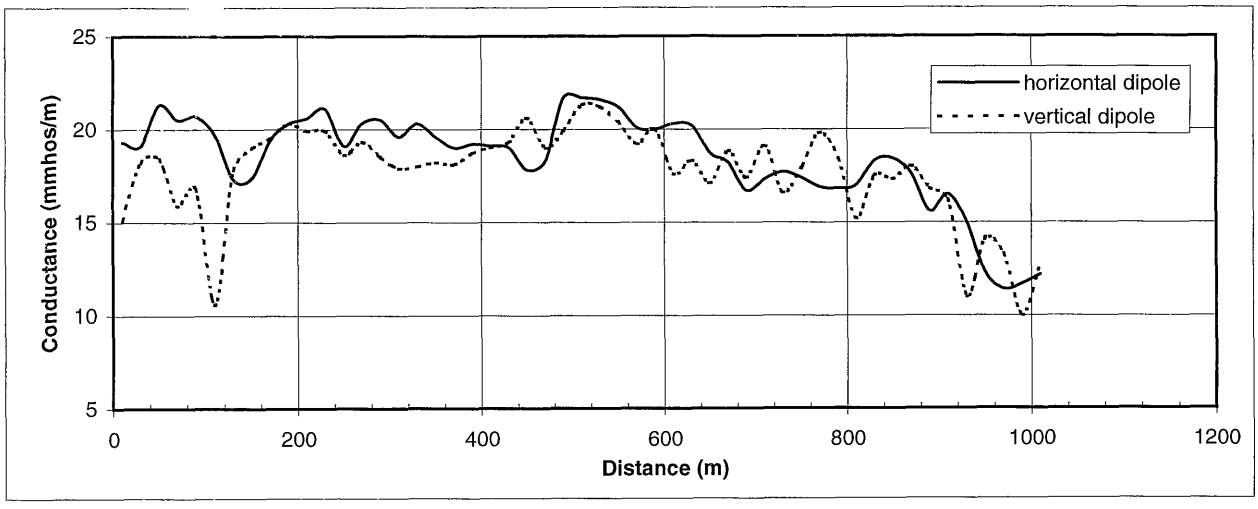
Strike:

position (m)	strike (deg)
0	2360
50	250
110	258
150	243
230	251
550	245
730	234
790	240
930	211

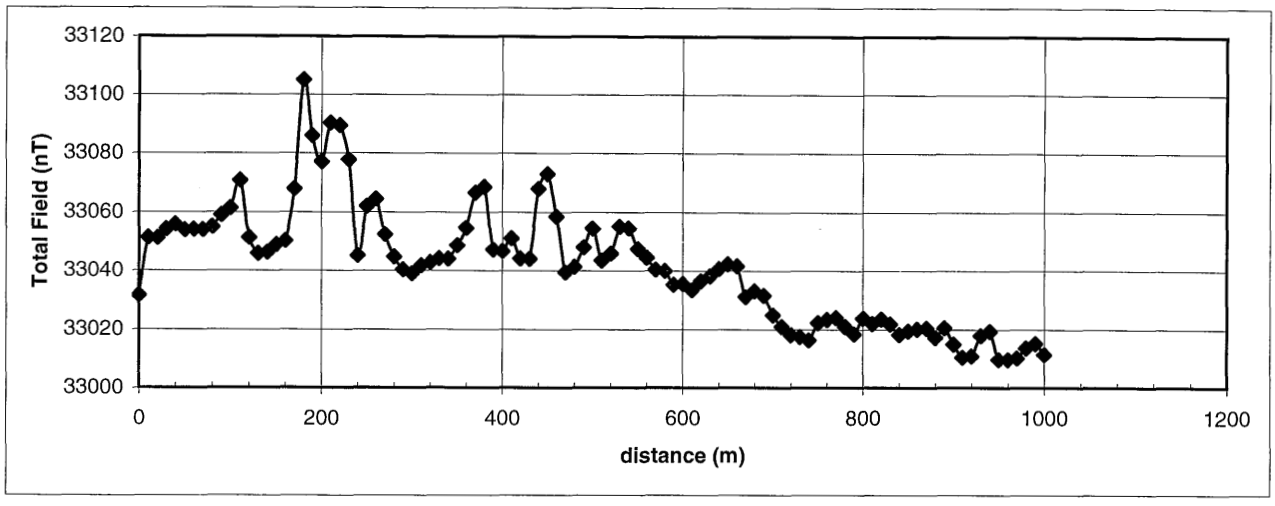
Comments:

position	comments
0	metal sign
40	roof 20
60	roof 30
80	roof 15
100	roof 25
110	roof 20
160	roof 15
180	roof 10
210	roof 10
220	roof 10
220	well 20
260	roof 15
370	roof 20
380	roof 20
400	roof 15
410	roof 15
440	roof 10
460	roof 15
530	roof 25
540	roof 25
640-680	roof 30
730	roof 40

OD7 (EM34):



OD8 (magnetic):



Odubwo OD9/10/11

GPS start: 6 52.201 8 29.847
GPS finish 6 52.388 8 29.963
Date and time: 10/11/97 10:30 - 15:00
Survey: (OD9) EM34 with 20 m spacing; both horizontal and vertical dipoles as OD10
(OD10) EM34 with 40 m spacings starting at peg in the village moving passed school to large tree
(OD11) EM34 with 10 m spacings as OD10

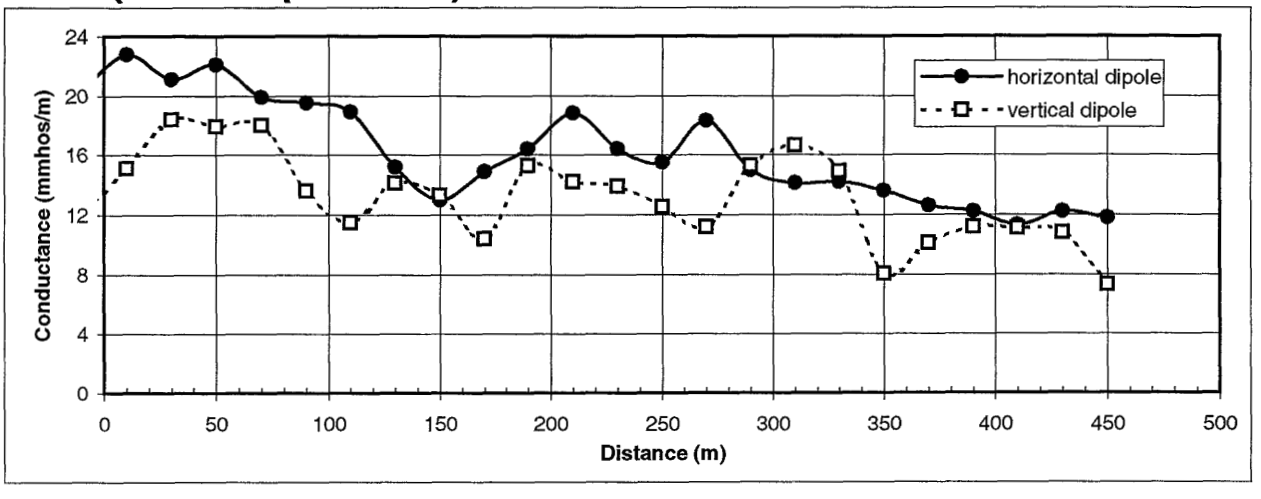
Strike:

position (m)	strike (deg)
0	199

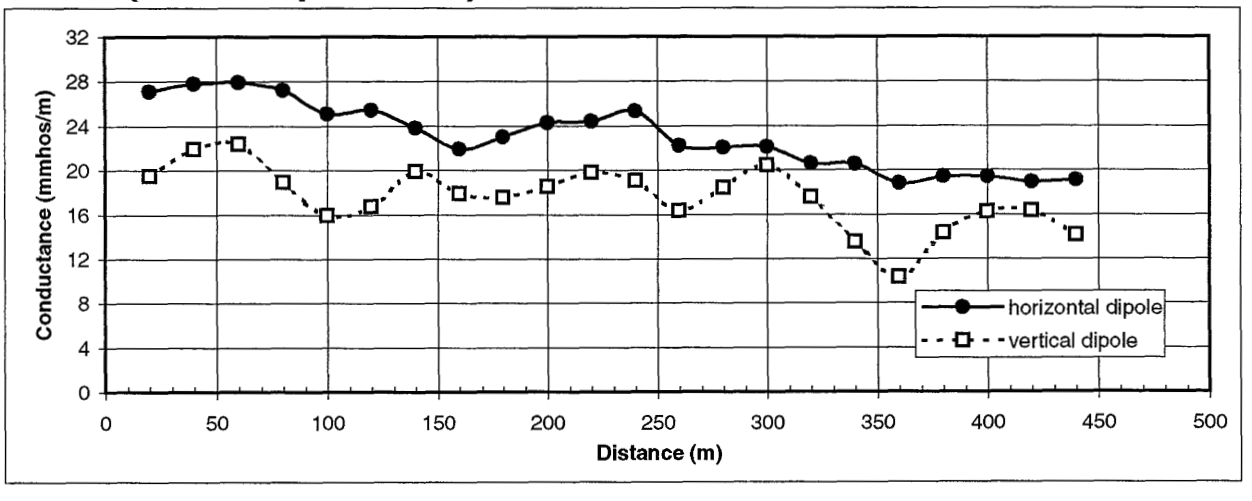
Comments:

position (m)	comments
0	peg
60	metal roof
100	by sign
140	small path
460	large tree

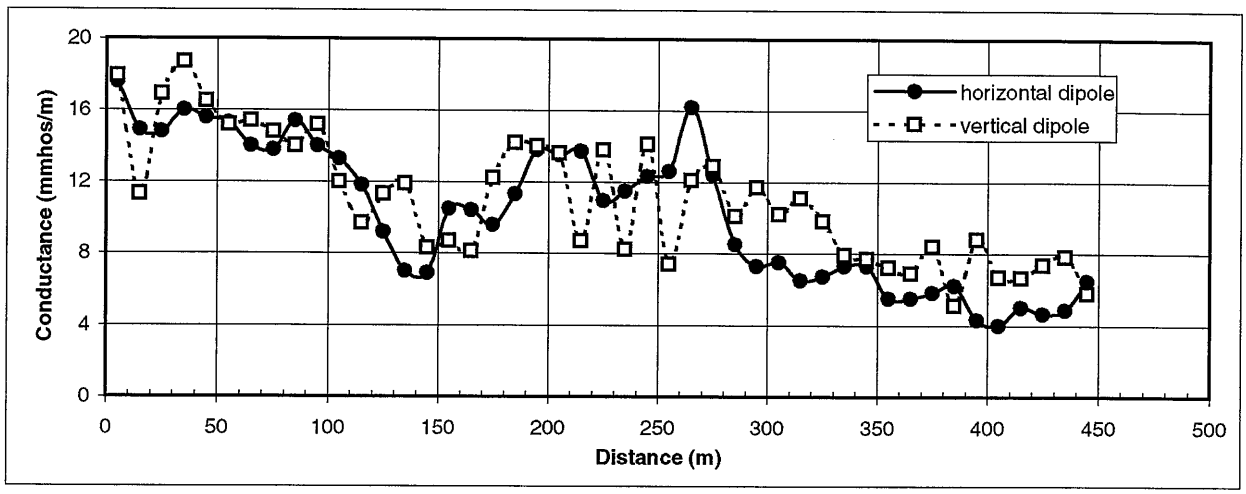
OD9 (20 m separation)



