BRITISH GEOLOGICAL SURVEY
Natural Environment Research Council

TECHNICAL REPORT WD/91/50

Hydrogeology Series

Technical Report WD/91/50

Development of Horizontal Drilling for Alluvial Aquifers of High Permeability. ODA/BGS R & D Project (91/7)
FINAL REPORT ON WORK IN ZIMBABWE

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for the Overseas
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Cover Photograph: The collector well, drilling equipment and compressor, Lupane River alluvial plain.

BRITISH GEOLOGICAL SURVEY

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1. MAIN AIMS OF WORK IN ZIMBABWE

Work for this project has taken place in Malaya, Zimbabwe and the UK and will finish in Botswana in 1991.

In Zimbabwe the work was carried out on flood land alluviums which are composed of fine to medium sized sands.

The main aims of the work in Zimbabwe were:

(a) to develop a low-cost means of dug well construction, and

(b) to further develop the so-called telescoped-jetting technique which was developed in Malaya for drilling the horizontal laterals from the base of dug wells.

A lesser aim of the project was:

(c) to investigate the potential for exploitation of alluviums by collector wells in Zimbabwe.

2. WORK DONE IN ZIMBABWE

2.1 The Occurrence of Alluvial Aquifers in Zimbabwe

Owen (1989) gives a distribution of alluvium in Zimbabwe. He identifies three main types: Mature River Alluvium (occurs in south-east and south lowveld areas), Scarp Alluvium (at base of scarps, Zambesi escarpment, foot of Mafungabusi plateau and Sabi valley) and Kalahari Sand Alluvium (north-west). Work for this BGS project was carried out on two flood plains of Mature Alluvium and Kalahari Alluvium. These flood plain deposits are widespread and can border narrower, coarser river channel deposits, otherwise named wadis. For various reasons, work in Zimbabwe did not include construction and drilling on the seasonally flooded river channel sands.

2.1.1 River channel sands

In Zimbabwe, Owen (1989, page 36) has shown that the permeability of river channel deposits can be high, in Kalahari Sands 20 to 30 m/d, and in Mature River Alluviums 40 to 60 m/d. These channel deposits will yield a great deal of water and construction of dug wells in them will consequently need heavy dewatering pumping capacity, construction will be more difficult and protection works against seasonal flooding will be required. Consequently, the rate of pumping could be huge but construction works will be expensive. There are places in Zimbabwe, the south and south-west borders (the Sashe and Limpopo rivers), where the river channel deposits can be exploited cheaply by constructing collector wells sited above the river channels on the river banks, thus avoiding the dug well construction difficulties mentioned above. This type of construction has, for reasons of logistics and chance, been chosen to be investigated in Botswana and will be reported in a companion volume.

2.2 Makusia School Well, River Lundi, Southern Lowveld

A dug well was sunk at Makusia School which is on the flood plain of the Lundi River and which was identified as an alluvial aquifer by Owen (1989, page 51, Appendices). The relevant map is reproduced as Fig. 1 and the alluvium is identified on it as Area 2. The map is at a scale of 1:250,000. The river channel is seasonally flooded and is between 10 to 20 m below the flood plain on which the BGS well was sited. It is estimated the extent of the plain and river channel were 3020 ha and 1185 ha respectively. Several villages, all water short, are located on the flood plain.

SUMMARY

Two dug-wells were constructed; one was in the Mature Alluvium deposits in southern Zimbabwe on the south bank of the Lundi River and the other was in a flood plain of a small river, crossing the edge of the Kalahari Sand in the north-west of Zimbabwe, near Lupane. The dug wells were easy to construct. In both cases the fine sand deposits meant there was little inflow to the well, the walls did not collapse during digging and so expensive dewatering pumping was not required. Local low-cost hand dug well techniques can be used to exploit these shallow aquifers.

Recommendations are given in the report for the optimum development of the alluvial plains. Fig. 8 summarises the recommendations.

At the dug well constructed in the north-west, collectors were successfully drilled out from the 2 m diameter shaft into the alluvium. Two-inch diameter screen was jetted through 4" diameter temporary casing which had previously been rotary drilled out to 10 m. Thirty metre long adits were shown to be possible using this telescoped-jetting technique.

Further work will be done in Botswana to investigate the exploitation of River Channel alluviums by collector wells sited on the Channel banks and above flood level.

