British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

LOW PERMEABILITY ROCKS IN SUB-SAHARAN AFRICA.

Visit to Ghana to disseminate project results, 16 – 23 March 2002.

Groundwater Systems and Water Quality Programme.

Internal Report IR/02/062

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/062

LOW PERMEABILITY ROCKS IN SUB-SAHARAN AFRICA.

Visit to Ghana to disseminate project results,16 – 23 March 2002.

Jeffrey Davies

Key words

Over used hand pumped borehole in central Donkorkrum, Afram Plains, Ghana.

Bibliographical reference

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Acknowledgements

Mr Gordon Mumbo of WaterAid is thanked for facilitating the visit of Mr Davies as well as his hospitality in Accra. Kurt Klitten continues to show exceptional enthusiasm for groundwater supply activities in Ghana inspite of his recent tragic loss. It was a pleasure to meet with Mr Modok, Ms Alima and the APDO staff in the Afram Plains once again. Mr Enoch Asare is thanked for making that visit possible and his demonstration of the ‘Diver’ system. May Bruce Baneoneg-Yakubo continue to enthuse students of hydrogeology.

Contents

1 Introduction

In March 2002 BGS hydrogeologist, Jeffrey Davies, visited Ghana to disseminate the results of hydrogeological studies undertaken in the Afram Plains, Eastern Region, Ghana, as part of DFID funded KAR project R7353, Low Permeability Rocks in Sub-Saharan Africa. The visit was facilitated by WaterAid Ghana. The itinerary of Mr Davies is detailed in Appendix 1 and a full list of persons met and institutions visited is given in Appendix 2. This back to office note reports the key findings of the visit and provides a record of activities undertaken, data collected and persons met.

The terms of reference for the visit were as follows:

1. Present the results of the KAR Project R7353 Low Permeability Rocks in Sub-Saharan Africa to interested parties in Ghana and obtain feedback from them
2. Collect additional data and reports relevant to groundwater development in the Afram Plains
3. Recommend follow-up work in Ghana.

2 The presentation of project results

The main presentation of project results was undertaken at a seminar held at the office of DANIDA, at the Danish Embassy in Accra. Two other presentations were made in Accra and a fourth at the Afram Plains Development Organisation (APDO) offices in Tease, as outlined below. At each presentation the contents of the draft Afram Plains report and associated database, held electronically with other project reports on CD, were described. Fortunately access to the CD by personal computer did not produce problems as all had access to Microsoft Windows 2000, or later versions, with Microsoft Office. The database is in both Microsoft Word and Microsoft Excel to ensure that additions can be made to the database and the relevant sections can be reproduced for distribution to communities as reports or used as training material. Laminated copies of a hydrogeological map of the Afram Plains and summary table, produced by the project, were also distributed (Appendix 3).

2.1 THE GEOLOGICAL SURVEY OF GHANA (18 MARCH 2002)

At the Ghana Geological Survey Mr Davies met with Mr Philip Amoako (acting director), Dr Feiko Kalsbeek (advisor to the Director from GEUS of Denmark) and The Head of the drawing office, with whom he discussed the geological content of the BGS report. They were especially interested in the photographs of rock unit exposures and borehole logs of units of the Voltaian sediments as seen in the Afram Plains at the southern end of the Volta Basin. Although the Volta Basin covers nearly one half of Ghana, due to its lack of economic mineral deposits, the Geological Survey of Ghana does not see the mapping of the Voltaian system as a priority area at this time. The Survey recognises the lack of knowledge of this geological system and that the results of the BGS studies will provide much useful data.

2.2 THE DANISH EMBASSY (19 MARCH 2002)

At a seminar held at the Danish Embassy, Accra the following were present:

- Mr Peiter van Dongen (Chief Advisor to the Ghana Water Commission),
- Mr Enoch Asare (Senior Hydrogeologist, Water Research Institute (WRI)),
- Mr Philip Darko (Hydrogeologist, Water Research Institute),
- Dr Bruce Baneoeng-Yakubo (Head of Hydrogeology, Geology Dept, University of Ghana, Legon),
- Mr Evans Asmenu (MSc student, Geology Dept, University of Ghana),
- Mr Kurt Klitten (Co-ordinator, DANIDA Water Sector Development Programme)
- Mr Gordon Mumbo (WaterAid Ghana)

The presentation of BGS project results included descriptions of:

- The manual of hydrogeological methods
- The draft Afram Plains hydrogeology report
- The Afram Plains hydrogeological database
- Geological logs of rock chip samples from four of the five DANIDA funded exploration boreholes drilled in the Afram Plains.

There followed presentations of water level monitoring data by Enoch Asare and geophysical wireline logging results by Mr Klitten, as undertaken in the five exploration boreholes. Unfortunately representatives from World Vision International (WVI), also active in groundwater development in the Afram Plains, were unable to attend. Mr Van Dongen, an experienced hydrogeologist from East Africa, commented that the manual of hydrogeological survey methods will form an important resource for the hydrogeological community in Africa and offered to review the document. Mr Klitten suggested that Mr Davies accompany Mr Asare to the Afram Plains in a DANIDA project vehicle so he could present the BGS project results to the Afram Plains Development Organisation during his visit. Copies of project reports, laminated maps and database in electronic form on CD were given to Mr van Dongen, Dr Baneoeng-Yakubo and Mr Asare.

2.3 THE DEPARTMENT OF GEOLOGY, UNIVERSITY OF GHANA (20 MARCH 2002)

A meeting was held at the Department of Geology, University of Ghana, Legon with Dr Bruce Baneoeng-Yakubo, and with Mr Evans Asmenu and Mr Vincent (MSc students) to further discuss the findings of the project. Mr Asmenu is using the results of geophysical surveys and test pumping undertaken as part of the DANIDA funded hydrogeological surveys in the Afram Plains as the basis of his MSc project. Access to the CD was checked and copies of other reports exchanged. The University has received rock chip samples from exploration boreholes numbers 1-4. Davies, Asmenu and Vincent geologically logged the rock chip samples from exploration Bh 1 and a series of representative samples from exploration Bh 5, the last obtained by Mr Asmenu during borehole drilling.

2.4 THE AFRAM PLAINS DEVELOPMENT ORGANISATION, TEASE (21/22 MARCH 2002).

Mr Davies accompanied Mr Asare, of the WRI, on a two-day visit to the Afram Plains. During this visit Mr Davies presented the results of the BGS studies to management and field staff at the APDO offices at Tease. On 21 March the project results were discussed with Mr Modok, the APDO manager and Ms Alima his deputy. The contents of the CD were downloaded onto the office computer and access to the various files and tables demonstrated, as were the hypertext links between the text of the main report and the database.

On 22 March the project results were described in detail to Mr Carlos Kuranteng, who had acted as technical counterpart to the BGS teams when in the Afram Plains. Access to the results was demonstrated both on laptop and the office computer. The importance of the location data that he and the other APDO field staff produce with the project GPS sets was emphasised, as was collection of representative rock chip samples from any production boreholes drilled. The boxed rock chip samples from the eight production boreholes drilled during 2001, and from exploration Bh 5 were noted at the APDO stores. The chip samples from exploration Bh 5 were logged during this visit (Appendix 4). The project results were further presented at an APDO staff meeting to Ms Alima and four area technicians using a series of overheads and the office computer. Again emphasis was placed upon the importance of collecting accurately located site data, their storage and analysis. These data should then be made available to National institutions such as the WRI who in turn should produce analyses in the form of distribution maps and development plans for the APDO. These analyses could then be used to better inform the local communities who in turn would be more enthusiastic about doing their own monitoring of borehole conditions and supplying such information to the APDO.

2.5 FEEDBACK

The stakeholders contacted appreciated the content of the database, manuals and report. This is the first accessible collation of borehole data from the Afram Plains. They felt that this is the way to proceed in the future and that there should be greater dissemination of the project results within Ghana and that similar projects could profitably be undertaken elsewhere in the country such as in the Northern Region. Geological Survey and WRI personnel should be encouraged to log the chip samples collected from boreholes to ensure better recognition of geological units penetrated.

3 Data collected

3.1 BOREHOLE GEOLOGICAL DATA

Rock chip samples, obtained at one-metre intervals from exploration borehole No. 5, were located at the APDO office in Tease where they were geologically logged

(Appendix 4). Additional rock chip samples obtained at one-metre intervals from eight production boreholes drilled by Technic-Eau during April-May 2001, are stored at APDO, Tease. Samples from four of these boreholes remain to be geologically logged.

Notes: The log shows alternations of conglomerate and sandstones with depth. Since the pebbles are broken up during drilling geologists need to be aware of how the formation appears at outcrop. These conglomerates and subordinate sandstones were investigated at the new ferry terminal (Sheet 1) where the relationship between clasts and sandstone matrices is well seen, as are patterns of weathering that impact upon groundwater occurrence especially at lithological boundaries.

3.2 WATER LEVEL MONITORING

'Diver' systems used to automatically monitor water level and barometric pressure changes were deployed by DANIDA/WRI in the five exploration boreholes during November 2001. Mr Asare of the WRI demonstrated the installation and use of the 'Diver' equipment at Tease, as shown on Sheet 2. All of the systems were found to be operating normally, including that at Exploration Bh5 that showed a water level rise probably due to delayed recovery of the local aquifer system after borehole installation and testing. Data derived from these sites were discussed during the meeting held at the Danish Embassy. These are presented in graphical form in Appendix 5. Monitoring is planned at these sites for a 2-year period.

Notes: The impact of lunar tides, diurnal pressure changes and nearby borehole pumping on borehole water levels are shown on these graphs. At Tease the operation of an adjacent hand pumped borehole appears to have resulted in a 4 m drop in water level during the November 2001 – March 2002 period in the exploration borehole. Changes brought about by the onset of the rainy season such as pressure changes and water level rise in response to aquifer recharge should be observed in the next two months or so. Monitoring probably needs to be for longer than the two years presently planned.

3.3 GEOPHYSICAL BOREHOLE LOGGING

The results of geophysical logging of exploration boreholes conducted for DANIDA are presented in Appendix 6. Logs undertaken include:

- Caliper
- Natural gamma
- Resistivity
- Focused resistivity
- Temperature
- Conductance
- Flow

Sheet 1

MIDDLE VOLTAIAN FORMATION – OBOSUM BEDS MASSIVE CONGLOMERATE AND SANDSTONE AT AMANKWA NEW FERRY SITE

Exfoliated weathered conglomerate and sandstone

Eroded conglomerates showing subrounded to sub angular pebble and gravel clasts in sandstone matrix, tillite formation?

Weathered interbedded ill-sorted sandy pebble and gravel deposits with wedges of silty to coarse grained sandstone.

Exfoliated blocks of conglomerate have slide down the weathered rock face to rest upon an accumulated weathered orange clayey ferrecrete deposit at right.

Capped exploration Bh No.2 at Tease and pumping APDO Bh.

Diver system located in borehole at end of nylon rope set at 20m below the water table, attached to the Bh cap

Diver barometric pressure cell without end cap

Sockets for computer connection line

Diver system used for water level change recording

Sheet 2 The Diver system barometric pressure and water level change sondes as installed at the Tease Exploration Bh No. 2.