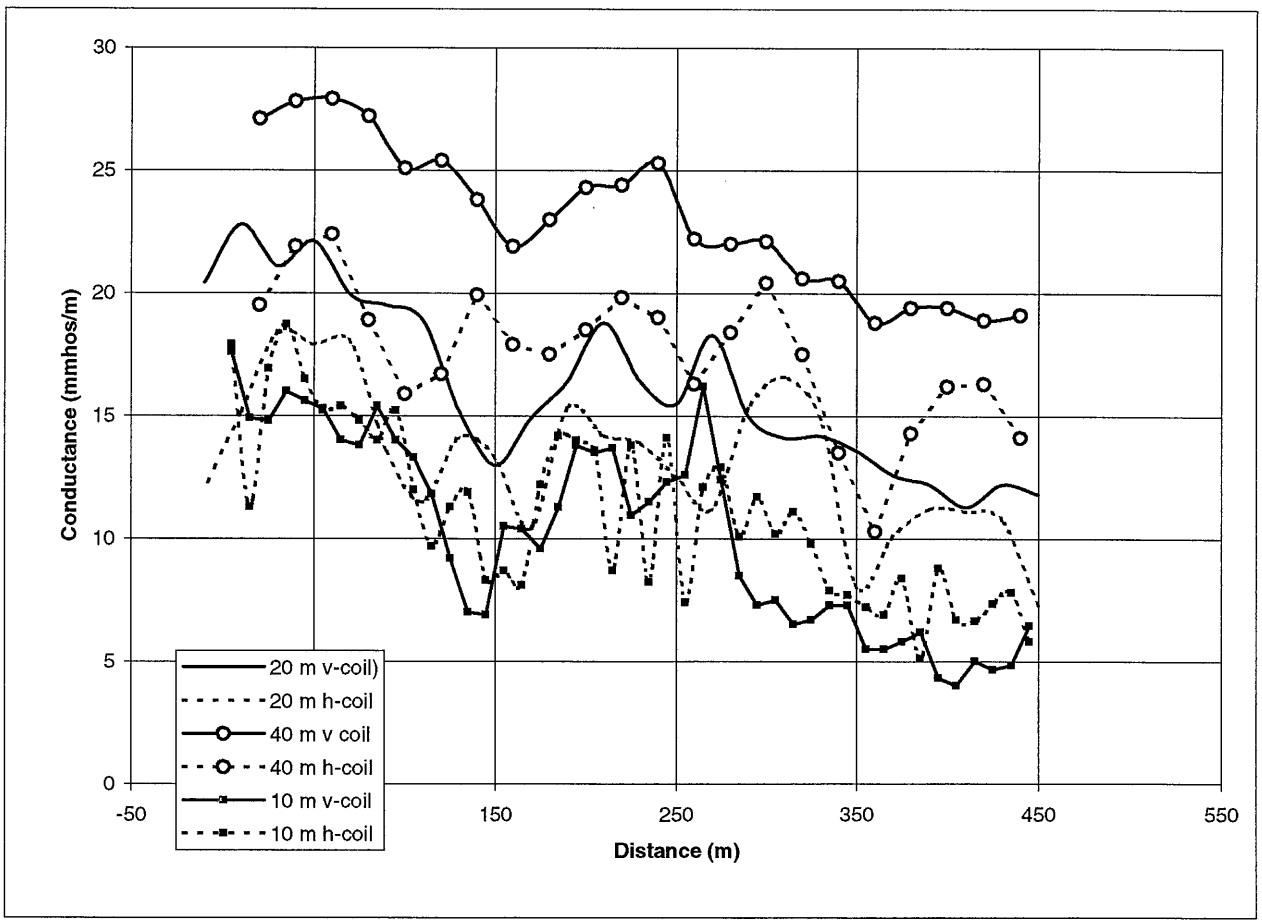
OD10 (40 m separation)



OD11 (10 m separation)



All Data



Odubwo

OD12

GPS start: 6 52.388 8 29.963
GPS finish 6 52.63 8 30.06
Date and time: 11/11/97 10:30 - 12:30
Survey: (OD12) EM34 with 40 m spacings from end OD11 towards river
(OD13) EM34 with 10 m spacings reverse of OD13

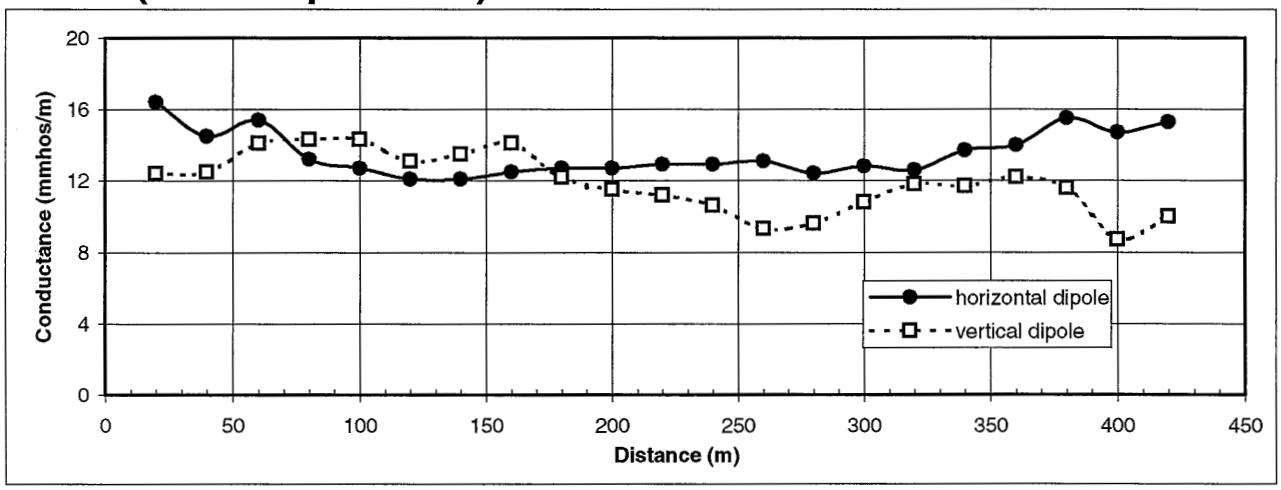
Strike:

position (m)	strike (deg)
0	20

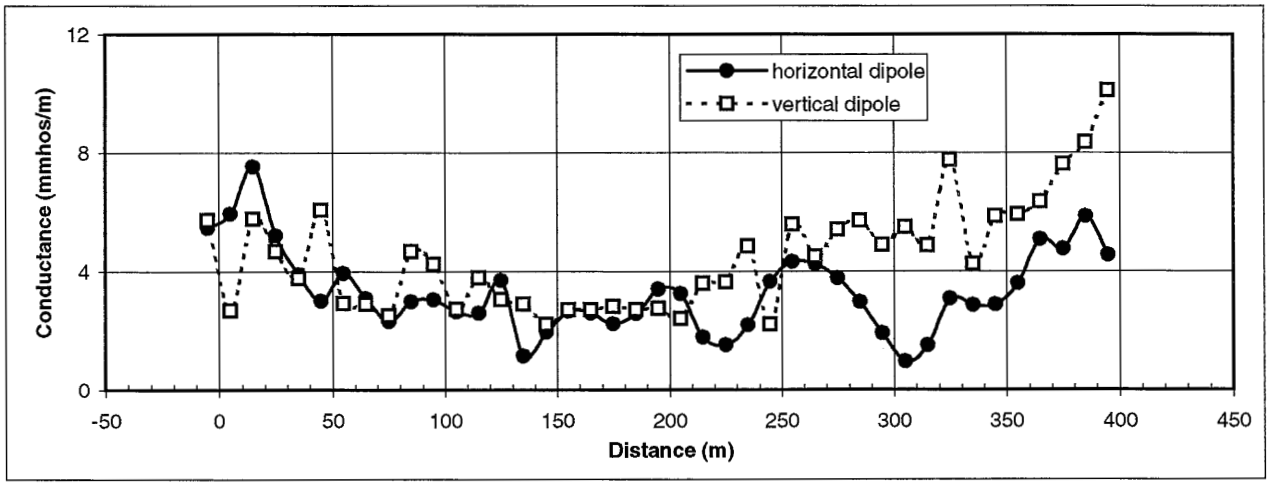
Comments:

position (m)	comments
0	peg
120	small path
240	base depression
400	peg

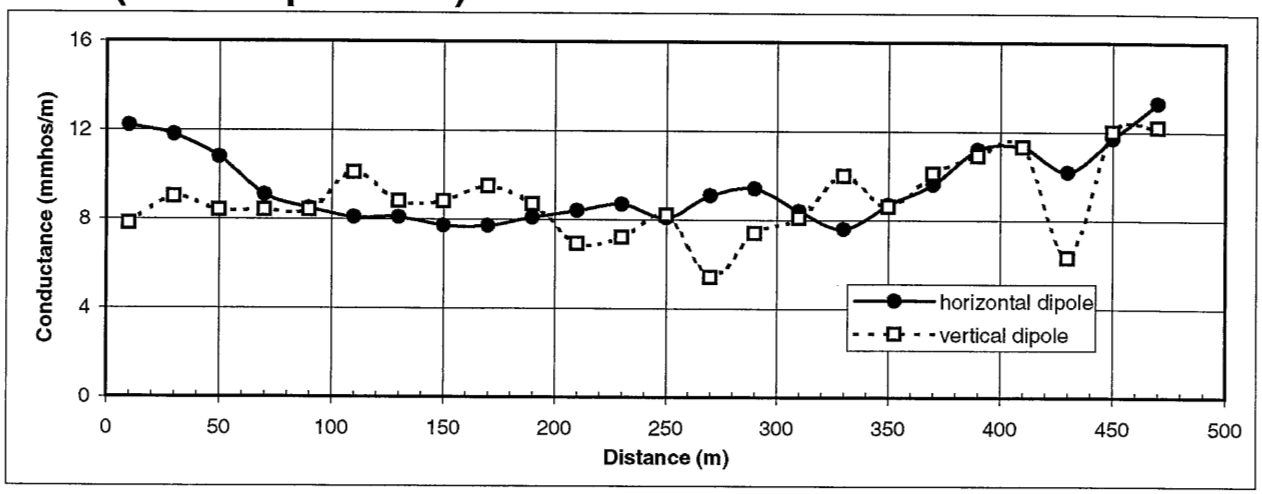
OD12 (40 m separation)