2.2.1 Drilling and Pumping Test Results at Makusia School

Fig. 2 is a sketch map, not to scale, which shows the relative locations of the river channel, Makusia school, an existing 6" diameter borehole with Bush pump, Owens well (unlined and used for a garden), the BGS dug well and the BGS exploratory boreholes BH1, 2 and 3. Hydrogeochemical data are presented in Tables 1 and 2 for the Bush pump and BH3. The BGS dug well was 2 m in diameter, 16 m deep (to basalt) and had a rest water level of 14.5 m. The well was constructed using Armco lining. The lining was built up at the surface in 1 m lengths and lowered gradually by manually underdigging it. The costs of the well are given in Appendix A. Unexpectedly the walls of the unlined hole dug did not collapse, even below the water table and so digging was relatively easy. Also, the only significant water flow encountered came into the well via a coarse bouldery layer, about 0.75 m thick, just at the base of the finished well and just above the base of the basalt bedrock.

The exploratory drilling carried out by rotary methods at this site and reported by both Owen and BGS, did not identify this layer, however, inspection of the records suggests this is a widespread phenomenon in the plain and it is typical of such alluvial plain deposits.

Pumping Tests on Dug Well:

Several pumping tests were carried out on the exploratory boreholes and the BGS dug well. The following result for the test on the dug well run on 22/10/89 was typical. The dug well was pumped for 20 minutes at 0.26 m^3/min and the drawdown observed in metres is plotted on Fig. 3. Software described by Barker (1989) was used to interpret the test and gave the following results:

		Transmissivity (m^2/d)	Storage Coefficient
Best values		80	0.04
50% confidence limits	MIN	65	0.02
	MAX	95	0.07

There was no indication the aquifer was leaky and the same software was used to plot out the drawdown for the test above using analytically exact theory which assumes that the flow in the aquifer is horizontal. The agreement is fairly good (see Fig. 3). Other tests gave similar results.

2.2.2 Development of Makusia School Alluvial Plain

In this situation where there is an extensive relatively permeable layer at the base of the aquifer, horizontal collectors drilled into the less permeable material will not increase the yield of dug wells significantly and it is very difficult to drill horizontally through the bouldery layer. It is clear that collector wells *per se* are not valuable in this particular alluvial plain. However, the dug well is easy and rapid to build, it gives a good yield (ca. 2 l/sec) and is not too expensive. It is interesting to have observed that since construction of the BGS dug well several locally-made 1½ m diameter dug wells have been sunk in villages close to the BGS site. It seems the BGS well at Makusia has acted as a catalyst for activity by the locals. In 1989 it was observed that one 1.3 m diameter dug well 12 m deep cost ca. Z$1000. It is clear that locally constructed dug wells are a reasonable way of exploiting this alluvial plain. Water levels should be monitored throughout a dry season to ensure there is a sustainable supply. If so, development of this aquifer could pursue apace using locally dug wells. Other hydrogeological factors posing a threat to development are (a) the coarse layer at the base of the aquifer may not be continuous and (b) if the Lundi river channel alluviums are ever overexploited, this could dry up the peripheral aquifers under the alluvial plain around Makusia School.

2.3 Ndambuleni School, Lupane River, Kalahari Sand Alluvium

A dug well 7 m deep was constructed in the flood plain of the Lupane River near to Ndambuleni School. The well's location can be found on the 1:50,000 Topo Survey Map no. 1827D$_4$ in square PK, reference: ^{6}007E, ^{79}062N. It is about a 15-minute drive on untarred roads from the town of Lupane. It is not on one of the major alluvial plains identified by Owen (1989) but is typical of smaller alluvial plains in the area.

2.3.1 Drilling and Pumping Test Results at Lupane River

Fig. 4 illustrates the results of exploratory auger drilling done on a line NE-SW cutting across the BGS dug well. The flood plain is about 300 m across. The soft sands are 9 m thick at the valley centre but thin to 0 m at the edges.

A thin layer of stones underlays the soft sands at the edges of the plain. The dug well was 7 m deep and digging was stopped when a hard consolidated sand was hit. It is possible that, like Makusia, the flood plain at the dug well is underlain by a coarse, relatively fast thin aquifer through which most of the groundwater flow would occur since the full depth of alluvium at the dug well may not have been penetrated. As at Makusia, the walls of the dug well did not collapse during digging and the only significant inflow of water occurred through the base of the dug well.

Fig. 5 is a sketch map showing the orientation of the two laterals drilled from the base of the dug well. Rotary drilling without temporary casing was not successful. The walls of the laterals stayed open but distorted sufficiently so as to not allow subsequent insertion of screen after the drill string was removed.