Some problems have been experienced with this equipment but it is hoped that WRI staff can complete flow logging at these boreholes and undertake similar suites of logs in two 120 m deep boreholes reported to have been drilled, by Parkman?, into shale formations within the south-west of the Afram Plains.

Notes: - water struck/flow zones can be well correlated with weathered zones indicated by calliper log enlargements, usually occurring at lithological boundaries. Additional interpretation of the results will be undertaken when the data are available in digital 'Viewlog' format.

3.4 ADDITIONAL PRODUCTION BOREHOLE DRILLING DATA

Geophysical survey and summary borehole lithology, construction and test data from production boreholes drilled by Technic-Eau during April-May 2001 were obtained in report form (Technic-Eau, 2001). Unit drilling costs for these production boreholes, obtained from WaterAid, Ghana are presented in Appendix 7.

Notes: Additional data are available in report form but some of the site locations on sketch maps are dubious.

WaterAid and APDO were requested to obtain data from production boreholes drilled for them by Geomechanic in 2000. APDO reported that up to 8 additional boreholes were drilled in the Afram Plains funded by GTZ and UNDP. Of these, four UNDP funded boreholes were drilled by Parkman (Nigeria) using cable-tool percussion rigs. Repeated requests for information from these boreholes to the organisations concerns have so far been without success.

4 Future studies

A proposal for a short term, three week, visit by a BGS hydrogeologist to include the following elements will be presented to DFID for funding by WaterAid and the Afram Plains Development Organisation, possibly under the Resource Centre Scheme:

- The acquisition of geological and hydrogeological data from two deep boreholes planned to be drilled by WaterAid in the difficult western Afram Plains area during June 2002. Information obtained from these boreholes would impact upon future borehole drilling programmes not only in that area but also in the Oku area to the west and other parts of the Voltaian Basin underlain by similar low permeability sandstone aquifers.
- Four sets of rock chip samples from production boreholes drilled as part of the 2001 drilling programme await logging at the APDO office. These could be used to demonstrate rock chip logging techniques to Geological Survey and WRI field staff as well as University Students. This would ensure local logging capacity for future drilling programmes, these staff inputs being paid for by WaterAid under short-term consultancy arrangements.
- The APDO are to request further presentation of project results to members of the district government in the Afram Plains to ensure enhanced collection of geological and hydrogeological data from drilling groups, other Aid organisations such as UNDP and GTZ, and local NGOs active within the Afram Plains. Mr Modok (of APDO) and WaterAid are anxious that adequate data are collected from a planned drilling programme to be financed by the World Bank in the Afram Plains. WaterAid suggest that similar presentations to their partner NGOs elsewhere in Ghana and in particular to World Vision in the north of Ghana would be beneficial. WaterAid plan to work in partnership with the Conrad Hilton Foundation and World Vision International in that area where WVI have just drilled 20 boreholes of which 17 were dry. Perhaps their planned 100 borehole-drilling programme would benefit from application of the methods advocated by BGS.

References

TECHNIC-EAU DRILLING, 2001. Borehole construction in the Afram Plains District, Eastern Region, Work Report, June 2001. Prepared for the Afram Plains Development Organisation (APDO), funded by WaterAid (Ghana).

Appendix 1 Itinerary

16th March

Departed from London (Heathrow) at 13:40 on flight BA081 to Accra, Ghana where arrived at 19:30.

17th March

Met with WaterAid country rep Gordon Mumbo who had just arrived back from Nigeria where he had visited the WaterAid office now located in Jos. He reported that in Ghana DFID have now moved away from the water sector, with reduced funding of WaterAid activities. Desmond Woode is still in post but difficult to get hold of. Amanda, who used to work with Bob Blakelock, should be moving from DFID London to set up an office in the BHC in Ghana during the next 6 months. Mumbo still wants to drill two deep 120m+ holes in the western Afram Plains during April-May this year. Discussed the contents of project report on the Afram Plains and the accompanying database on CD. Contacted Kurt Klitten of DANIDA at the Danish Embassy who suggested a meeting at his office at 9:00 on Tuesday. He reported that some geophysical logging of the exploration boreholes has been done and a water level monitoring system has been established. Gave a copy of the groundwater in SSA report, draft manual of methods and CD to Mumbo.

18th March

To the WaterAid office to sort slides and reconfirm return air ticket. Mumbo advised that I should visit the APDO in the Afram Plains to present the project results. To the Ghana Geological Survey where met with the acting director Mr Philip Amoako and Dr Feiko Kalsbeek his advisor from GEUS. Discussed the proposed EU funded mapping project with them. There had been a mix up over the co-ordinates of the proposed areas. As soon as they have informed the EU of the updated co-ordinates they will inform BGS by e-mail. The area will not include the Voltaian basin as this is not seen as a priority area – no gold. We discussed photographs of typical exposures of the component units of the Voltaian sequence, which were considered to be representative. We also discussed other geological borehole data held on the Afram Plains database CD and the results of the KAR project as a whole. Left a copy of the CD with them that holds the project reports and database. Ordered two replacement geology maps of parts of northern Ghana.

19th March

Created three database/project report CDs. With Mumbo to the Danish Embassy at 8:45 for a meeting attended by Mr Peiter van Dongen (Water Commission), Mr Enoch Asare (Water Research Institute), Mr Philip Darko (Water Research Institute), Dr Bruce Baneoeng-Yakubo (Geology Dept, University of Ghana), Mr Evans Asmenu (Geology Dept, University of Ghana), Mr Kurt Klitten (Co-ordinator, DANIDA Water Sector Development Programme) and Mr Gordon Mumbo (WaterAid Ghana). The results of BGS studies in the Afram Plains were presented with reference to project reports and database. Copies of the CD containg the reports and database were presented to Mr van Dongen, Mr Asare and Dr Baneoeng-Yakubo. Mr Asare presented the initial water level monitoring results following installation of 'diver' systems at the 5 exploration boreholes. Mr Klitten described the results of the geophysical wireline logging of the exploration boreholes. The meeting ended at 11:00. Arrangements were made for me to accompany Enoch to the Afram Plains on Thursday/Friday when he would check the condition of 2 of the 5 Diver systems. To the WaterAid office where photocopied the final Technic-Eau report presented to WaterAid including geophysical surveys and drilling results from boreholes installed during April-May 2001. Noted that Kurt Klitten would like the EU mapping project to include some of the Voltaian Basin. His successor in post should be a specialist in water supply currently in Uganda.

20th March

To Legon campus of University of Ghana where visited the Geology Department. Discussed the content of the BGS project reports and database in detail with Dr Baneoeng Yakubo and his MSc students Evans Asmenu and Vincent. Also discussed the results of the university's geophysical survey work in the Afram Plains and the interpretation of test pumping data. The WaterAid driver brought several boxes of drilling rock chip samples apparently from exploration Bh 5. These were logged but turned out to be from Test Borehole 1 at Samanhyia. A few samples from exploration Bh 5 collected by Evans at major lithological change zones, when the borehole was being drilled, were also logged. They have Arcview 3.2 on their computing system. At the WaterAid office Modok, the head of the APDO, and discussed the proposed visit to the Afram Plains.

21st March

Departed from Accra at 4:30 am. With Mr Enoch Asare of the Water Research Institute in their DANIDA supplied vehicle for the Afram Plains on the understanding that I covered the cost of fuel, ferries, tolls and the driver's per diem. Drove to Kpando where caught the 8:00 ferry across the Volta lake. Arrived at the APDO offices in Tease at 11:00 where met with Modok and Alima, his deputy, with who discussed the results of the KAR project. Passed onto them paper copies of project reports, several copies of the laminated A4 hydrogeological potential map of the Afram Plains and summary table, and a CD with reports and database. The last were transferred to the APDO office PC so that the staff could practice accessing the data and digital photograph files. Enoch travelled on the Gazeri Camp to download the 'Diver' system data from the exploration borehole there. Modok informed me that GTZ and UNDP had both financed the drilling of 4 boreholes each in the Afram Plains during the past year. Unfortunately no data have been forthcoming from any of the boreholes. The UNDP boreholes were drilled using cable tool percussion rigs brought into the country from Nigeria by Parkman. Poor results were apparently obtained. During the afternoon logged the first 109 m of chip samples from exploration Bh 5. The samples from 8 production boreholes drilled last year by Technic Eau are also stored at the APDO office –of these four sets of samples are still to be logged.

22nd March

Drove from Donkorkrom to Tease where logged the remainder of the samples from exploration Bh 5. Went through the results of the project in detail with Carlos, who had acted as counterpart to the BGS team during the 2001 fieldwork programme. Supplied him with replacement batteries for two GPS systems and the dippers supplied by the project. Stressed the need for accurate location all villages, boreholes and social institutions such as schools, clinics and schools. The basis of such a baseline study is already on the CD but the spelling of the village names and their field locations need to be checked and the populations of the villages estimated and recorded. Showed him what data were available and where the gaps in the database are present. Also demonstrated the hypertext links between the report and the database. At the APDO morning staff meeting, presented the KAR project results to the other staff members present. In this way the deputy project manager Alima received the message three times and Carlos twice so hopefully a fair bit of what I was trying to put over was taken in. Modok is anxious that the importance of data collection and dissemination of informed data and analyses down to the communities and upwards to the institutions for planning should be further demonstrated to all involved. I stressed that the flow of information and data must be a two way affair even if Enoch from the Water Research Institute thought that the proposed process was ambitious, but I stressed that all those involved needed to be interested if the process was to work. Enoch demonstrated the use of the barometric and water level 'Diver' systems at the Tease exploration Bh 2 where they are installed. The data collected was transferred to the project laptop in Microsoft Excel format. Travelled back to the ferry station for the afternoon ferry to Kpando. Inspected outcrops of the cross-bedded quartzitic sandstone and Obosum conglomerate on the way as well as looking at the effects of the lowering of the lake level by several metres during the past couple of years. Caught the 17:00 hrs ferry to Kpanda where arrived at 19:00 hrs and drove back to Accra where arrived at 22:30 hrs.

23rd March

Discussed the results of my visit to the Afram Plains with Mumbo, who was in Tamale for a meeting with the Conrad Hilton Foundation. He had met with Desmond Woode (BHC) in Bolgatanga who was accompanying two visiting UK MPs. Entered remainder of log of exploration Bh 5 onto laptop and started writing up back to office report. To the airport at 18:30hrs where departed at 22:20hrs on flight BA078 to London Heathrow.

24th March

Arrived at London (Heathrow) at 05:15 hrs from where travelled to Oxford.