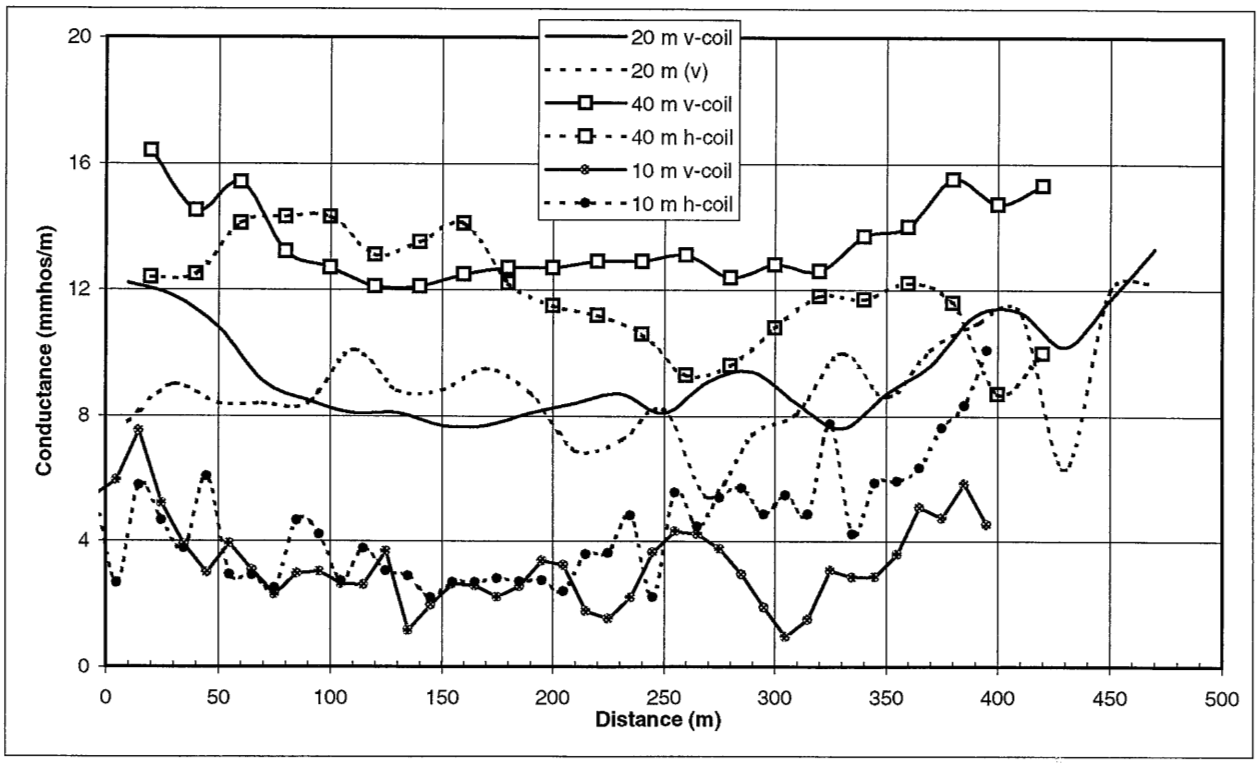
OD13 (10 m separation)



OD3 (20 m separation)



all data (3/12/13)



Odubwo

OD14/15

GPS start: 6 52.768 8 30.161
GPS finish 6 52.876 8 30.212
Date and time: 11/11/97 1:00 - 15:00
Survey: OD14 EM34 40 m spacings
'from corner (1.2 km from junction) towards river
OD15 EM34 10 m spacings
opposite to OD14

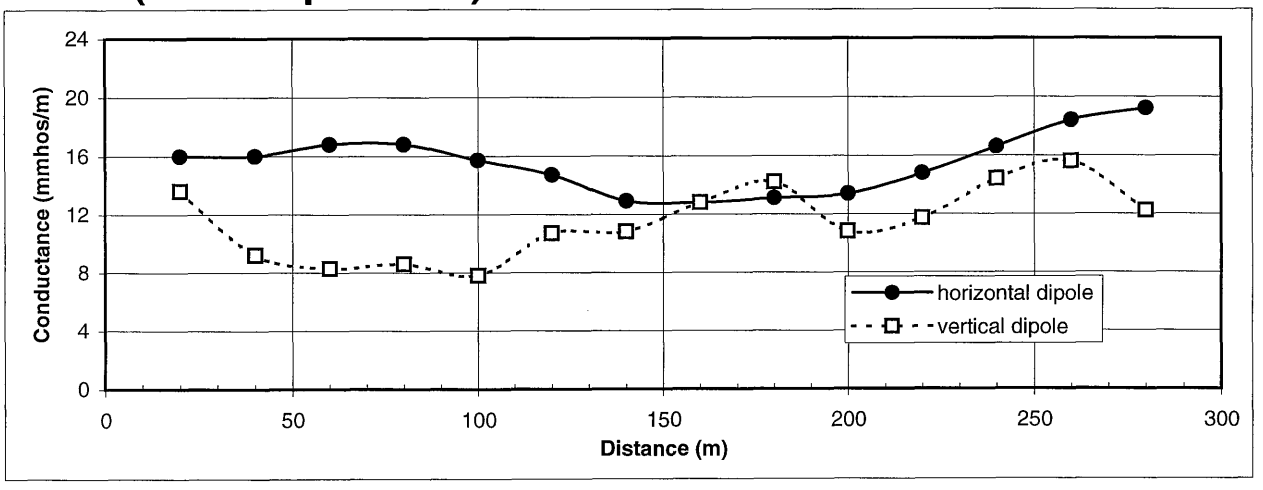
Strike:

position (m)	strike (deg)
0	22
160	34
220	52

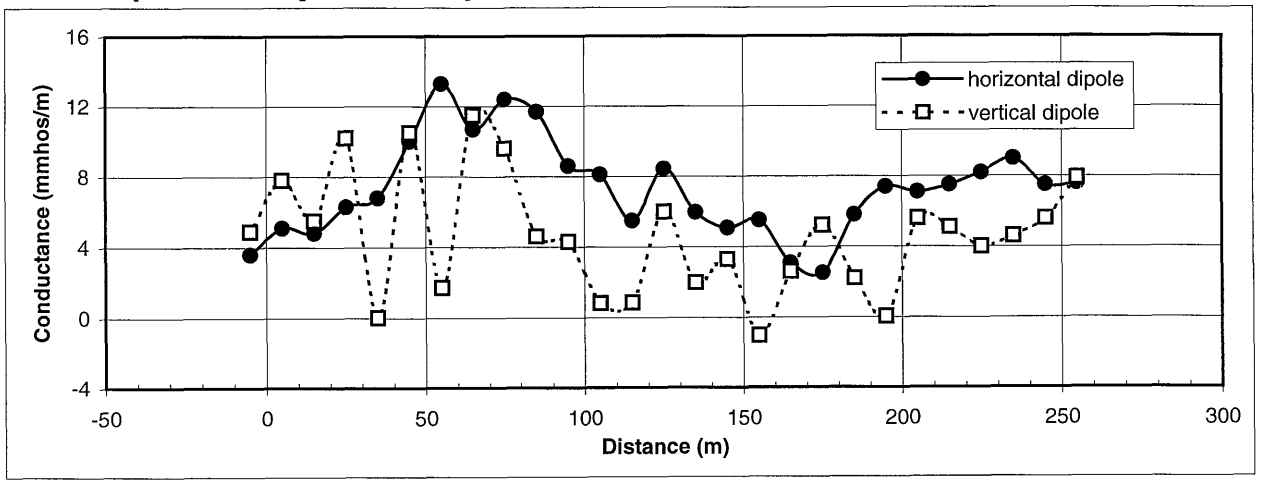
Comments:

position (m)	comments
0	peg
180	bottom depression
260	peg

OD14 (40 m separation)



OD15 (10 m separation)

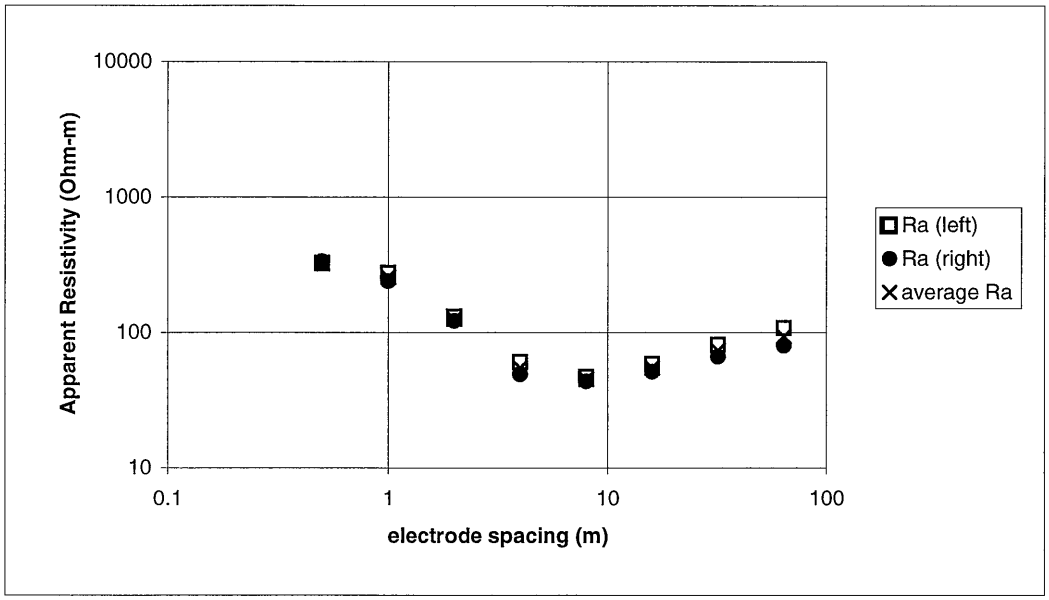


Odubwo

OD16

Resistivity Survey 1
Located at junction (-10 m along OD3)
Offset Wenner
Strike 199 degs left to river
03/04/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	102.1	106.5	320.594	334.41	327.502
1	43.7	37.9	274.436	238.012	256.224
2	10.39	9.71	130.4984	121.9576	126.228
4	2.4	1.954	60.288	49.08448	54.68624
8	0.935	0.865	46.9744	43.4576	45.216
16	0.58	0.511	58.2784	51.34528	54.81184
32	0.403	0.329	80.98688	66.11584	73.55136
64	0.267	0.198	107.3126	79.58016	93.4464



DATA SET: OD 16

CLIENT: WaterAid DATE: APril 1998
LOCATION: Odubwo SOUNDING: 1
COUNTY: Oju AZIMUTH: 199 degs
PROJECT: Water Supply and Sanitation EQUIPMENT: BGS128
ELEVATION: 3063.00
SOUNDING COORDINATES: X: 4944.0000 Y: 7152.0000

Offset Wenner Configuration

FITTING ERROR: 1.027 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			3063.0		
1	342.2	1.01	3061.9	0.00298	348.7
2	41.91	12.75	3049.2	0.304	534.7
3	116.5				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	328.075	342.242	358.408
	2	39.458	41.913	44.316
	3	105.945	116.530	132.260
THICK	1	0.968	1.019	1.073
	2	10.487	12.758	15.655
DEPTH	1	0.968	1.019	1.073
	2	11.528	13.777	16.652

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	327.5	324.6	0.859
2	1.00	256.2	257.6	-0.583
3	2.00	126.2	127.1	-0.791
4	4.00	54.70	53.76	1.70
5	8.00	45.20	46.03	-1.85
6	16.00	54.80	54.52	0.504

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	73.60	73.44	0.211
8	64.00	93.40	93.51	-0.122

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
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	0.00	-0.01	0.00	0.98