Lateral No. 1 was finally successfully emplaced by rotating in 10 m of 4" casing. Then 21 m of 2" slotted Demco terrascreen was jetted through the temporary casing. It is felt it would have been easy to drill to 30 m but there were difficulties with the threads of the wash pipe used inside the terrascreen. In the end, 19 m of 2" diameter screen were left in place and water flowed into the well from a half-full lateral.

Lateral No. 2 was drilled towards the centre of the plain. Again 10 m of temporary 4" diameter casing were rotated in dry. Then 15 m of 2" Demco slotted screen were jetted through the temporary casing. This time it was problems with the jetting pump that limited the jetting to 15 m. No inflow was observed from this lateral, which met only fine wet sand.

A sand sample was taken directly from the wall of one lateral. This had the following composition:

	% by weight
Coarse gravel	0
Medium gravel	0.5
Fine gravel	0.97
Coarse sand	6.66
Medium sand	34.9
Fine sand	38.8
Mud	18.5

The high mud content of the above composition suggests the sandy alluvial material comprising much of the river plain will have a permeability of 1 m/day or less.

Pumping Tests:

Several pumping tests were carried out on the large diameter well dug by BGS.

A small drawdown test of 17 minutes duration was carried out on 10 May 1991. The well was pumped at two different rates: 0.047 m^3/min for 15 minutes and then at 0.360 m^3/min until 17 minutes had elapsed. The recovery was followed for 450 minutes. The water table was initially 2.76 m below the well surround, about 2.36 m below ground level. The change in drawdown observed (in metres) during the test is plotted on Fig. 6. Software described by Barker (1989) was again used to interpret the test and gave the following results:

		Transmissivity (m^2/d)	Storage Coefficient
Best values		3.7	0.005
50% confidence limits	MIN	2.2	0.0004
	MAX	6.5	0.05

The fit found is an excellent one. Fig. 6 shows the comparison between the drawdowns calculated theoretically using the above hydraulic parameters and those observed in the test. It seems reasonable to assume the aquifer is unconfined and has a low transmissivity value. The test described was designed to have small drawdowns in the well, thus, allowing the analytical technique used by Barker (1989) to apply, even to unconfined aquifers, the technique's main requirement being that of horizontal flow of groundwater.

Two further tests were run, both having large drawdowns. These were carried out before and after the drilling of the horizontal laterals from the base of the dug well. Both tests were pumped at 379 m^3/day for 50 and 60 minutes respectively until the well was dry and the recovery of levels was monitored. Fig. 7 is a plot of the drawdowns in metres observed in the well for both tests. It is clear that the water levels recovered much faster after the collectors had been drilled.

2.3.2 Development of Minor Alluvial Plains near Lupane

The alluvial plain at Lupane on which the well was dug is typical of many plains adjacent to rivers crossing the Kalahari sediments in NW Zimbabwe. Thomas and Shaw (1990) describe the distribution of the Kalahari Sandbeds. The site is on the southernmost edge of these deposits and their entire thickness varies from 0 to 200 m in Zimbabwe. It is likely that the 7 m thickness recorded on the alluvial plain is the full thickness to bedrock at this site.

Only one of the two laterals drilled yielded significant water. This lateral was drilled towards the thinning edge of the alluvial deposits and intersected a coarser layer at their base. There was no evidence of this coarser layer at the site of the dug well but it is possible that it does exist below the consolidated sands found there.

The site could therefore be very like that at Makusia School, however, there is no evidence that the basal faster layer does exist everywhere and hence that dug wells would be the best way to exploit the deep, thin faster layer and that laterals would not be needed. What has been shown is that dug wells or collector wells can provide significant supplies in these alluvial plains. It is recommended that detailed site investigation drilling be carried out at each site prior to deciding on the best means of water abstraction. Just as at Makusia, it would also be necessary to determine the permanency of the groundwater supply prior to development.

2.3.3 Drilling Techniques

Telescoped jetting was used successfully to create laterals in the fine sands of the Lupane Alluvial Plain, thus confirming the suitability of the technique first tried in Malaysia for this purpose. In this technique, temporary 4" diameter casing is drilled into the sands. Then 2" diameter screen connected around a blank wash pipe is jetted through the 4" casing as far as is required. The wash pipe and 4" diameter temporary casing are subsequently withdrawn.

Recently, Herbert (1990), has shown that in aquifers having transmissivities less than 300 m^2/d, adits of only 1½" diameter will be adequate to carry the extra flow. This means that in the Lupane plain the low-cost moling techniques described by Morris (1991) would be the appropriate way of creating the adits of collector wells should they be required.