Appendix 2 Contacts

Afram Plains Development Organisation, Donkorkrom and Tease.
Mr A Y O Modoc, Project Manager APDO, Donkorkrom office tel/FAX No. 0848 22029, Tease office tel: 0803 610316, home tel 0848 22078
Alima, Deputy Project Manager, APDO
Mr Carlos Kuranteng, Senior Technical Supervisor APDO
Richard Detsa-Akornor, Technical Supervisor, APDO

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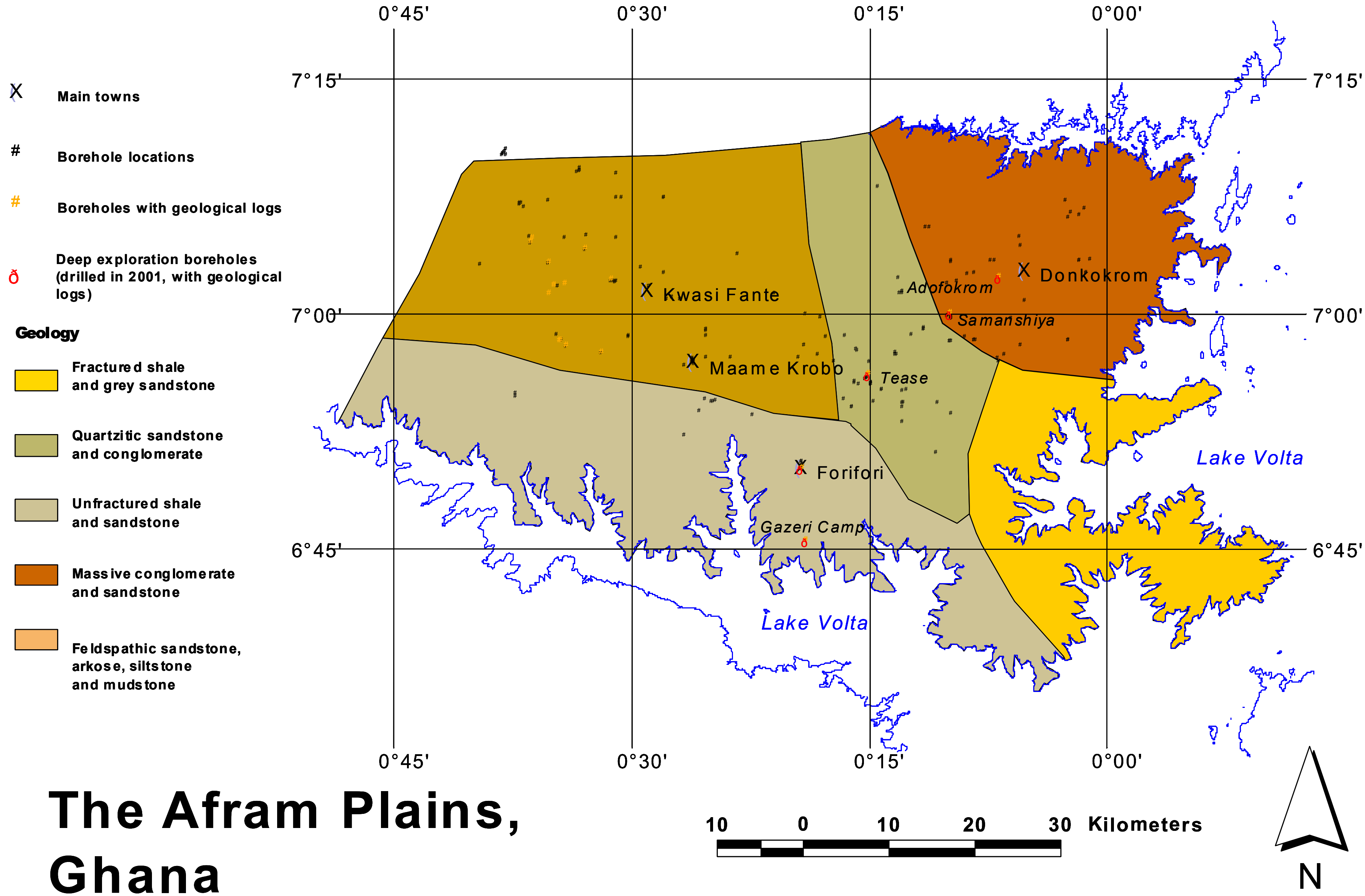
Appendix 3 Hydrogeological Map of the Afram Plains and summary table.



The Afram Plains, Ghana

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

WaterAid

DFID Department for International Development

	Description of rock/ hydrogeology unit	Groundwater targets	Ground-water potential	Groundwater quality	Field techniques	Technology	Comments
Obosum Beds –Upper Voltaian System	Massive conglomerate and sandstone.	Weathered zones and fracture zones Success rate ~66% wet 38% ≥ 30 l/min	**	Good. Presence of NO_3.N and NH_4 indicates of pollution in heavily used village centre Bhs.	Weathered conglomerate gravel often visible at surface: **EM34** – used to locate fractures and sandstones/conglomerate near surface. **VES** - depth of weathering	Boreholes 60-100 m.	Good recharge, best sites located in valleys, boreholes should be drilled to below present day lake level. May be able to induce flow from the lake along fracture zones. Problems with pollution with Bhs in villages.
	Quartzitic sandstone and conglomerate.	Weathered zones and fracture zones Success rate ~67% wet 40% ≥ 30 l/min	**	Good	Quartzitic sands often visible at surface.. **EM34** – used to locate fractures and sandstones/conglomerate near surface. **VES** - depth of weathering	Boreholes 100-150m.	Moderate recharge, best sites located in valleys, boreholes should be drilled to below present day lake level. May be able to induce flow from the lake along fracture zones. Problems with pollution with Bhs in villages.
	Feldspathic sandstone, arkose, siltstone and mudstone.	Weathered zones and fracture zones Success rate ~66% wet 39% ≥ 30 l/min	*/**	Good.	Weathered purple brown sandstone platform surface beneath thin ferrecrete. Difficult to identify fractures with **EM34,** sandstones have been recemented to 60m. **VES** - depth of weathering	Boreholes 100-150m	Very poor recharge potential due to recemented layer down to ~60m. Deep holes may intercept weathered zones. Remoteness precludes direct recharge from lake along fractures. Fractures poorly defined.
	Unfractured shale and grey sandstone	Weathered zones and fracture zones Success rate ~50% wet 14% ≥ 30 l/min	*	Poor to saline.	Low lying low altitude lake side areas. **EM34** – moderate to high conductivities, used to locate fracture zones **VES** - depth of weathering	Boreholes – 50-100 m.	Poor to moderate recharge to tight formation except where conglomeratic bands area present. boreholes should be drilled to below present day lake level.
	Fractured shale and sandstone	Weathered zones and fracture zones Success rate Unknown due to lack of data	*?	Poor to saline?	Low lying low altitude lake side areas. **EM34** – moderate to high conductivities, used to locate fracture zones **VES** - depth of weathering	Boreholes – 50-100 m	Unknown

KEY	**Groundwater potential:** *** Low** **** Moderate** ***** High**	**Note:** Groundwater Potential is an overall function of groundwater storage, groundwater yield and groundwater residence time (length of time groundwater remains in the unit, i.e. rate of groundwater throughflow). It indicates both the available yields and the length of time these are available for: i.e. high, moderate or low yields, available only during the wet season & immediately afterwards, or year-round. See Comments column for more detail.	EM34 conductivity response: High > 50 mmhos/m Moderate 20 – 50 mmhos/m Low < 20 mmhos/m	Yield: High > 1 l/s Moderate ~ 0.5 l/s Low < 0.2 l/s

Note: *Where groundwater residence times are long, groundwater availability is likely to be less vulnerable to variations in seasonal rainfall – e.g. one year of drought. Where few data are available locally, the interpretations given here are preliminary, and should be updated as new data are provided by continuing groundwater development work.*

GROUNDWATER POTENTIAL IN THE AFRAM PLAINS AREA, EASTERN REGION, GHANA

For any site of interest in the area, use the map overleaf to identify the rock units in which groundwater may be found at that site. Use the table to see an overview of the groundwater potential of these rock units, including any water quality indicators, and an indication of field techniques which can be used to increase the likelihood of finding a suitable groundwater supply.

Appendix 4 Lithological Log of Exploration Borehole No.5

Borehole No.	Exploration Borehole No 5
Location	Adufokrom, Afram Plains
Latitude	N 07°02.297
Longitude	W00°06.816
Date started	20/05/2001
Date completed	22/05/2001
Altitude	about 575 ft amsl (175.3m) – about 325ft (99.06m) above lake level

SUMMARY LITHOLOGICAL LOG

Depth(m) From	To	
0	2	Sandy silt top soil
2	3	Clay and silt
3	4	Weathered conglomerate with kaolin clay
4	15	Weathered conglomerate
15	20	Coarse-grained sandstone and gravel
20	24	Conglomerate with sandstone
24	27	Coarse-grained sandstone with gravel
27	29	Conglomerate with sandstone
29	36	Coarse-grained sandstone and gravel
36	42	Conglomerate and sandstone
42	50	Coarse-grained sandstone
50	65	Conglomerate
65	67	Medium to coarse sandstone and gravel
67	78	Medium to coarse-grained sandstone
78	86	Conglomerate
86	96	Coarse-grained sandstone and gravel
96	101	Conglomerate
101	112	Coarse sandstone and gravel
112	117	Conglomerate
117	122	Coarse-grained sandstone and gravel
122	130	Conglomerate
130	134	Coarse-grained sandstone with gravel
134	136	Conglomerate
136	140	Coarse-grained sandstone and gravel
140	145	Conglomerate
145	148	Coarse to medium grained sandstone
148	153	Conglomerate

COMMENTS ON WATER PRODUCTION ZONES

First water struck – small amount (41 l/m) in weathered zone at 7-8m

Flow rate diminished with depth to 18 l/min at 43m

Additional flows from fractures at 67-68m (92 l/min) and at 76-77m (200 l/min) in medium sandstone.

Flow diminished within underlying conglomerate to 120 l/min.

Flow from below 99m at level of Volta Lake, therefore increased flow (400 l/min) at 116m probably due to inflow of lake water

Presence of pyrite at 94-95m and 140-142m due to reducing conditions below former base flow level.