WaterAid Compound

WA 1

GPS Lat 6 degs 52.310 North, 8 degs 26.152' East
date: 06/04/98

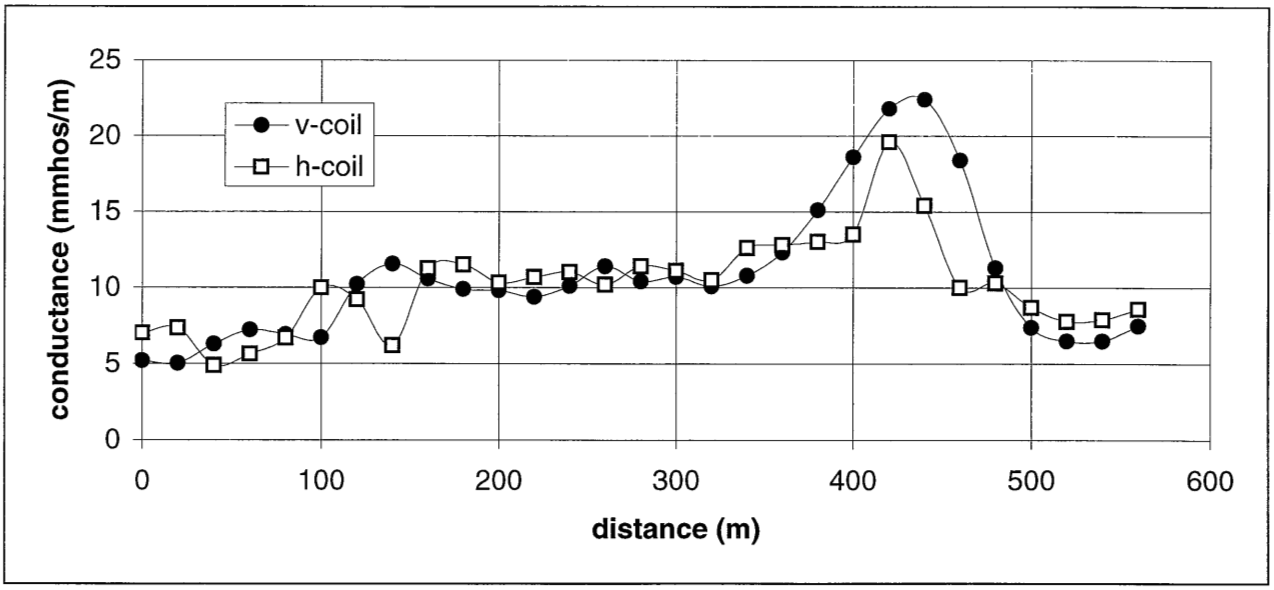
Survey WA1 from culvert (100 m towards town from compound) past compound to next culvert

Strike:

position (m	strike (deg)
0	96
500	96

Comments:

position (m)	comments
0	15 from culvert
100	BGS1
110	gate of compound
330	borehole to right
500	Andy's borehole
773	culvert

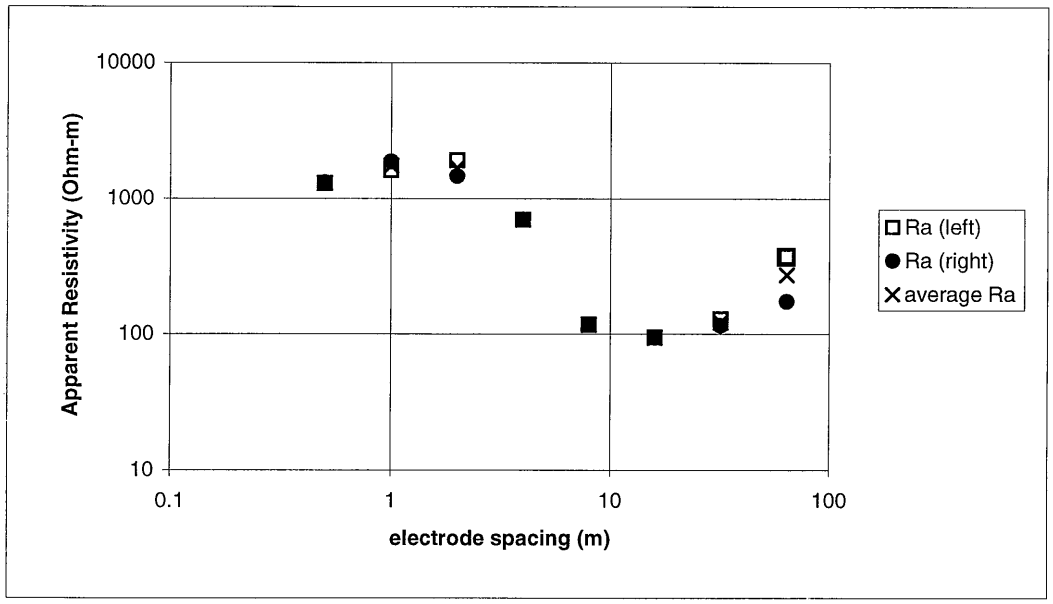


WaterAid

WA 2

Resistivity Survey 1
Located at borehole 10 m towards road (100 m WA1)
Offset Wenner
Strike 277 degs degs
03/04/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	411	417	1290.54	1309.38	1299.96
1	257	297	1613.96	1865.16	1739.56
2	151.7	116.4	1905.352	1461.984	1683.668
4	27.7	27.9	695.824	700.848	698.336
8	2.33	2.32	117.0592	116.5568	116.808
16	0.94	0.932	94.4512	93.64736	94.04928
32	0.64	0.574	128.6144	115.351	121.9827
64	0.928	0.432	372.9818	173.6294	273.3056



DATA SET: WA2

CLIENT: WaterAid DATE: April 1998
LOCATION: WaterAid Compound SOUNDING: 1
COUNTY: Oju AZIMUTH: 277 degs
PROJECT: Water abd Sanitation EQUIPMENT: BGS128
ELEVATION: 3063.00
SOUNDING COORDINATES: X: 4944.0000 Y: 7152.0000

Offset Wenner Configuration

FITTING ERROR: 6.498 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			3063.0		
1	710.6	0.289	3062.7	4.080E-04	206.0
2	5661.3	0.676	3062.0	1.196E-04	3831.6
3	69.36	21.43	3040.5	0.309	1486.9
4	1935.1				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	196.240	710.639	1183.150
	2	3288.188	5661.318	12361.426
	3	55.178	69.365	81.647
	4	875.262	1935.185	12071.125
THICK	1	0.076	0.290	0.523
	2	0.311	0.677	1.177
	3	16.004	21.436	27.517
DEPTH	1	0.076	0.290	0.523
	2	0.628	0.967	1.440
	3	17.031	22.403	28.435

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	1300.0	1301.2	-0.0981
2	1.00	1740.0	1801.4	-3.52

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
3	2.00	1683.0	1641.6	2.45
4	4.00	698.0	668.0	4.28
5	8.00	117.0	123.7	-5.78
6	16.00	94.00	87.50	6.90
7	32.00	122.0	136.9	-12.27
8	64.00	273.0	252.2	7.61

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.59						
P 2	0.03	0.52					
P 3	0.03	-0.01	0.92				
P 4	0.00	0.00	-0.02	0.06			
T 1	-0.43	-0.05	0.04	0.01	0.51		
T 2	-0.01	0.48	0.02	0.00	0.09	0.51	
T 3	0.03	-0.01	-0.10	-0.12	0.04	0.02	0.85

* BRITISH GEOLOGICAL SURVEY *

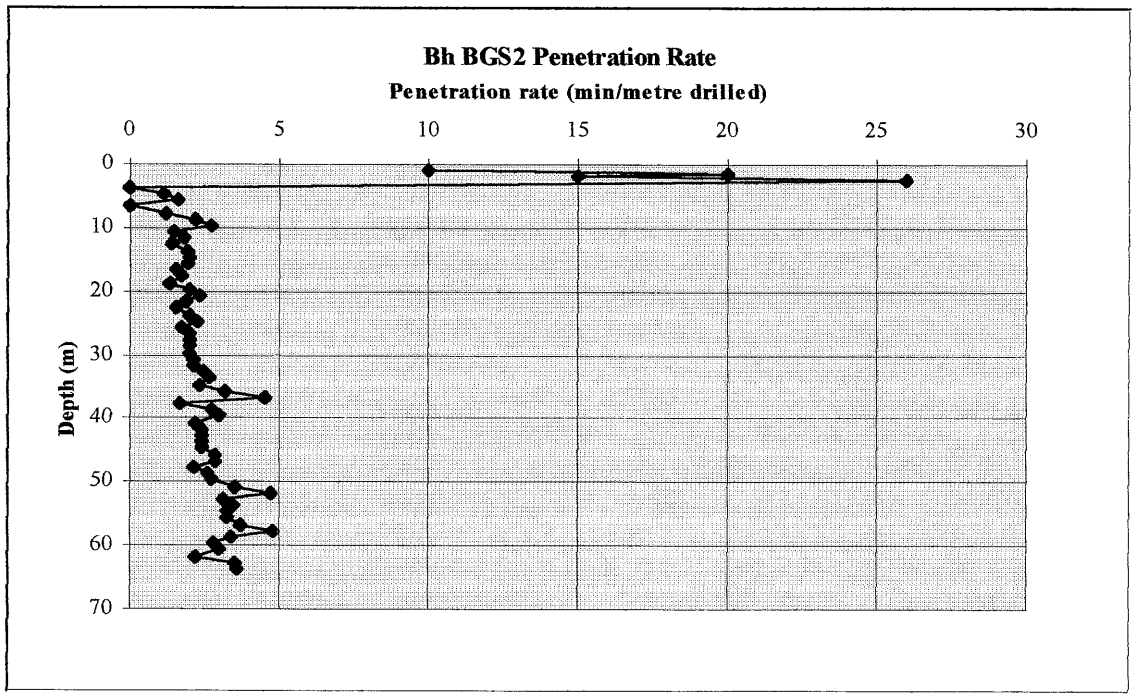
Annex 2: Drilling and borehole construction data

Borehole No. BGS1

Borehole Drilling/Construction Details	
Date drilling started	14/11/97
Date drilling completed	17/11/97
14/11/97 - Cored at 3"	0.00 - 0.75m
15/11/97 - Cored at 3"	0.75 - 4.50m
16/11/97 - Cored at 3"	4.50 - 11.80m
17/11/97 - Reamed with $6^1/_2$" tricone	to 11.80m
Depth of borehole on completion	11.80mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x5.8mx125mm screen
	1x2.9mx125mm screen
	1x2.9mx125mm casing
Original top of casing above ground level	0.7m
Total length of casing/screen	11.6m
Depth of borehole after gravel packing	11.3mbtoc
Amount of casing removed	0.37m
Rest water level below casing top	2.97m

Borehole BGS2

Borehole Drilling/Construction	
Date drilling started	18/11/97
Date drilling completed	20/11/97
18/11/97 - Drilled with 8.5" tricone	0.0 - 2.5m
18/11/97 - Drilled with 6.5" hammer	2.5 - 36.7m
19/11/97 - Drilled with 6.5" hammer	36.7 - 63.7m
Depths water struck	11.7 (damp), 14.7 (damp), 15.7, 16.7, 19.7 (flowing), 20.7 (more water), 23.7 (more water), 30.7, 34.7 (more water), 35.7 (more water), 36.7 (more water), 51.7 (much more water), 57.7 (more water)
Depth of borehole on completion	63.7mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x3.0mx204mm casing 6x2.9mx125mm casing 5x2.9mx125mm screen 6x5.8mx125mm screen
Original top of casing above ground level	0.26m
Total length of casing/screen	65.68m
Amount of casing removed	1.83m
Rest water level below casing top	1.99m



Borehole BGS2A

Borehole Drilling/Construction	
Date drilling started	20/11/97
Date drilling completed	22/11/97
20/11/97 - Cored at 3"	0.0 - 5.67m
21/11/97 - Cored at 3"	5.67 - 14.20m
22/11/97 - Cored at 3"	14.20 - 20.80m
Depth of borehole on completion	20.8mbgs
Borehole diameter	4"
Casing erected in hole	none
Rest water level below casing top	3.90m