3. POTENTIAL FOR DEVELOPMENT OF ALLUVIALS OF ZIMBABWE

Section 2 gives the occurrence of alluvial aquifers in Zimbabwe. There are three regionally different types. Also, each type has two components; an alluvial plain and a river channel sand.

On the alluvial plains it is recommended that at every location, prior to development, a site investigation is carried out to determine whether there is a perennially available 2 to 3 m minimum thickness of saturated sands. Secondly, on the alluvial plains, it should be established if there is a thin basal, high permeability layer present or not. If there is, dug well techniques will be adequate for development, if there is not, collector wells will give better yields than dug wells. Wherever the transmissivity of the sands is less than 300 m^2/d, moling, rather than telescoped jetting should be used. There may be some flood plains where transmissivity is so low, <1 m^2/d, slim deep boreholes penetrating the bedrock below will on average give better yields than shallow large diameter wells in the alluvium above. Fig. 8 summarises the recommendations given above.

There are high yielding river channel sands in some of the rivers of Zimbabwe. The Sashe, Limpopo and the Lundi are three such rivers. Work will be described in a companion volume on collector wells sited on the banks of such rivers with the collectors penetrating the sand river gravels through the river banks. This can only be done using the relatively cheap equipment described in this report when the bedrock under the river bed is no greater than 20 m below the banks and where the banks do not overflood. Other techniques are available for exploitation of such sand rivers but these are either destroyed annually by flooding or require major civil engineering and are beyond the aims of this report which are restricted to development of rural supplies using relatively cheap techniques.

REFERENCES

Barker, J A (1989) Programs to simulate and analyse pumping tests in large-diameter wells. BGS Report No. WD/89/23.

Herbert, R (1990) Dug well vs. collector well performance. BGS Technical Report No. WD/90/34.

Morris, B L (1991) Radial collector wells in alluvium project: Progress report 2 on aquifer characteristics evaluation at Carmer Wood. BGS Technical Report No. WD/91/1.

Owen, R J S (1989) The use of shallow alluvial aquifers for small-scale irrigation with reference to Zimbabwe. ODA Project R4239. (Copies held at University of Southampton and University of Zimbabwe).

Thomas, D S G and Shaw, P A (1990) The deposition and development of the Kalahari Group sediments, Central Southern Africa. Jl. of African Earth Sciences, 10, No. 1/2, pp 187-197.

APPENDIX A

1989 Dug Well Costs, Makusia School (Lower Veld Alluvium)

	Zimbabwe Dollars (Z$)				
	Salary**	Diesel	Compressor*	Misc.	Totals
August	1195	-	-	-	1195
September	932	504	-	100	1536
October	335	126	437	-	898
					3629