DETAILED LITHOLOGICAL LOG

Depth(m)

From	To	
Sandy silt top soil		
0.0	1.0	Ochre brown sandy silty soil
1.0	2.0	Light brown clayey sandy soil
Clay and silt		
2.0	3.0	Yellow, white and light brown grey clayey silt
Weathered conglomerate with kaolin clay		
3.0	4.0	Light brown clayey angular quartzitic gravels of dark brown silcrete fragments, some white kaolin clay
Weathered conglomerate		
4.0	5.0	Very weathered quartzitic pebbly conglomerate
5.0	6.0	Greenish grey, orange red and brown quartzitic gravels
6.0	7.0	Orange and brown rounded pebble fragments, very weathered conglomerate
7.0	8.0	Light grey brown gravel and pebble fragments and some micaceous gneiss, weathered conglomerate *Fracture 7-8m*
8.0	9.0	Greenish grey, orange and white weathered rounded gravels
9.0	10.0	Dark grey, pink and brown coarse-grained sandstone and gravels
10.0	11.0	Greyish pink coarse-grained sandstone, very weathered with rounded dark grey and white gravel
11.0	12.0	Orange, light grey and brown fractured pebbles and gravels, weathered conglomerate
12.0	13.0	Dark green-grey, orange and brown gravel, some pebble fragments, weathered *Flow @ 12.5m – 41 l/min*
13.0	14.0	Dark grey-green, orange and brown weathered broken gravel
14.0	15.0	Dark grey-green, white, orange and brown fragmented gravel
Coarse-grained sandstone and gravel		
15.0	16.0	Grey, pink and white weathered coarse sandstone and gravel
16.0	17.0	Grey, brown white and orange rounded gravel and weathered coarse-grained sandstone
17.0	18.0	Pink and grey weathered coarse sandstone and grey and white gravel
18.0	19.0	Greenish grey and white gravel with weathered pink brown coarse sandstone matrix *Flow @ 18.6m – 35 l/min*
19.0	20.0	Red pink and grey gravel with pink and red coarse-grained sandstone and gravel, well cemented
Conglomerate with sandstone		
20.0	21.0	White greenish-grey and yellow coarse gravel with some dark red and grey siliceous gravel and sandstone.
21.0	22.0	White, yellow and greenish-grey gravel with dark grey and pink coarse sandstone matrix
22.0	23.0	Grey and brown gravel with pink and dark grey well cemented coarse sandstone matrix
23.0	24.0	Greenish grey, white and pink gravel and coarse sand
Coarse-grained sandstone with gravel		
24.0	25.0	White and dark grey gravely coarse-grained sandstone *Flow @ 24.7m – 30 l/min*
25.0	26.0	Dark brown grey and pink friable coarse-grained sandstone with grey and white gravel
26.0	27.0	Brown and dark grey friable sandstone with dark grey and yellow gravel
Conglomerate with sandstone		
27.0	28.0	Dark grey green and white gravel with pink brown and grey weathered coarse-grained sandstone
28.0	29.0	Off white and red grey siliceous gravel with some coarse sandstone matrix
Coarse-grained sandstone and gravel		
29.0	30.0	Brown, white and dark grey very coarse sand and gravel
30.0	31.0	Grey brown and pink coarse sandstone with grey white and dark red gravel *Flow @ 30.8m – 26 l/min*
31.0	32.0	Dark brown grey and pink silty coarse to medium grained sandstone, some gravel
32.0	33.0	Greenish grey white and brown gravel with some coarse to medium grained pink and grey sandstone
33.0	34.0	Brown, pink and grey coarse to medium silty sandstone with greenish grey white and red gravel

34.0	35.0	Brown white and greenish grey gravel with some pink and grey silty medium to coarse sandstone.
35.0	36.0	Pink and grey silty coarse-grained sandstone with white and dark grey gravel
Conglomerate and sandstone		
36.0	37.0	Pink, yellow and greenish grey gravel with pink and grey well cemented medium to coarse sandstone *Flow @ 36.9m – 23 l/min*
37.0	38.0	Pink, grey, white and grown rounded gravel with pinkish grey well cemented medium to coarse-grained sandstone
38.0	39.0	Pink, grey, white and grown rounded gravel with pinkish grey well cemented medium to coarse-grained sandstone
39.0	40.0	Dark greenish grey, brown, pink and white gravel with some pink, brown and grey medium to coarse sandstone
40.0	41.0	Dark greenish grey, brown, pink and white gravel with some pink, brown and grey medium to coarse sandstone
41.0	42.0	Brown, red and grey weathered gravel
Coarse-grained sandstone		
42.0	43.0	Brown grey and pink silty medium to coarse-grained sandstone, some quartz gravel *Flow @ 43m – 18 l/min*
43.0	44.0	Brown, grey and pink friable silty medium to coarse sandstone
44.0	45.0	Pink brown and grey friable to hard silty medium to coarse-grained sandstone
45.0	46.0	Pink brown and grey friable to hard silty medium to coarse-grained sandstone
46.0	47.0	Pink brown and grey friable to hard silty medium to coarse-grained sandstone
47.0	48.0	Pink brown and grey friable to hard silty medium to coarse-grained sandstone
48.0	49.0	Pink grey and brown coarse to medium friable sandstone, some white quartz fragments *Flow @ 49m – 18 l/min*
49.0	50.0	Pink brown and black medium to coarse-grained friable sandstone
Conglomerate		
50.0	51.0	Dark grey gravel with pink grey and brown coarse sandstone
51.0	52.0	Dark grey and brown gravel, some brown cemented pink and grey medium to coarse-grained sandstone
52.0	53.0	Grey pink and white rounded gravel
53.0	54.0	Dark grey brown and pink rounded gravel to coarse-grained sand
54.0	55.0	Dark grey brown and pink rounded gravel to coarse-grained sand
55.0	56.0	Dark grey rounded gravel with pink grey and brown very coarse to medium-grained silty sandstone *Flow @ 55.2m – 18 l/min*
56.0	57.0	Dark grey brown and pink rounded gravel
57.0	58.0	Dark grey pink white and brown rounded gravel
58.0	59.0	Dark brown grey and pink white rounded gravel
59.0	60.0	Dark greenish grey and brown grey rounded gravel
60.0	61.0	Brown and dark green grey subrounded gravel with brown silty sand matrix
61.0	62.0	Dark green grey and brown and some pink and white gravel with dark grey and pink silty coarse sand matrix *Flow @ 61.3m – 18 l/min*
62.0	63.0	Dark grey brown and pink gravel with grey brown silty medium to coarse sandstone matrix
63.0	64.0	Dark grey and white fine gravel and brown silty coarse sandstone
64.0	65.0	Grey and white rounded very coarse sandstone and fine gravel with dark brown and pink silty medium to coarse sandstone matrix
Medium to coarse sandstone and gravel		
65.0	66.0	Dark grey brown and pink silty medium to coarse sandstone with dark grey and white gravel
66.0	67.0	Light grey pink and brown silty medium to coarse sandstone with white black and brown gravel
Medium to coarse-grained sandstone		
67.0	68.0	Pink light grey silty medium to coarse sandstone *Flow @ 67.4m – 20 l/min, fracture – 67-68m, flow @ 68m – 92 l/min*
68.0	69.0	Pink light grey silty medium to coarse sandstone with dark grey and pink gravel
69.0	70.0	Pink and light grey friable to hard silty medium grained sandstone
70.0	71.0	Light grey pink silty medium grained compact sandstone
71.0	72.0	Pink brown and grey friable to hard silty medium to coarse sandstone

72.0	73.0	Pink brown and grey friable to hard silty medium to coarse sandstone
73.0	74.0	Pink light grey silty medium sandstone *Flow @ 73.5m – 92 l/min*
74.0	75.0	Light grey and pink grey hard silty medium sandstone
75.0	76.0	Pink grey hard medium to coarse silty sandstone
76.0	77.0	Pink grey hard medium to coarse silty sandstone *Fracture 76-77m*
77.0	78.0	Brown pink and grey silty coarse to medium sandstone
Conglomerate		
78.0	79.0	Brown red and grey gravel
79.0	80.0	Pink grey white and brown gravel and coarse sandstone *Flow @ 79.6m – 200 l/min*
80.0	81.0	Pink brown and grey rounded gravel with pinkish dark grey well cemented sandstone matrix
81.0	82.0	Pink grey brown and white gravel with dark brown grey silty well cemented fine grained sandstone
82.0	83.0	Pink grey and white very coarse sand and gravel
83.0	84.0	Pink grey white and brown rounded gravel and very coarse sand
84.0	85.0	Pink grey and brown coarse sand and fine gravel
85.0	86.0	Brown grey pink and white fine gravel and coarse sand *Flow @ 85.7m – 120 l/min*
Coarse-grained sandstone and gravel		
86.0	87.0	Pink and dark grey coarse sandstone with dark green grey and brown gravel
87.0	88.0	Pink and dark grey coarse sandstone with dark green grey and brown gravel
88.0	89.0	Pink and dark grey coarse sandstone with dark green grey and brown gravel
89.0	90.0	Dark green grey and brown fine gravel with pink and dark grey coarse to medium sand
90.0	91.0	Pink brown and grey silty coarse to medium sand with pink and dark green grey fine gravel
91.0	92.0	Friable brown pink and dark grey very coarse to medium grained sandstone *Flow @ 91.8m – 120 l/min*
92.0	93.0	Brown pink grey silty coarse to medium sandstone with some brown and white gravel
93.0	94.0	Brown pink grey silty coarse to medium sandstone with some brown and white gravel
94.0	95.0	Silty red and grey friable medium to coarse sandstone, some weathered orange grains, some rounded gravel grains
95.0	96.0	Pink and dark grey coarse-grained sandstone, coarse sand and gravel
Conglomerate		
96.0	97.0	Dark greenish grey and brown rounded gravel with pink brown and grey coarse sandstone
97.0	98.0	Dark greenish grey and brown rounded gravel with pink brown and grey coarse sandstone
98.0	99.0	Dark grey white and pink fine gravel and very coarse sand *Flow @ 98m – 120 l/min*
99.0	100.0	Dark green grey brown and white gravel
100.0	101.0	Pink dark grey and brown gravel with pink grey and white silty coarse sandstone
Coarse sandstone and gravel		
101.0	102.0	Dark grey pink and brown very coarse sand and gravel
102.0	103.0	Pink white and grey fractured coarse sand and gravel
103.0	104.0	Dark grey green brown pink and white very coarse sand and gravel
104.0	105.0	Dark grey green brown pink and white very coarse sand and gravel
105.0	106.0	Dark grey gravel with pink grey and white coarse sand
106.0	107.0	Pink brown grey and white coarse sand to fine gravel
107.0	108.0	Pink and dark grey coarse sandstone with brown and dark grey fine gravel
108.0	109.0	Brown pink grey and white coarse sand and fine gravel
109.0	110.0	Brown pink grey and white coarse sand and fine gravel
110.0	111.0	Dark grey pink brown and white gravels *Flow @ 110.1m – 120 l/min*
111.0	112.0	Dark grey pink brown gravel and coarse sand with dark grey and pink well cemented coarse sandstone
Conglomerate		
112.0	113.0	Brown white pink and grey rounded quartz gravel and coarse sand
113.0	114.0	Brown, red, pink, grey and white very coarse sand and rounded gravel. *Fracture 113-114m*
114.0	115.0	Dark grey, pink, brown and white gravel and very coarse sand
115.0	116.0	Brown, grey, pink and green gravel
116.0	117.0	Grey, brown and pink gravel with pink and dark grey coarse sand and gravel *Flow @ 116.2m – 400 l/min*
Coarse-grained sandstone and gravel		

117.0 118.0 Pink and grey well cemented very coarse sandstone
118.0 119.0 Pink, grey, brown and white well cemented very coarse sandstone and gravel
119.0 120.0 Pink, grey, brown and white well cemented to siliceous coarse sand and gravel
120.0 121.0 Pink, grey, brown and white well cemented to siliceous coarse sand and gravel
121.0 122.0 Pink and red grey well cemented coarse sandstone and gravel

Conglomerate
122.0 123.0 Grey red pink and brown broken gravel *Flow @ 122.3m – 400 l/min*
123.0 124.0 Grey red pink and brown broken gravel
124.0 125.0 Brown, red, grey and white silicified coarse sandstone and gravel
125.0 126.0 Pink, brown, white and grey subrounded coarse gravel
126.0 127.0 Pink, brown, white and grey subrounded coarse gravel
127.0 128.0 Pink, grey, brown and white gravels with silicified pink and dark grey coarse sand
128.0 129.0 Pink, grey, brown and white gravels with silicified pink and dark grey coarse sand *Flow @ 128.4m – 400 l/min*
129.0 130.0 Pink, grey, brown and white gravels with silicified pink and dark grey coarse sand

Coarse-grained sandstone with gravel
130.0 131.0 Grey brown and white weathered coarse sand with grey and white gravel
131.0 132.0 Brown and dark grey friable silt to coarse sandstone with some pink, dark grey and white silicified coarse sand and gravel
132.0 133.0 Grey, pink and brown gravel with some silty brown medium sand matrix
133.0 134.0 Grey, pink and brown medium to coarse sand and gravel

Conglomerate
134.0 135.0 Brown, grey, pink and white gravel and very coarse sand *Flow @ 134.5m – 400 l/min*
135.0 136.0 Grey, red and white gravel with coarse to very coarse sand.