Borehole BGS2B

Borehole Drilling/Construction	
Date drilling started	23/11/97
Date drilling completed	23/11/97
23/11/97 - Drilled with 6.5" hammer	0.0 - 19.5m
Depth of borehole on completion	19.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x2.9mx125mm casing 3x5.8mx125mm screen

Annex 3: Lithological logs

Lithological log: BGS 1

Soil/ferrecrete zone		
0.00 -	0.65	Light brown loamy soil 7.5YR4/4
0.65 -	1.80	Red brown 5YR4/4 fine grained clayey silt matrix with dark red 2.5YR3/3 pea gravel of ferrecrete
1.80 -	1.85	Bright red earthy ferricrete layer 2.5YR4/6
1.85 -	2.00	Yellow 10YR6/8 limonite coated concretions of dark red 10R3/2 haematitic ferricrete in light red earthy matrix, concretions up to 15mm long
2.00 -	2.20	Concretions joined together with some light grey clay
2.20 -	2.40	Black manganiferous and dark red concretions joined together with grey and light yellow limonitic to pink 7.5YR8/4 kaolin rich earthy matrix
2.40 -	3.00	Dark pink red and grey white vuggy ferrecrete with some black manganiferous partings with groundmass of light grey clay, pink white 7.5YR8/2 clay, yellow and light blue grey 2 8/1 clay in parts, very porous forms base of the oxidised zone
Clayey very weathered zone		
3.00 -	3.25	Compact mottled light blue grey and orange yellow clay
3.25 -	3.35	Layered ochre and light blue grey clayey siltones with dark brown iron rich layers, bedding discernable
3.35 -	3.50	Mottled light blue grey and orange clay
3.50 -	3.75	Weathered light brown siltstone with thin manganiferous partings
3.75 -	3.90	Light blue grey and orange yellow mottled silty clay
3.90 -	4.20	Weathered light brown thinnly bedded biscuit like siltstones becoming harder with depth
4.20 -	4.30	Light red brown clay
4.30 -	4.40	Mottled bright yellow orange and light blue grey silty clay
4.40 -	4.50	Black manganiferous layer above light brown silty clay
Non-weathered zone with calcite veining - water bearing sapprolite		
4.50 -	11.80	Compact dark grey black hard very convoluted phylitic mudstones some iron staining at 4.50m
Water producing? calcite lined breaks noted at 7.45, 7.83, 8.65, 9.05, 10.60, 11.40 and 11.50 metres		

Lithological log: BGS 2

Soil/ferrecrete zone	
0.0 - 2.0	Dark grey unweathered and light brown soft weathered shaley mudstone
2.0 - 2.5	Dark grey black shaley mudstones, very soft weathered red brown mudstones with light brown partings.
Clayey very weathered zone	
2.5 - 3.7	Dark grey black shaley mudstones, blocky, weathered with brown oxidised partings
3.7 - 4.7	Very weathered bright orange and brown mudstones, and non-weathered dark grey black mudstones.
4.7 - 5.7	Very weathered dark grey black mudstones with brown and orange partings
Weathered zone	
5.7 - 6.7	Dark grey black carbonaceous mudstone - soft and weathered, with light brown and orange partings.
6.7 - 7.7	Dark grey black carbonaceous mudstone - soft and weathered, with light brown and orange partings.
7.7 - 8.7	Dark grey carbonaceous mudstone, weathered but more compact with splintery fracture.
Non-weathered zone - water bearing sapprolite	
8.7 - 9.7	Dark grey carbonaceous mudstone; compact with splintery fracture - some softer layers.
9.7-10.7	Dark grey carbonaceous mudstone; compact with splintery fracture - some softer layers.
10.7-11.7	Dark grey black carbonaceous mudstone, compact, but soft with earthy fracture.
11.7-12.7	Dark grey black carbonaceous mudstone, compact, but soft with earthy fracture.
12.7 - 13.7	Dark grey black carbonaceous mudstone, compact, but soft with earthy fracture becoming damp.
Calcite veined zone - water producing zone	
13.7 - 14.7	Dark grey black carbonaceous mudstone, compact -harder with occasional **calcite** veining.
14.7 - 15.7	Dark grey black carbonaeous mudstone, compact -harder with occasional **calcite** veining, some clay - very wet.
15.7 - 16.7	Dark grey black carbonaceous mudstone, compact -harder with occasional **calcite** veining, increased clay; some iron **pyrite**; yellowish brown staining on fracture surfaces.
Weathered zone	
16.7 - 17.7	Dark grey black soft carbonaceous mudstone with much light grey and reddish yellow clay.
17.7 - 18.7	Dark grey black soft carbonaceous mudstone with much light grey and reddish yellow clay.
Calcite veined zone - water producing zone	
18.7 - 19.7	Dark grey black soft shaley carbonaceous mudstone, soft and compact, little clay, yellowish brown partings.
19.7 - 20.7	Dark grey black soft carbonaceous shaley mudstone; no clay; yellowish brown partings and some **calcite** veining.
20.7 - 21.7	Dark grey black soft carbonaceous shaley mudstone; no clay; yellowish brown partings and some **calcite** veining.
21.7 - 22.7	Dark grey black soft shaley mudstone with yellowish red partings and **calcite** veining (2-3 mm).
22.7 - 23.7	Dark grey black carbonaceous mudstone; compact with splintery fracture, medium fragments.
Massive hard rock zone some weathering	
23.7 - 24.7	Dark grey black soft carbonaceous shaley mudstone, compact, medium to large fragments; some brownish yellow partings.
24.7 - 25.7	Dark grey black soft carbonaceous shaley mudstone, compact, small to medium fragments; some brownish yellow partings.
25.7 - 26.7	Dark grey black soft carbonaceous shaley mudstone, compact, small to medium fragments; some brownish yellow partings, with iron **pyrite**
26.7 - 27.7	Dark grey black soft carbonaceous shaley mudstone; fairly compact with some softer clay layers.
27.7 - 28.7	Dark grey black carbonaceous shaley mudstone with yellowish brown partings.
Calcite veined zone - water producing zone	
28.7 - 29.7	Dark grey black carbonaceous shaley mudstone with yellowish brown partings, less compact with some **calcite** veining.

29.7 - 30.7	Dark grey black carbonaceous shaley mudstone - very large fragments - brownish partings.
30.7 - 31.7	Dark grey black soft carbonaceous shaley mudstone - compact.
31.7 - 32.7	Dark grey black soft carbonaceous shaley mudstone - compact with brown partings
32.7 - 33.7	Dark grey black carbonaceous shaley mudstone -medium to large fragments - brownish partings and some **calcite** veining.
33.7 - 34.7	Dark grey black carbonaceous shaley mudstone -medium to large fragments - brownish partings and some **calcite** veining.
34.7 - 35.7	Dark grey black carbonaceous shaley mudstone -small to medium fragments - brownish partings and some **calcite** veining
Massive hard rock zone	
35.7 - 36.7	Dark grey black soft carbonaceous shaley mudstone, compact, small fragments
36.7 - 37.7	Dark grey black soft carbonaceous shaley mudstone, compact, small fragments
37.7 - 38.7	Dark grey black soft carbonaceous shaley mudstone, compact, medium fragments
38.7 - 39.7	Dark grey black soft carbonaceous shaley mudstone, earthy fracture, compact, medium fragments, some large
39.7 - 40.7	Dark grey black soft carbonaceous shaley mudstone, earthy fracture, compact, medium to large fragments
Massive hard rock zone - some weathering	
40.7 - 41.7	Dark grey (softer) and black (harder but still soft) carbonaceous shaley mudstone, earthy fracture, oddd ochre coloured fragments, medium to large fragments - fractured formation
41.7 - 42.7	Dark grey black soft and harder carbonaceous shaley mudstone, earthy fracture, some ochre coloured fragments, odd brassy yellow fragment of iron **pyrite**, many large (>0.5") fragments
42.7 - 43.7	Dark grey black soft carbonaceous shaley mudstone, earthy fracture, compact, small to medium fragments, some iron **pyrite** fragments
43.7 - 44.7	Dark grey black soft carbonaceous shaley mudstone, earthy fracture, fairly compact, large fragments, several very large fragments, some light ochre brown partings, fractured formation
44.7 - 45.7	Dark grey black soft carbonaceous shaley mudstone, earthy fracture, several large fragments with ochre/light brown partings, fractured formation
Calcite veined zone - water producing zone	
45.7 - 46.7	Dark grey black soft carbonaceous shaley mudstone, fairly compact, earthy fracture, some small fragments of white crystaline vein **calcite**, several large fragments.
46.7 - 47.7	Dark grey black soft carbonaceous shaley mudstone, fairly compact, earthy fracture, increased small fragments of white crystaline vein **calcite**, several large fragments.
47.7 - 48.7	Dark grey black soft carbonaceous shaley mudstone, compact, earthy fracture, small to medium fragments
48.7 - 49.7	Dark grey black harder carbonaceous shaley mudstone, earthy fracture with large fragments, fractures
49.7 - 50.7	Dark grey black soft carbonaceous shaley mudstone with hard and soft layers, mainly medium fragments, some very large fragments, **calcite** partings, fractures.
50.7 - 51.7	Dark grey black carbonaceous soft compact shaley mudstones, some very large fragments, some thick ochre partings, possible fractures.
51.7 - 52.7	Dark grey black carbonaceous fairly hard to soft compact shaley mudstones, medium fragments, many large fragments with disseminated **pyrite**
52.7 - 53.7	Dark grey black carbonaceous soft compact shaley mudstones, earthy fracture, medium fragments, odd large fragments with disseminated **pyrite**
53.7 - 54.7	Dark grey black carbonaceous hard splintery shaley mudstones, earthy fracture, medium to large fragments, white vein **calcite**
Massive hard rock zone	
54.7 - 55.7	Dark grey black carbonaceous fairly hard shaley mudstones, earthy fracture, medium to large fragments
55.7 - 56.7	Dark grey black carbonaceous fairly hard shaley mudstones, earthy fracture, medium to large fragments
56.7 - 57.7	Dark grey black carbonaceous fairly hard shaley mudstones, earthy fracture, medium to large fragments

57.7 - 58.7	Dark grey black carbonaceous soft compact shaley mudstones, earthy fracture, small to medium fragments
58.7 - 59.7	Dark grey black carbonaceous soft compact shaley mudstones, earthy fracture, small to medium fragments, some **pyrite**
Calcite veined zone - water producing zone	
59.7 - 60.7	Dark grey black carbonaceous soft compact shaley mudstones, earthy fracture, medium to large fragments, much white vein **calcite**
60.7 - 61.7	Dark grey black carbonaceous soft fractured shaley mudstones, earthy fracture, medium to large fragments, much white vein **calcite**
61.7 - 62.7	Dark grey black carbonaceous soft fractured shaley mudstones, earthy fracture, medium to large fragments, increased white vein **calcite**
62.7 - 63.7	Dark grey black carbonaceous soft fractured shaley mudstones, earthy fracture, medium to large fragments, with ochreous partings, much **pyrite** and white vein **calcite**, many fractures