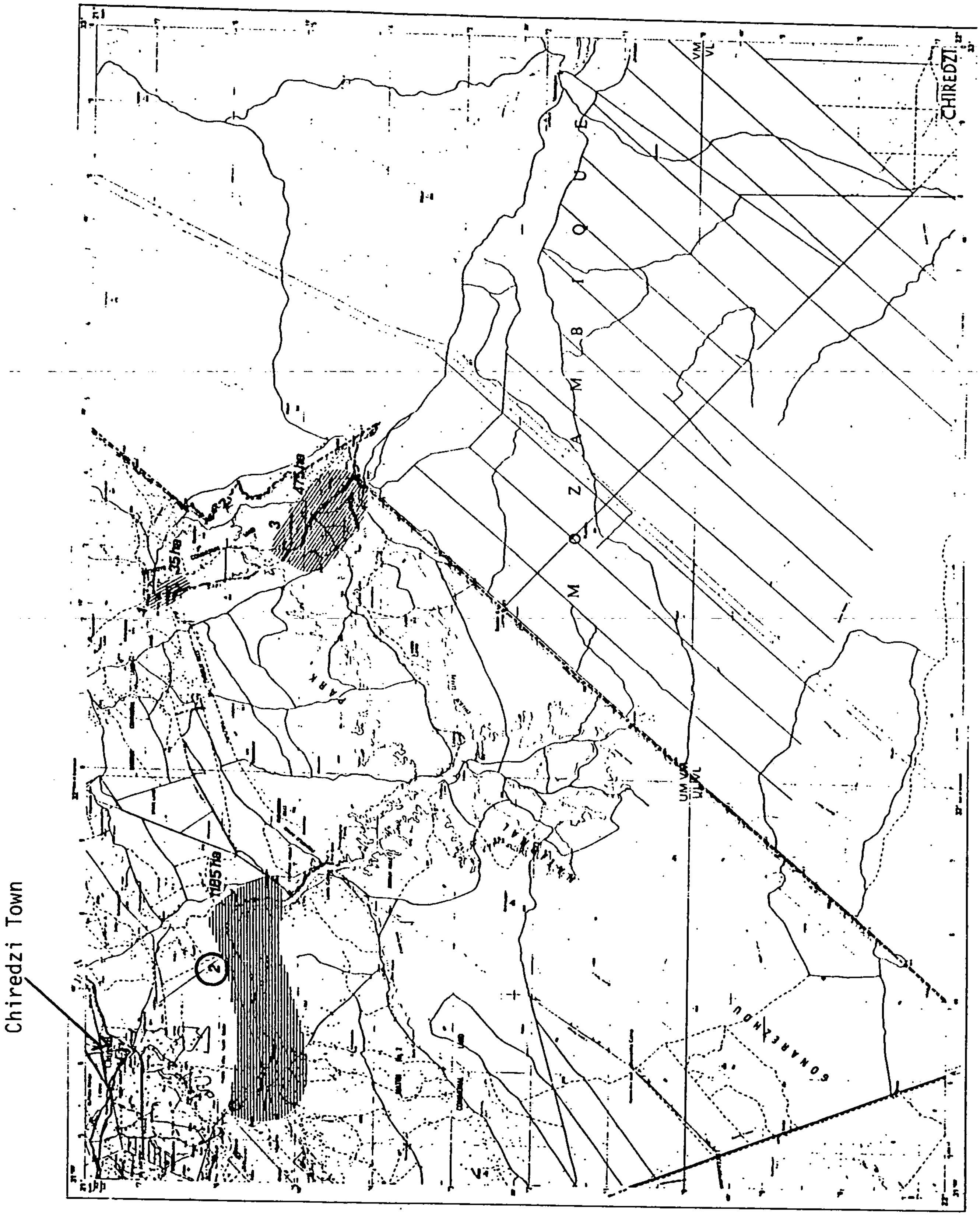
Additional Cost of Armco Lining*** 16 m @ Z$626/m = 10016

∴ Total cost per dug well for a rolling project = 13645

NB: * Compressor costs quoted are for assumed purchase then use over a 10-year period. Assuming spares at 5% per annum, construction of nine wells per annum and an interest rate of 5%, the compressor cost per well is Z$437.

** The above represents 44 days digging, 21 days preparing site, transporting equipment, holidays etc.

*** 3 mm thick lining was used at a cost of £184/m (Z$626/m). The work has shown only 2 mm lining is necessary at a cost of £106/m (Z$330/m). These costs are inclusive of shipping.



Scale: 1 : 250,000

CHIREDZI MAP

Fig. 1. The Location of the Flood Plain at the Makusia School.