Coarse-grained sandstone and gravel
136.0 137.0 Brown grey and red coarse sand and gravel
137.0 138.0 Grey, brown and red coarse to very coarse sand and some gravel
138.0 139.0 Pinkish dark grey very hard medium to coarse sandstone, some gravel
139.0 140.0 Brown and grey friable to hard, medium to coarse sandstone, some grey and white gravel

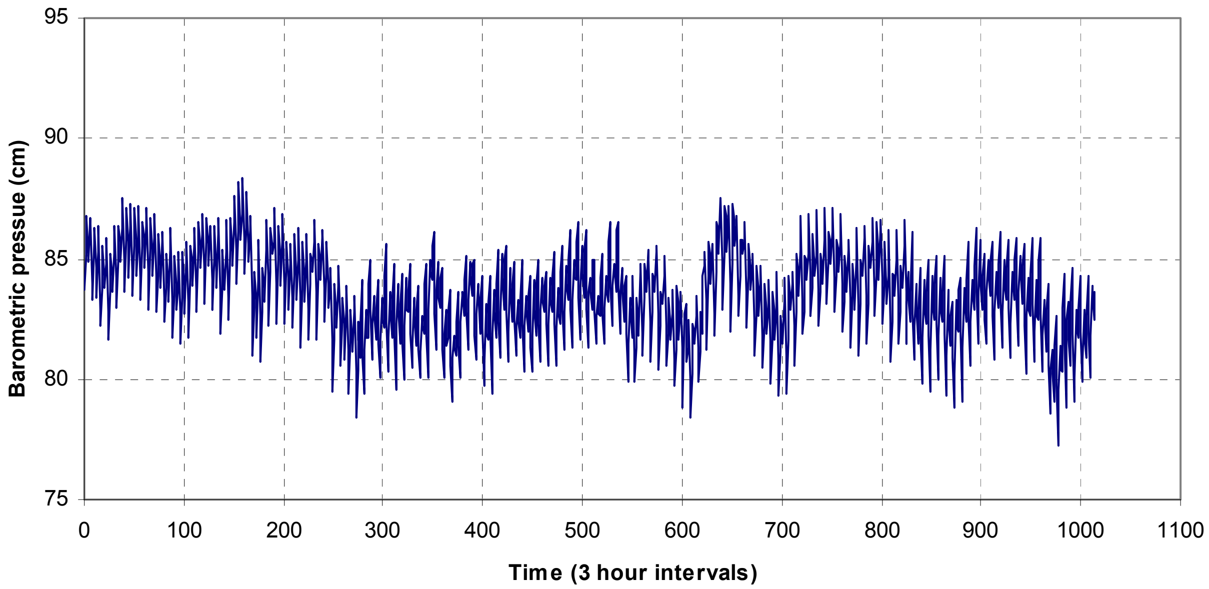
Conglomerate
140.0 141.0 Grey white and brown rounded gravel and very coarse sand *Flow @ 140.6m – 400 l/min*
141.0 142.0 Brown, pink, white and grey gravel
142.0 143.0 Brown, pink, white and grey gravel
143.0 144.0 Brown grey and white gravel with coarse sand
144.0 145.0 Brown grey and white gravel with coarse sand

Coarse to medium grained sandstone
145.0 146.0 Pink, brown and grey silicified coarse-grained sandstone
146.0 147.0 Pink, brown, grey, white and green coarse sand and gravel *Flow @146.7m – 400 l/min*
147.0 148.0 Pink, brown, grey and white coarse sandstone, some friable silty medium brown sandstone

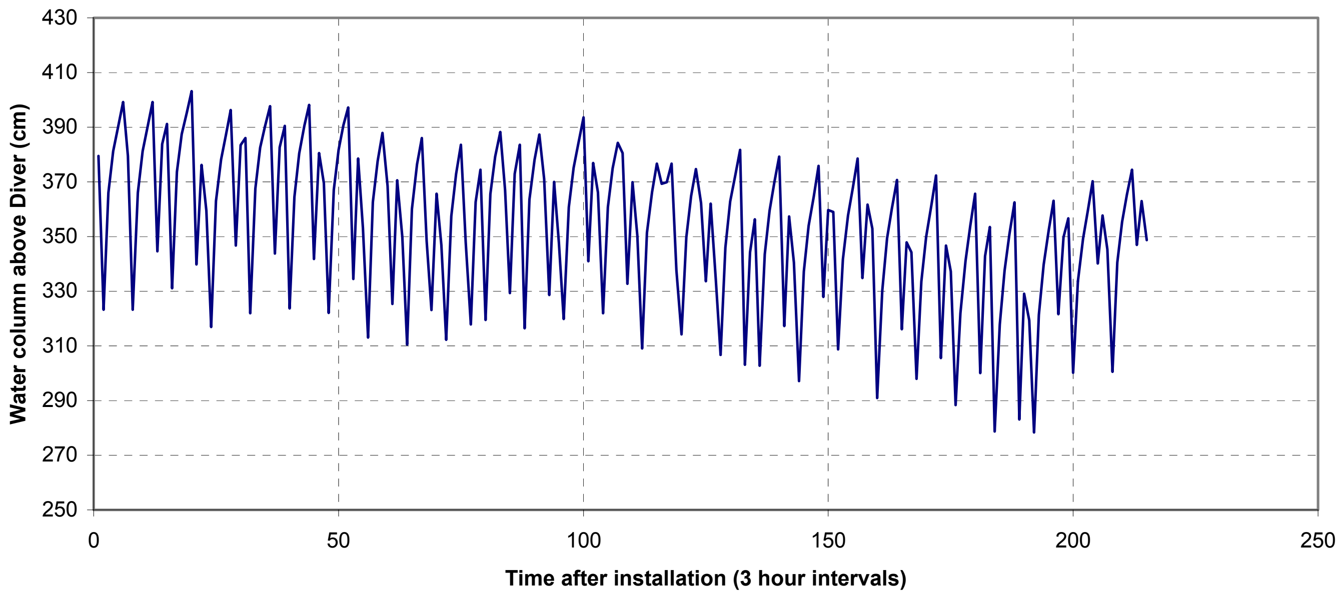
Conglomerate
148.0 149.0 Red, grey, brown and white gravel and coarse sandstone
149.0 150.0 Red, grey, brown and white gravel and coarse sandstone
150.0 151.0 Grey, brown, white and pink gravel with coarse sand
151.0 152.0 Grey, brown, white and pink gravel with coarse sand
152.0 153.0 Angular gravel fragments, reddened with some jasper *Flow @ 152.8m – 400 l/min*

Appendix 5 Water level and barometric change monitoring data

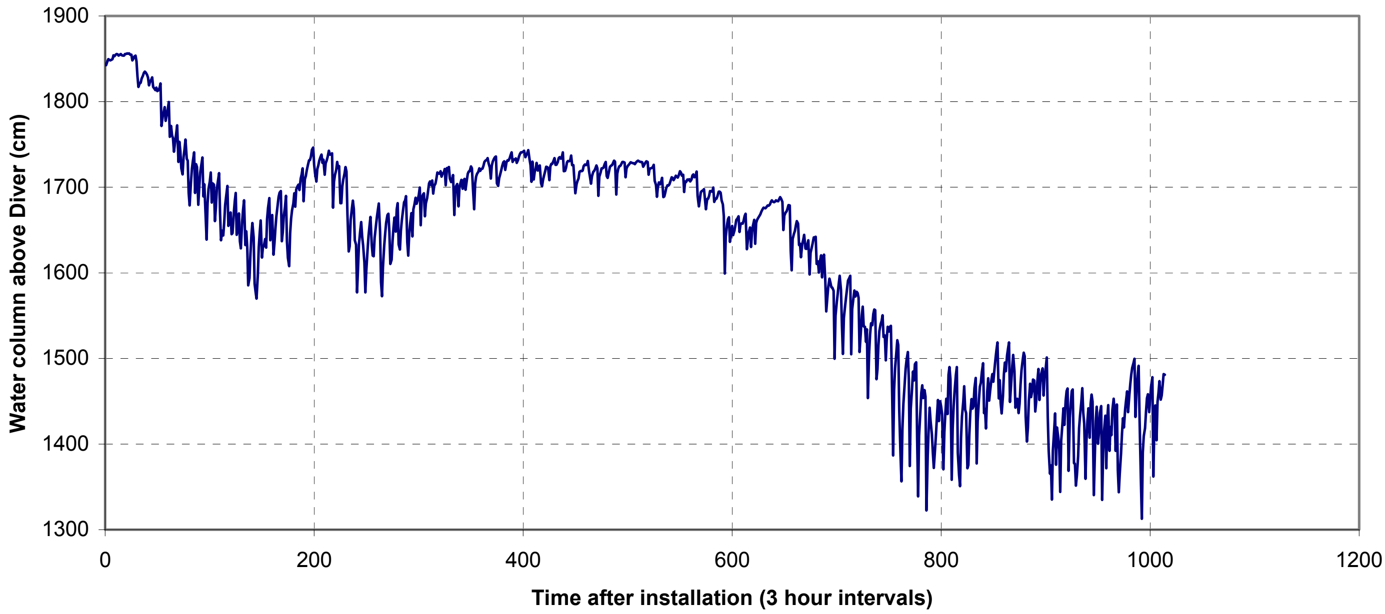
BAROMETRIC PRESSURE CHANGES AT TEASE EXPLORATION Bh 2