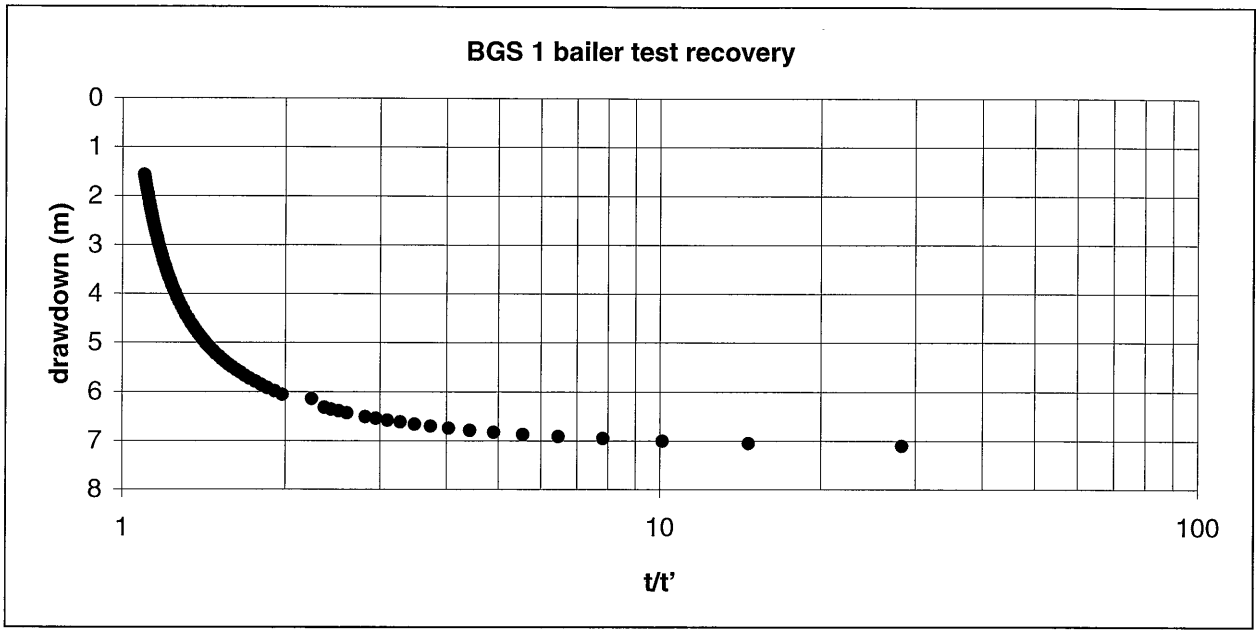
Lithological log: BGS 2a

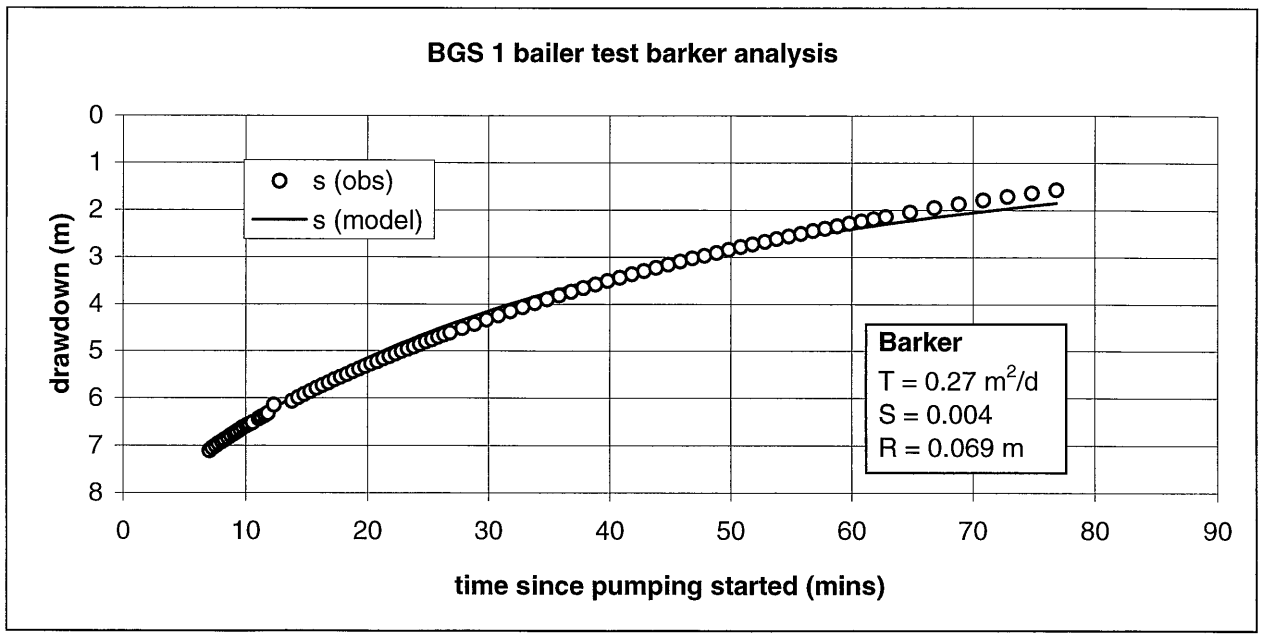
Soil/ferrecrete horizon	
0.00 - 0.90	Very weathered grey black shale with orange pink partings, no soil layer.
0.90 - 1.10	Some clayey nodular material within weathered shales - very weathered
1.10 - 1.25	Compact clayey grey to orange pink very weathered layer, nodular - approximates to ferrecrete zone but is mainly a zone of kaolin clay accumulation
1.25 - 1.40	Compact clayey grey to orange pink less weathered layer, nodular zone of clay accumulation
1.40 - 1.60	Orange brown to grey, very soft clayey broken very weathered horizon
1.60 - 1.80	Harder band where shales have been weathered to light brown green colour, retains bedding structure
1.80 - 1.95	Orange brown / grey clayey very weathered very broken horizon some manganese
1.95 - 2.40	Light brown to grey weathered broken shaley mudstones, with some black partings, bedding still recognizable.
Clay very weathered horizon	
2.40 - 2.50	Pink brown and light grey very weathered clay rich horizon
2.50 - 3.85	Dark grey broken mudstones with light brown weathered partings, blocky fractures
3.85 - 4.00	Weathered zone, broken, with clayey light blue grey kaolin enrichment horizon
4.00 - 4.40	Weathered dark grey mudstones, very broken and blocky, with weathered light brown partings.
4.40 - 4.50	Very weathered clayey horizon, some clay development within blocky mudstones
4.50 - 4.80	Weathered blocky mudstones
4.80 - 5.60	Core lost, blown away during drilling but probably composed of blocky weathered mudstones.
Weathered horizon	
5.60 - 6.30	High angle of slatey cleavage, competent and compact hard dark grey mudstone, orange brown iron oxide staining along cleavage planes.
6.30 - 6.70	Fractured rock becoming softer with depth, cleavage less pronounced, dendritic type breaks, quite a dense pattern in parts probably resulting in higher secondary permeability
6.70 - 6.90	Blocky mudstones, much softer, broken, no noticable slatey cleavage apparent, much dust produced during drilling
6.90 - 7.62	Harder more competent bands, slatey cleavage, iron oxide staining along bedding planes
7.62 - 7.85	Competent mudstone with slatey cleavage
7.85 - 8.35	Very weathered, black, broken with brown partings
Non-weathered rock - water bearing sapprolite	
8.35 - 8.60	Compact with slatey cleavage
8.60 - 9.90	Hard compact slatey mudstone, high cleavage dip of 56° from horizontal, **pyrite** at 9.00m and **calcite** vein at 9.70 - 9.80m
9.90 - 11.10	Very compact hard mudstone, prominant crack at 10.80m that produced increase in water, attitude of crack 35° from horizontal
11.10 - 11.85	Hard compact black to dark grey mudstones, high angle of cleavage, water forced from adjacent borehole BGS2 on reaching 11.50m depth
Calcite veined zone - water producing zone	
11.85 - 14.05	Hard slatey competent massive mudstones, high cleavage angle parallel to bedding, dark grey black with white **calcite** veining along water producing joints, some possible slickensliding with **calcite** filled crack at 13.75m, thin **calcite** vein at 14.70m and a possible ashy layer at 14.23-14.25m
14.05 - 15.93	Hard black grey carbonaceous slatey mudstones with high cleavage angle, some **calcite** veins
15.93 - 17.9	Massive hard dark grey black carbonaceous slatey mudstones with **calcite** lines fractures at 16.08 - 16.14, 16.20, 16.82-16.88 and 16.95-17.05m, and broken at 17.08 and 17.35-17.38m
Massive hard rock zone	
17.90 - 20.80	Massive hard dark grey black carbonaceous slatey mudstones with no breaks, retreived as a single 3 metre long stick of core.

Annex 4: Pump test data

BGS 1: bailer test

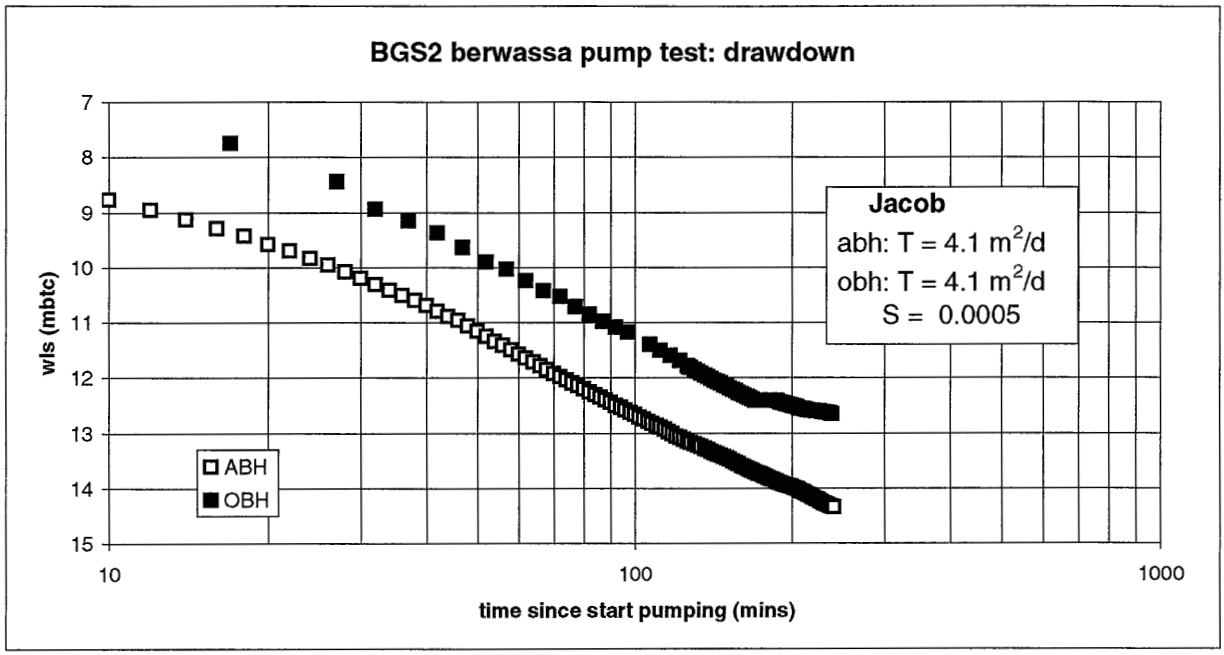
07/04/98
casing: 0.28 magl
rwl: 3.254 m
25 bails in 6:50 mins
= 0.305 l/s = 26.3 m^3/d