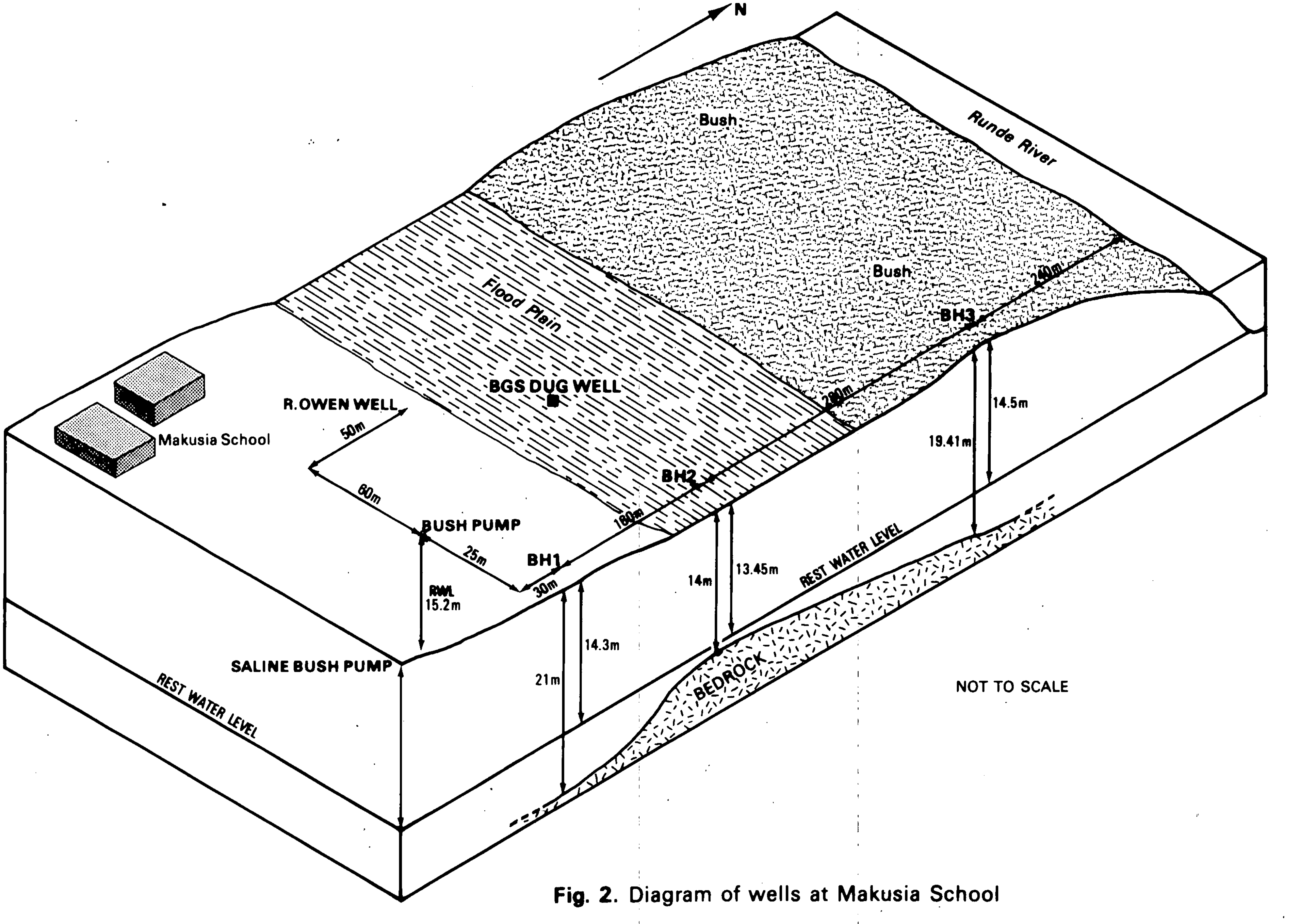