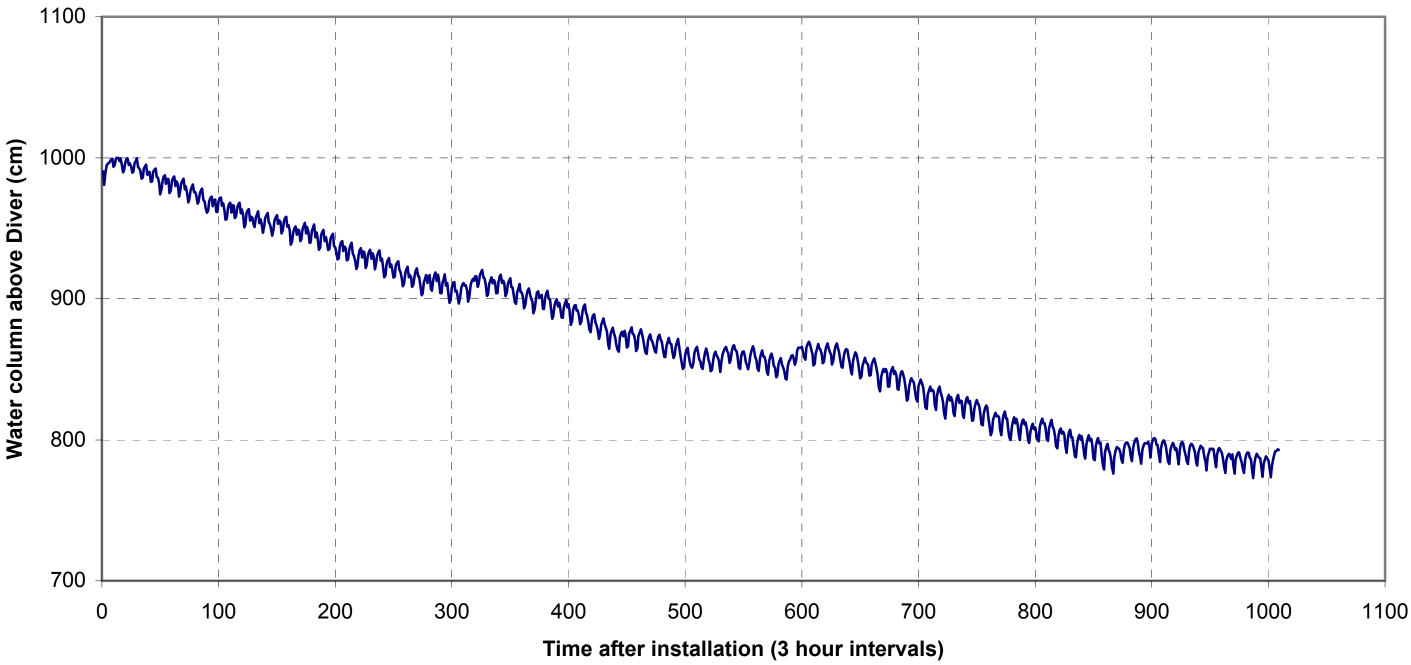
WATER LEVEL CHANGE AT SAMANHYIA (After 1/2/2002)

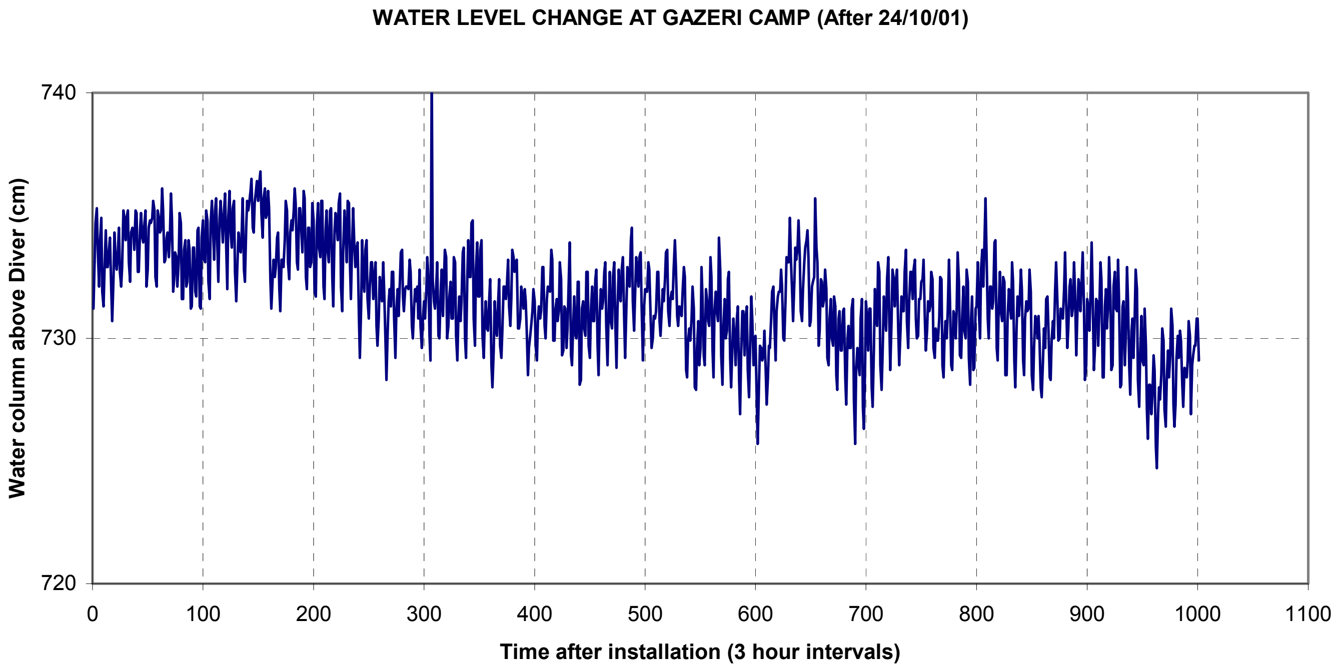


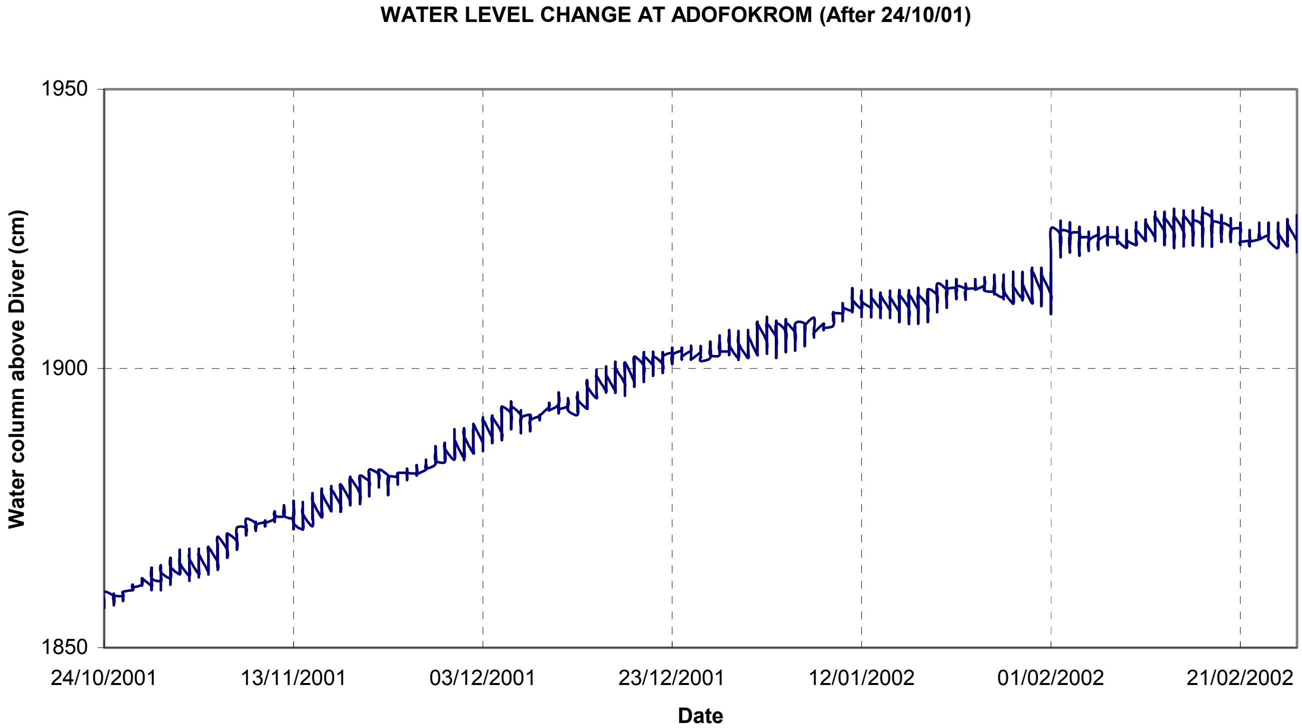
WATER LEVEL CHANGE AT TEASE (After 24/10/01)



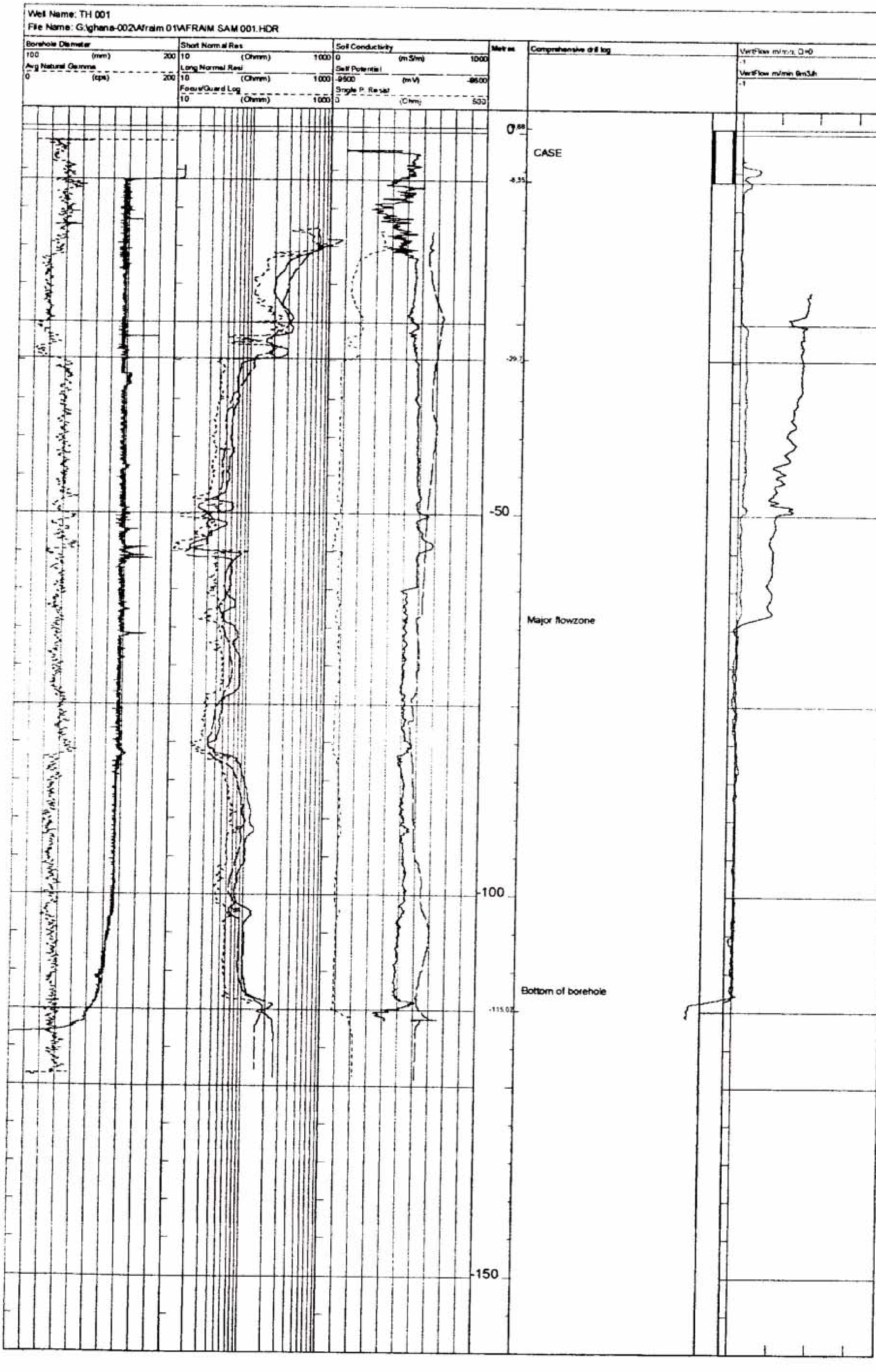
WATER LEVEL CHANGE AT FORIFORI (After 24/10/01)