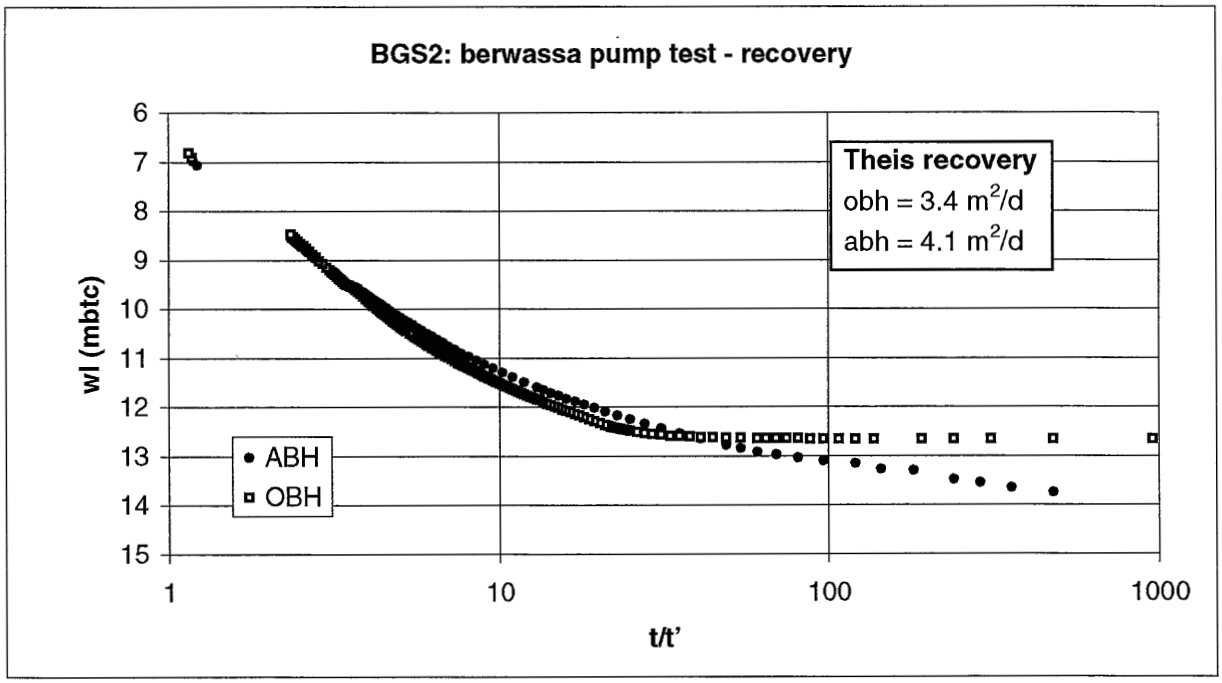




BGS 2: Berwassa pump test unit

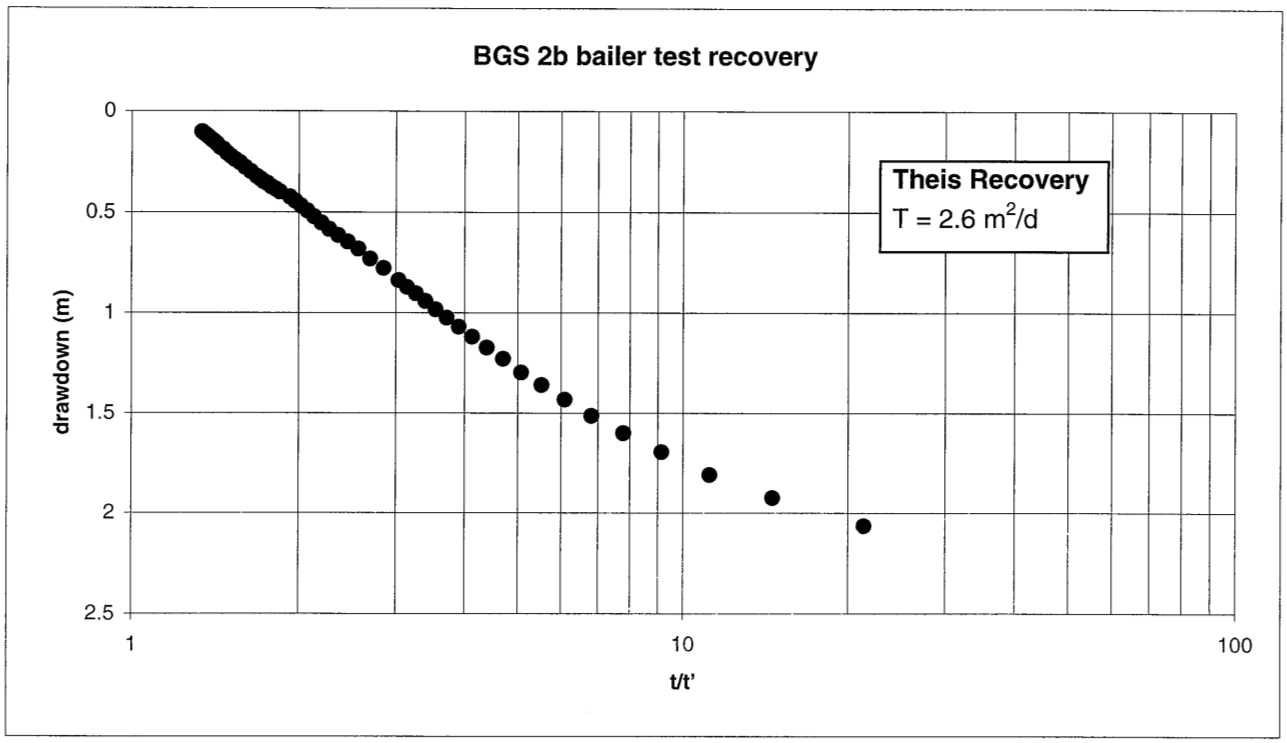
07/03/98
abh (BGS2) casing = 0.3 m agl
obh (BGS2b) casing = 0.3 m agl distance between BGS2 and BGS2b = 12.25 m
rwl BGS2 = 6.65 mbc
rwl BGS2b = 6.60 mbc
average rate 1.25 l/s 108 m^3/d
length test 4 hours

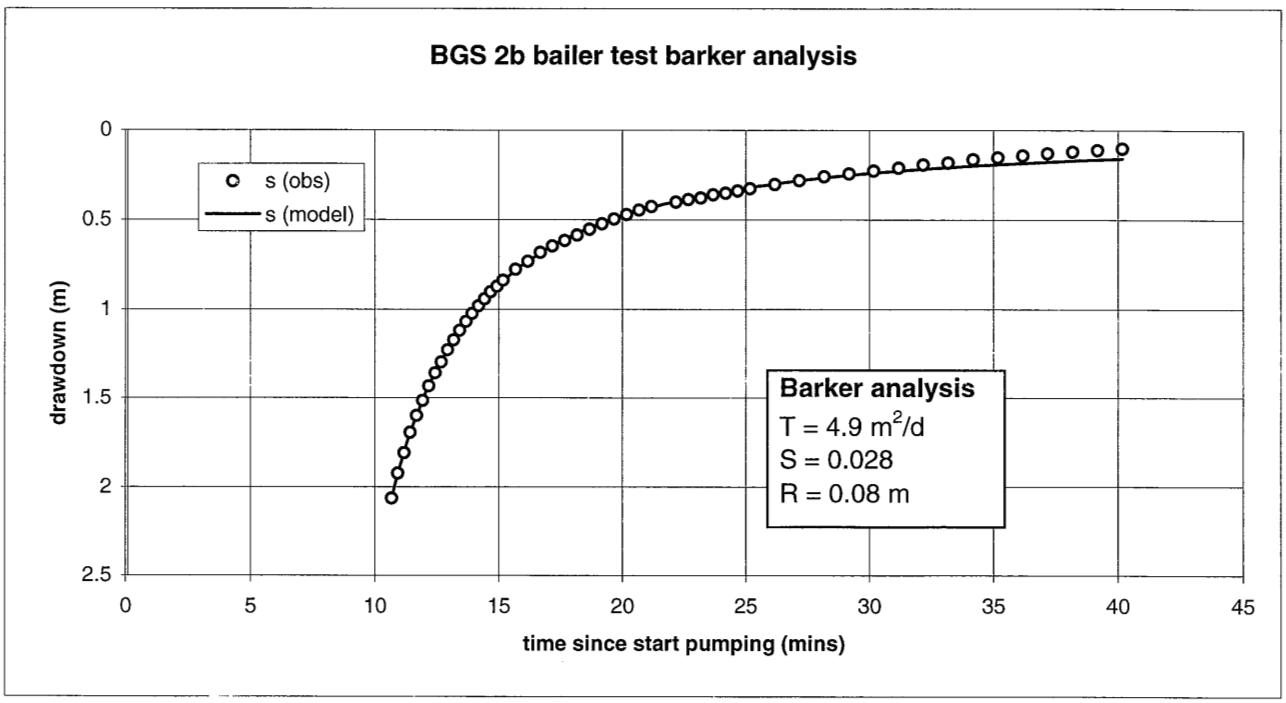




BGS 2b: bailer test

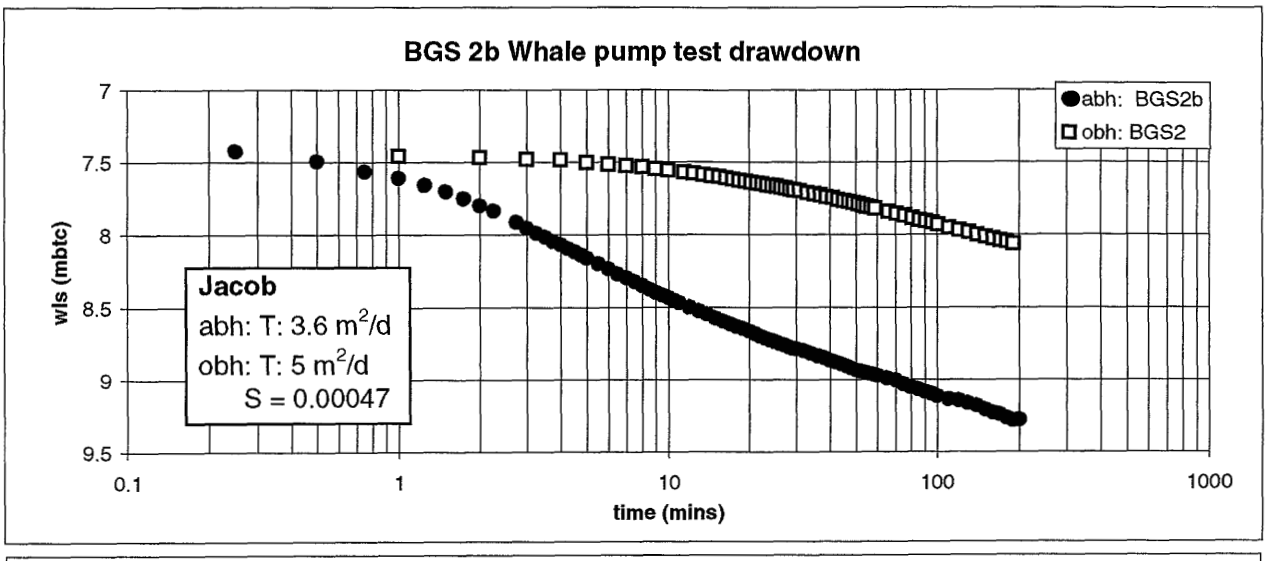
bailer test 28/03/98
rwl abh: 7.365 m
casing = 0.3 m agl distance between BGS2 and BGS2b = 12.25 m
No of bails = 39
time pumping10:11 mins
prate: 0.32 l/s = 27.6 m3/d