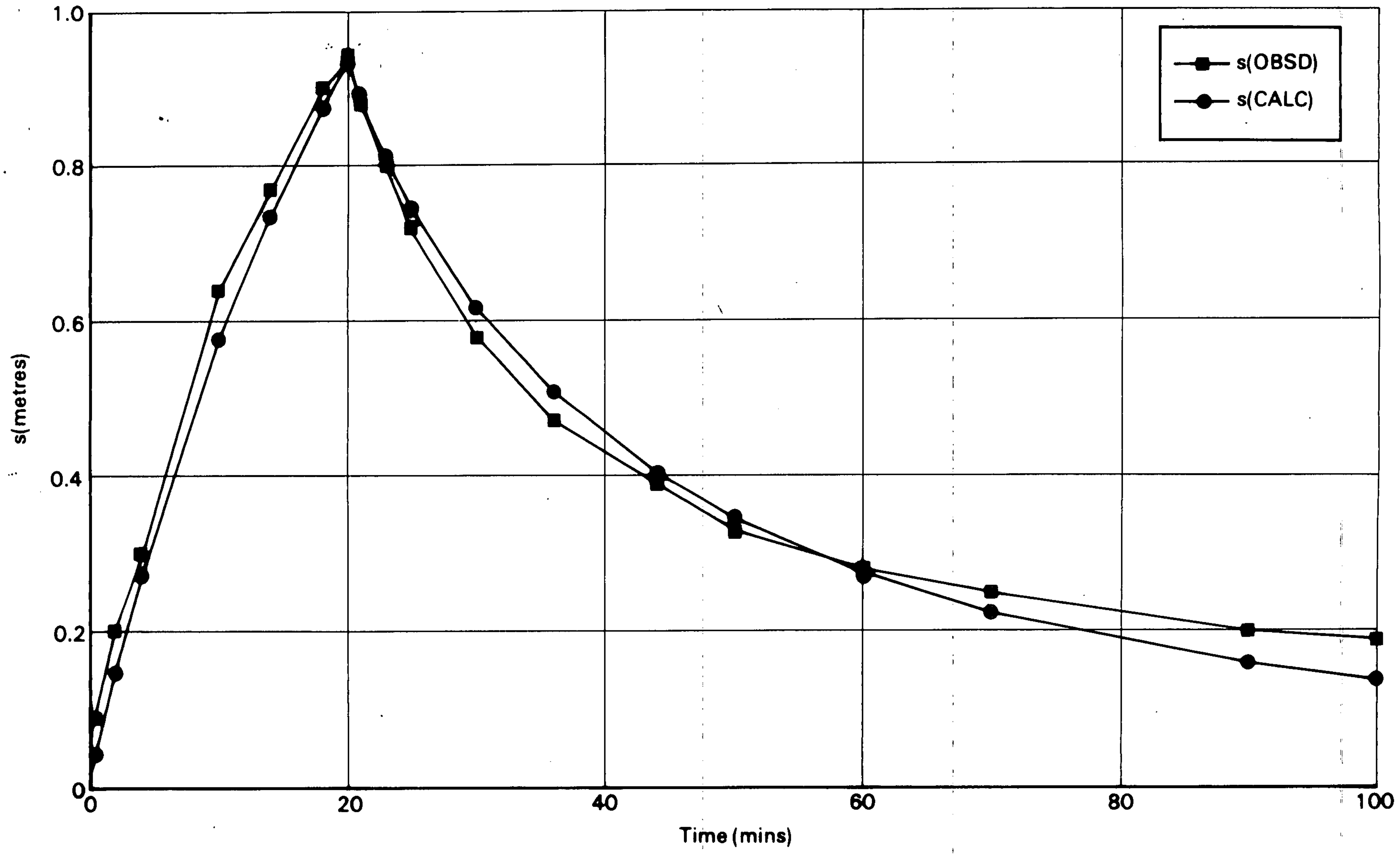