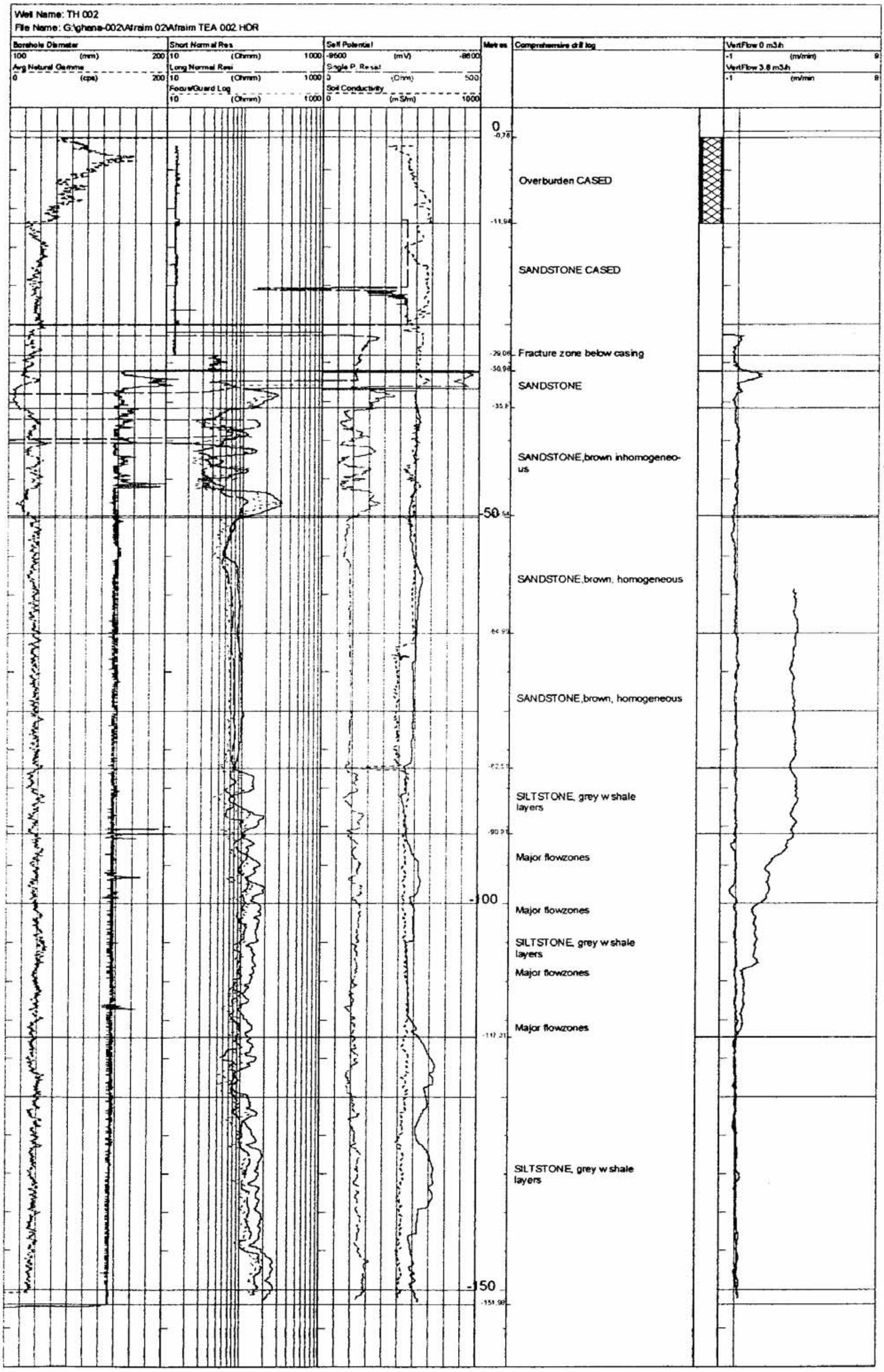



WATER LEVEL CHANGE AT GAZERI CAMP (After 24/10/01)
Water column above Diver (cm)
740
730
720
0
100
200
300
400
500
600
700
800
900
1000
1100
Time after installation (3 hour intervals)


WATER LEVEL CHANGE AT ADOFOKROM (After 24/10/01)
Water column above Diver (cm)
1950
1900
1850
24/10/2001
13/11/2001
03/12/2001
23/12/2001
12/01/2002
01/02/2002
21/02/2002
Date

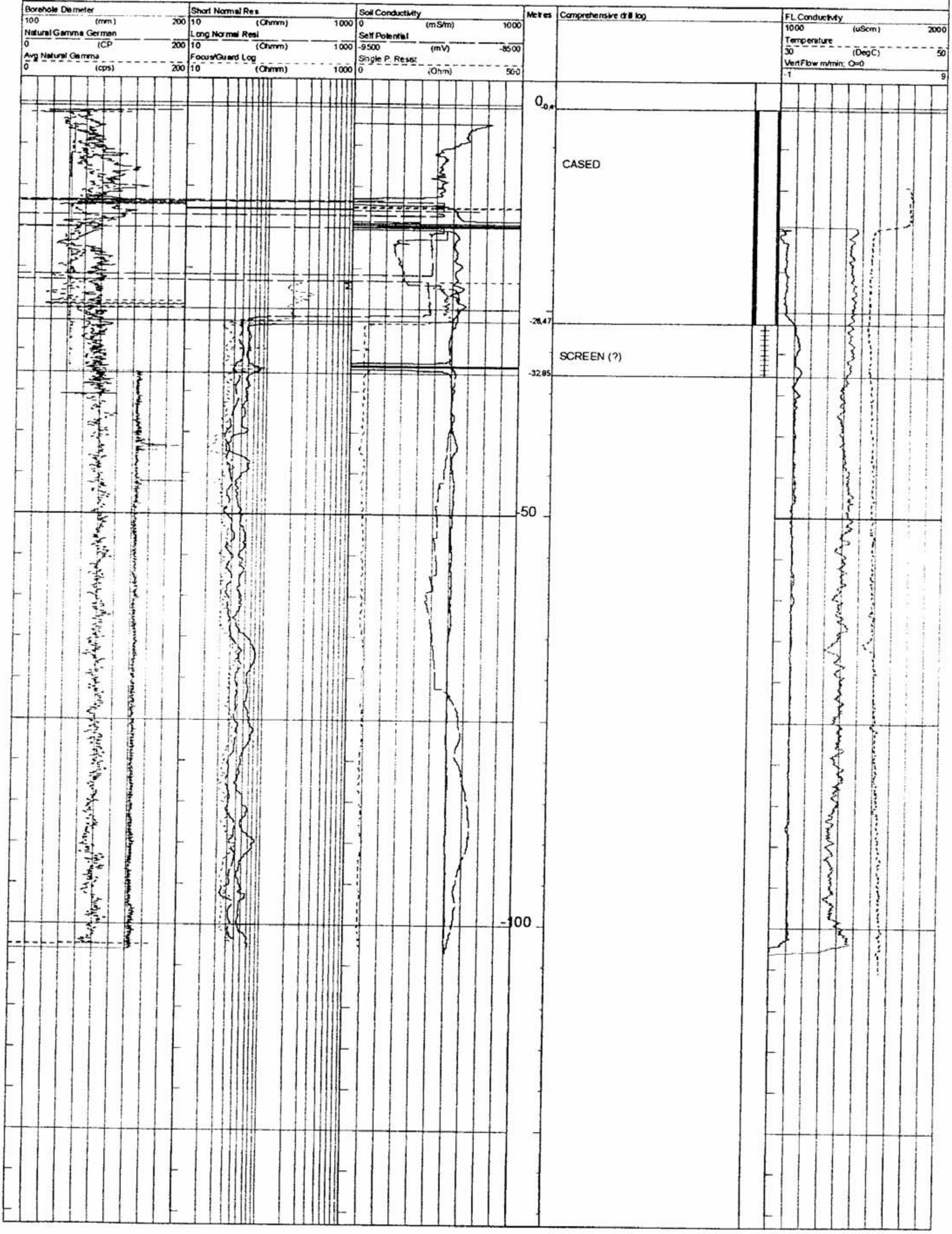
Appendix 6 Geophysical logs of exploration boreholes 1-5, Afram Plains