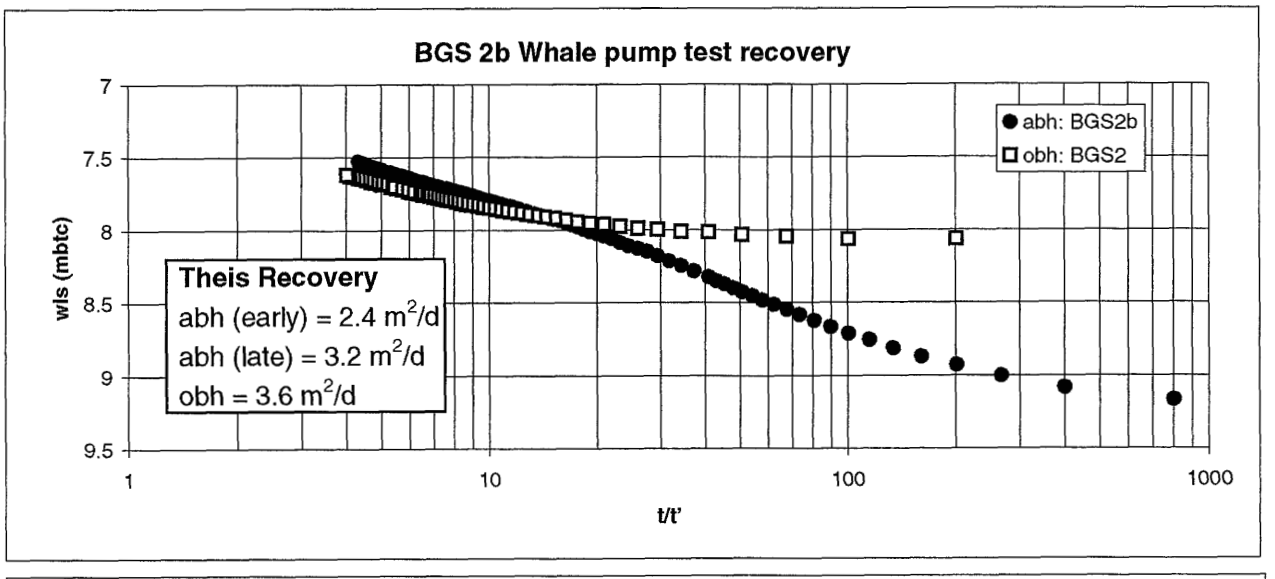


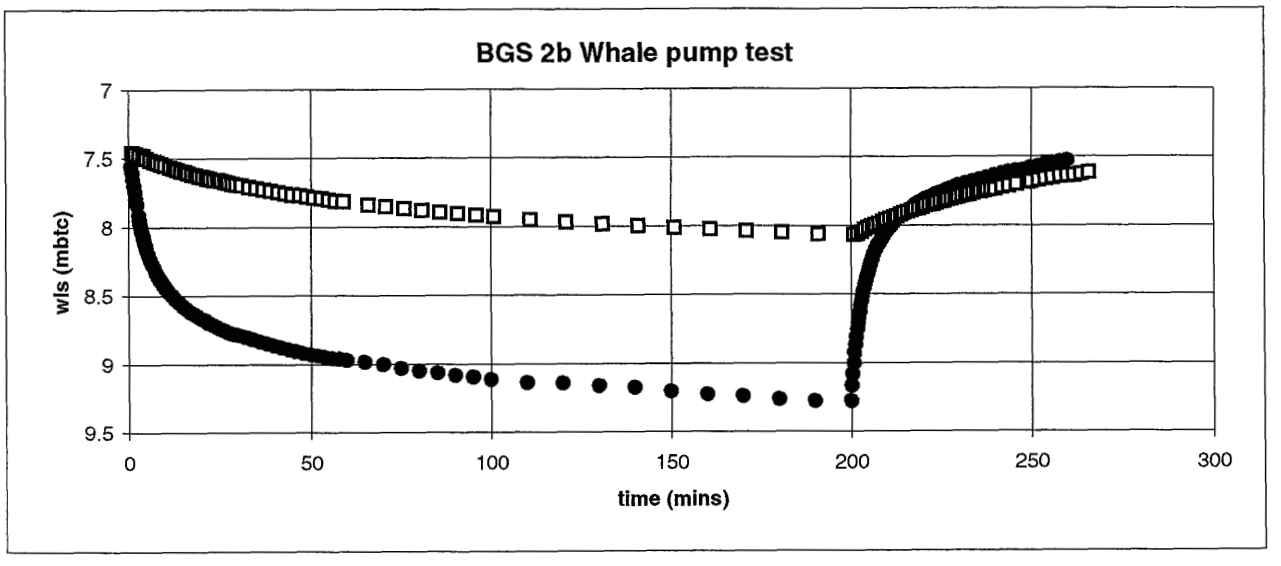


BGS 2b: whale pump test

28/03/98
rwl BGS2b: 7.323 m casing 0.3 m distance between BGS2 and BGS2b = 12.25 m
rwl BGS2: 7.47 m casing 0.3 m
time pumping 200 mins
prate: 0.15 l/s = 13.1 m^3/d

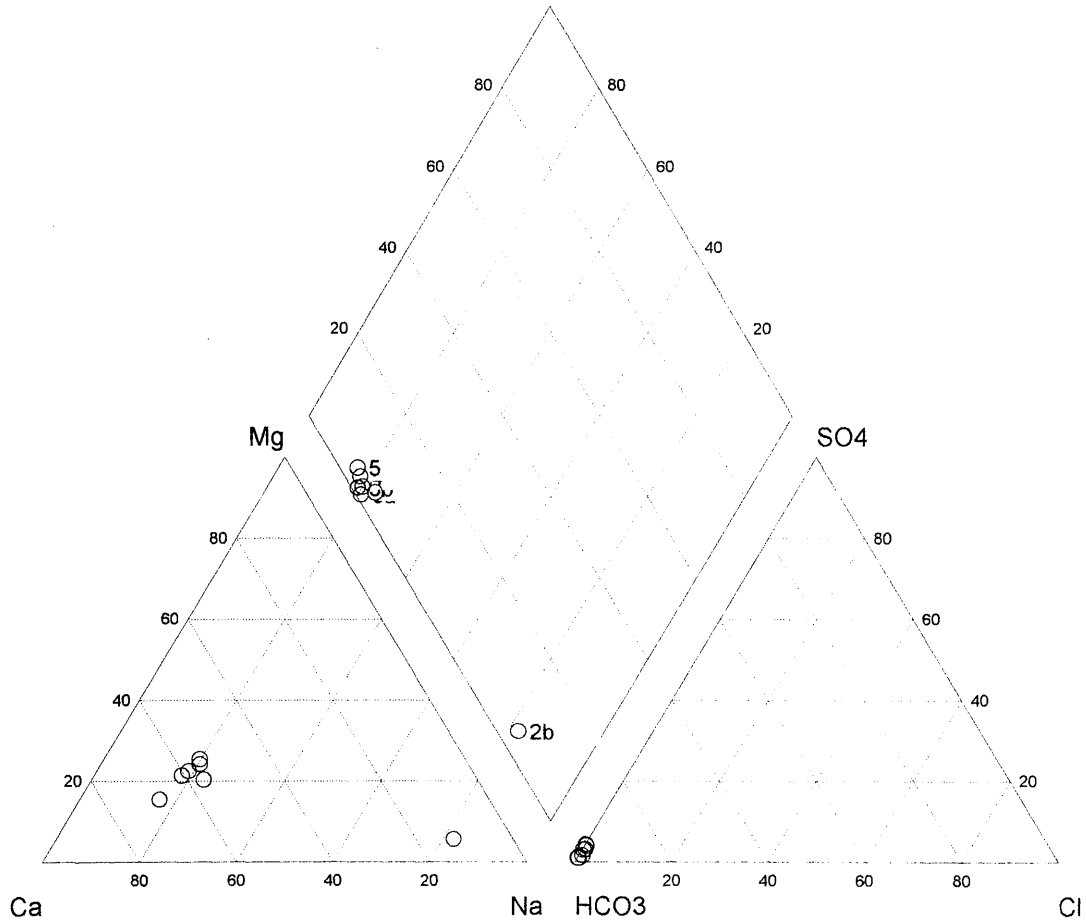






Annex 5: Water quality data

Groundwater Chemistry - Odubwo/WaterAid



Odubwo and surrounding area

Jan-Apr 1998

Easting	Northing	Sample Id	Bh No	pH	Temp DegC	Cond mS/cm	HCO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l
8.44	6.869	Oju1	Andy's Bh	7	29.6	592	368	28.5	0.5	68.7	19.3	4.8	1.8
8.446	6.864	Oju2	Zion Hill	7.08	29.4	526	305	22.4	0.4	74.2	12.2	1.8	0.6
8.451	6.858	Oju3	Professor	6.87	29.5	855	512	40.2	0.6	117	25	12.3	1.1
8.46	6.856	Oju4	Anyitunkpo		29.2	559	324	20	0.4	85.1	10.3	8.4	4.3
8.469	6.856	Oju5	Bethesda H	6.85	29.7	834	541	35.3	1.1	127	17.4	14.1	2
8.463	6.846	Oju6	Orphanage	7.05	28.9	644	414	45.6	0.9	80.9	13.8	13.1	2.9
8.463	6.849	Oju7	Orphanage	6.9	29.2	646	441	9.8	0.4	119	11.5	7	1.1
8.497833	6.871167	227	BGS2A	6.93	29.5	905	563	54.1	1.2	115	25	18.5	
8.43972	6.86943	254	Andys	7.2	28.9	583	395	30	0.6	69.2	20	4	
8.4627	6.8462	255	Bethesda	7.17	28.6	660	412	47.8	1.2	78.6	14.1	12.7	
8.497833	6.871167	259	BGS2A	7.05	29.5	915	607	74.2	1.2	95.9	27	21.7	
8.435867	6.8718	260	WaterAid	7.51	29	616	419	32.8	2	77.6	20.5	3.3	

Sample Id	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
Oju1		18.8	0.558	0.113	0.047	0.04	1.72	0.7	0.0019	0.17	0.009
Oju2		22	0.29	0.052	0.044		1.75	0.53	0.0019	0.24	0.005
Oju3		19.1	1.06	0.187	0.04	0.03	1.94	0.144	0.0125	0.25	0.012
Oju4		29.1	0.359	0.058	0.052		1.71	0.783	0.0047	0.24	0.013
Oju5		18	0.982	0.115	0.031	0.03	0.59	0.072	0.0102	0.18	0.063
Oju6		19.2	0.76	0.117	0.033		0.2	0.23	0.0053	0.29	0.013
Oju7		14.1	0.361	0.102	0.022		1.19	0.25	0.0033	0.27	0.007
227		14.4	1.66	0.12	0.036	0.07	0.25	0.169	0.0244		
254		19.6	0.56	0.119	0.049	-0.03	0.9	0.682	0.0012		
255		18.8	0.766	0.114	0.032	-0.03	0.2	0.222	0.0059		
259		14.6	1.93	0.079	0.032	0.09	0.31	0.067	0.0317		
260		17.1	0.504	0.016	0.046	-0.03	2.17	0.183	0.0037		