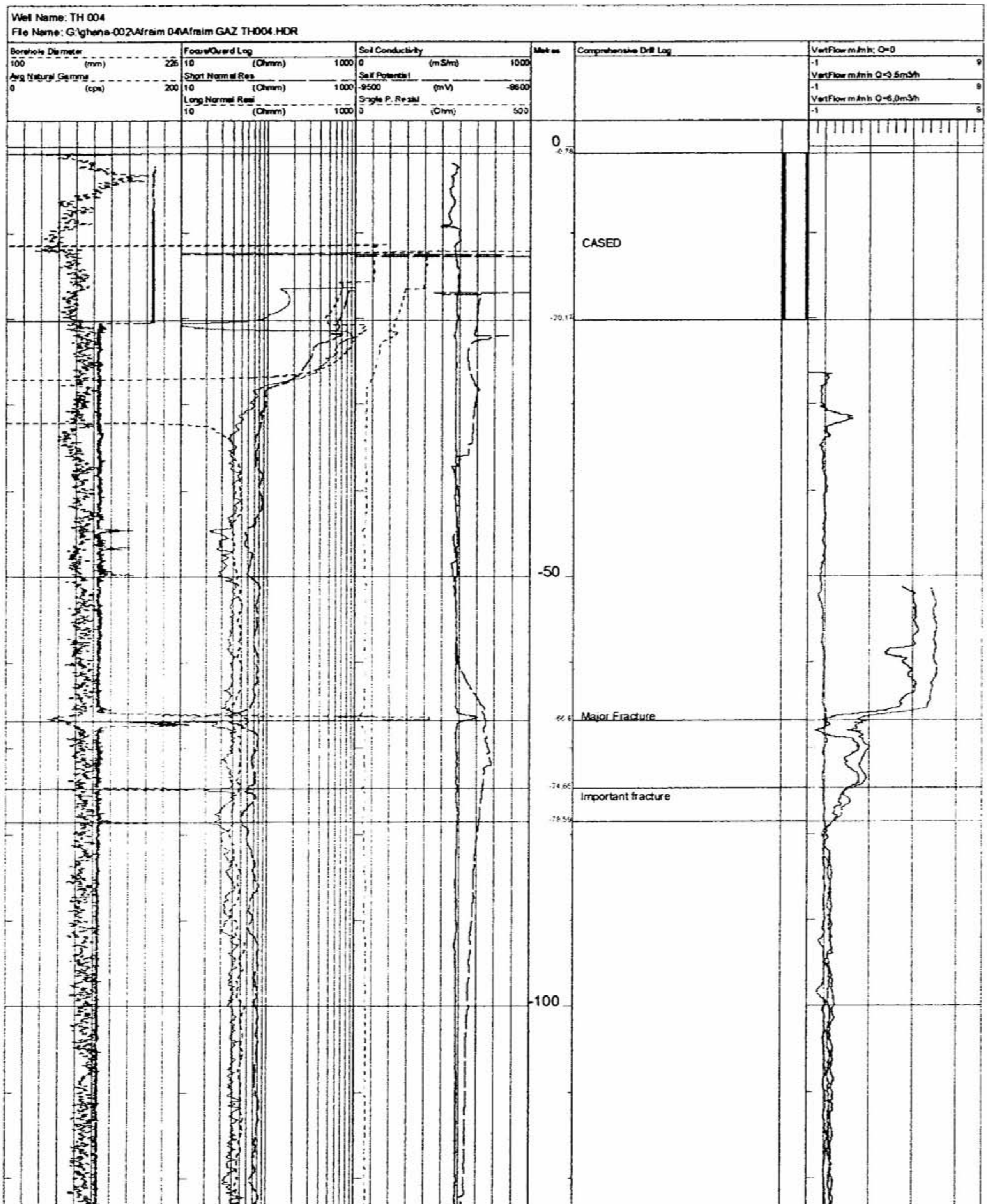

Well Name: TH 001
File Name: G:\ghana-002\Afraim 01\AFRAIM SAM 001.HDR
Borehole Diameter
100 (mm) 200
Avg Natural Gamma
0 (cps) 200
Short Normal Res
10 (Ohmm) 1000
Long Normal Resi
10 (Ohmm) 1000
Focus/Guard Log
10 (Ohmm) 1000
Soil Conductivity
0 (mS/m) 1000
Self Potential
-9500 (mV) -8600
Single P. Resist
0 (Ohm) 500
Metres
Comprehensive drill log
VertFlow m/min, Q=0
-1 19
VertFlow m/min 6m3/h
-1 19
0
0.88
CASE
-8.35
-29.7
-50
Major flowzone
-100
Bottom of borehole
-115.02
-150


Well Name: TH 002
File Name: G:\ghana-002\Afraim 02\Afraim TEA 002.HDR
Borehole Diameter
100 (mm) 200
Avg Natural Gamma
0 (cps) 200
Short Normal Res
10 (Ohmm) 1000
Long Normal Resi
10 (Ohmm) 1000
Focus/Guard Log
10 (Ohmm) 1000
Self Potential
-9500 (mV) -8600
Single P. Resist
0 (Ohm) 500
Soil Conductivity
0 (mS/m) 1000
Metres
Comprehensive drill log
VertFlow 0 m3/h
-1 (m/min) 9
VertFlow 3.8 m3/h
-1 (m/min) 9
0
50
100
150
Overburden CASED
SANDSTONE CASED
Fracture zone below casing
SANDSTONE
SANDSTONE, brown inhomogeneous
SANDSTONE, brown, homogeneous
SANDSTONE, brown, homogeneous
SILTSTONE, grey w shale layers
Major flowzones
Major flowzones
SILTSTONE, grey w shale layers
Major flowzones
Major flowzones
SILTSTONE, grey w shale layers

Well Name: TH 003 + Adjacent well

File Name: G:\ghana-002\Afraim 03\Afraim FOR 003.HDR

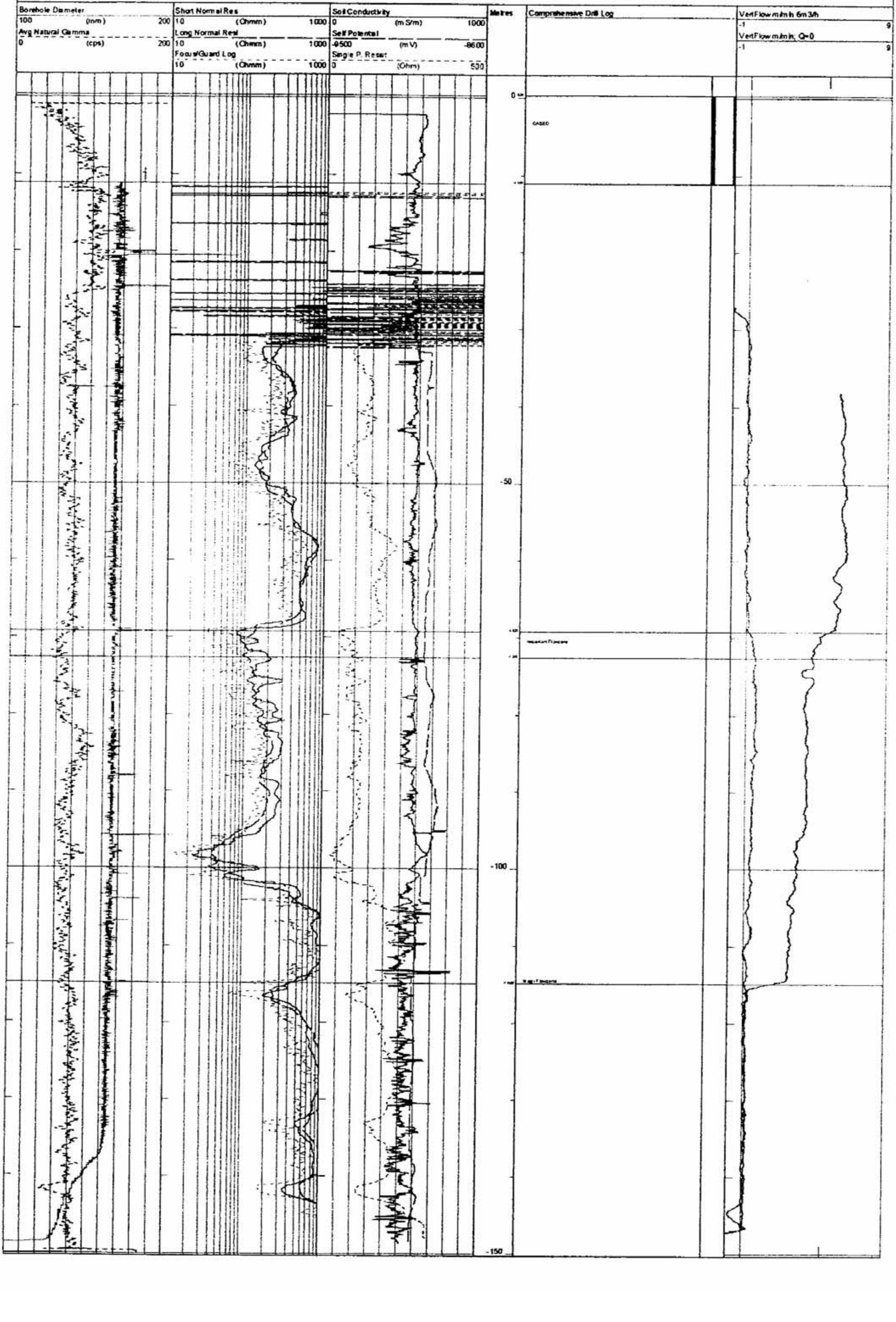




Well Name: TH 004
File Name: G:\ghana-002\Afraim 04\Afraim GAZ TH004.HDR
Borehole Diameter
100 (mm) 226
Avg Natural Gamma
0 (cps) 200
Focus/Guard Log
10 (Ohmm) 1000
Short Normal Res
10 (Ohmm) 1000
Long Normal Resi
10 (Ohmm) 1000
Soil Conductivity
0 (mS/m) 1000
Self Potential
-9500 (mV) -8600
Single P. Resist
0 (Ohm) 500
Metres
Comprehensive Drill Log
VertFlow m/min; Q=0
-1 9
VertFlow m/min Q=3.5m3/h
-1 9
VertFlow m/min Q=6,0m3/h
-1 9
0
-50
-100
-150
CASED
Major Fracture
Important fracture

Well Name: TH 005

File Name: G:\ghana-002\Afraim05\Afraim ADO TH005.HDR



Appendix 7 Unit drilling costs for boreholes drilled for wateraid (Ghana) by Technic-Eau during 2001

Financial Proposal for Drilled Boreholes
Example for a 60m borehole, Afram Plains
Bill of Quantity

Item	Description	Unit	Quantity	Unit price US$	Total US$
1	**Mobilisation**				
1a	Mobilisation and move to first site	1	1	1000	
2	**Moves**				
2a	Travel between sites and set up	U	1	375	375
3	**Drilling and Equipment**				
3a	Drilling air (soft, diameter 95/8 inch)	m	20	47	940
3b	Drilling (hard, diamter 61/2 inch)	m	40	50	2000
3c	Protection PVC casing 180/200mm	m	0	25	0
3d	PVC plain pipes 126/140mm	m	48	13.5	648
3e	PVC screen pipes 126/140 mm	m	12	15.5	188
3f	Gravel pack	m	20	4.25	85
3g	Backfill	m	35	2.25	78.75
3h	Grouting	m	5	12	60
4	**Development and Borehole Testing**				
4a	Air-lift' development	Hr	3	85	255
4b	Drawdown test, 3 Hrs, 3 steps	Hr	4	80	320
4c	Recovery	Hr	3	40	120
4d	Chemical analysis	U	1	85	85
5	**Waiting of Drilling Rig**				
5a	Without operation of power	Hr	0	85	
5b	With operation of power	Hr	0	120	
6	**Concrete Pad**				
6a	Construction of apron	U	1	450	450
7	**Geophysical Surveys**				
7a	Electrical resistivity, Electromagnetic (EM)	U	0	650	
8	**Hydrofracturing**				
	Including:	U	0	1150	
	Mobilisation/demobilisation of equipment				
	Setting up of H/F unit at borehole				
	Move from one site to the next				
	Supply of water				
	H/F at first packer position				
	H/F at additional packer position				
9	**Hand Pump Provision**				
	Afridev handpump for 30m	U	0	1000	
	Afridev handpump for 35m	U	0	1125	
	Afridev handpump for 40m	U	0	1250	
	Afridev handpump for 45m	U	0	1375	
	Ghana modified MkII 45m	U	0	2775	
	Ghana modified MkII 50m	U	0	3100	
				Total	5604.8