Fig. 2. Diagram of wells at Makusia School

Fig. 3. Makusia BGS dug well test 22/10/89



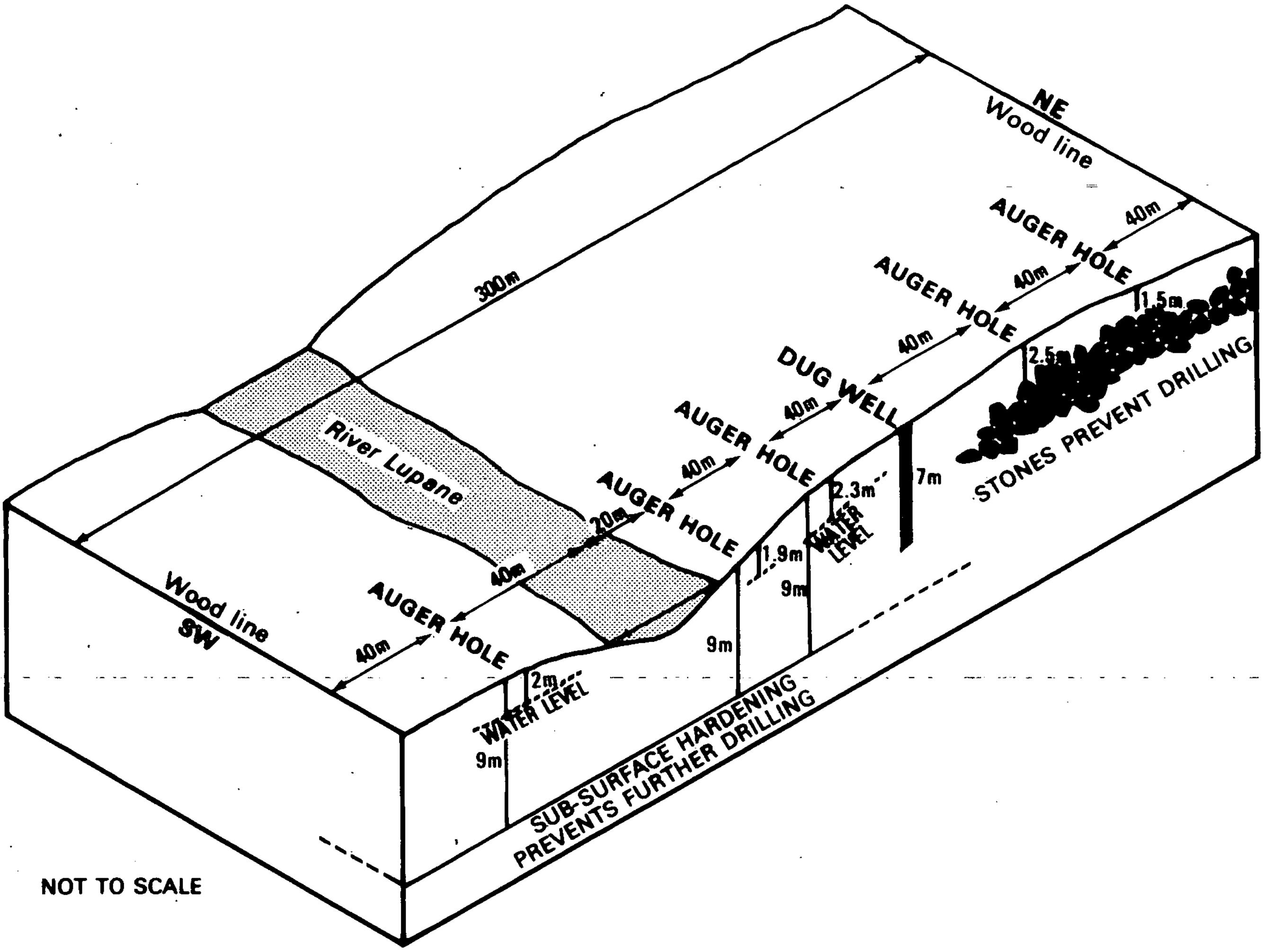


Fig. 4. Diagram of wells at Lupane River

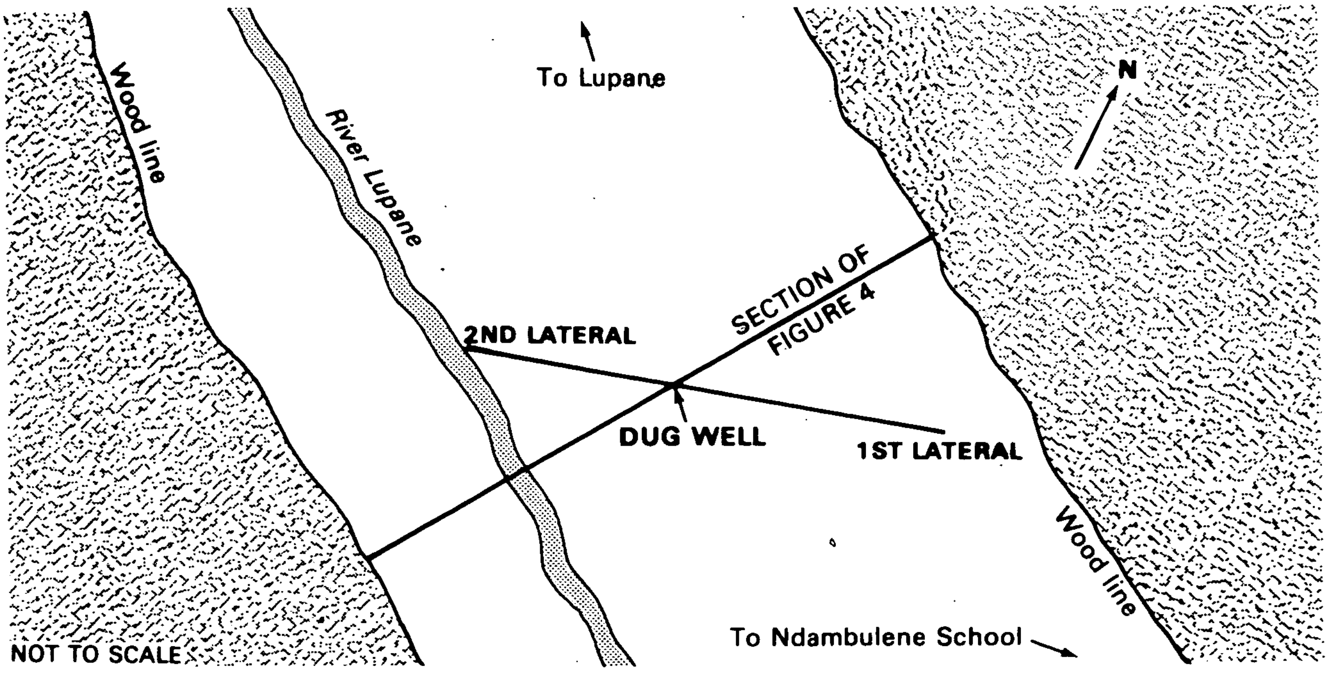
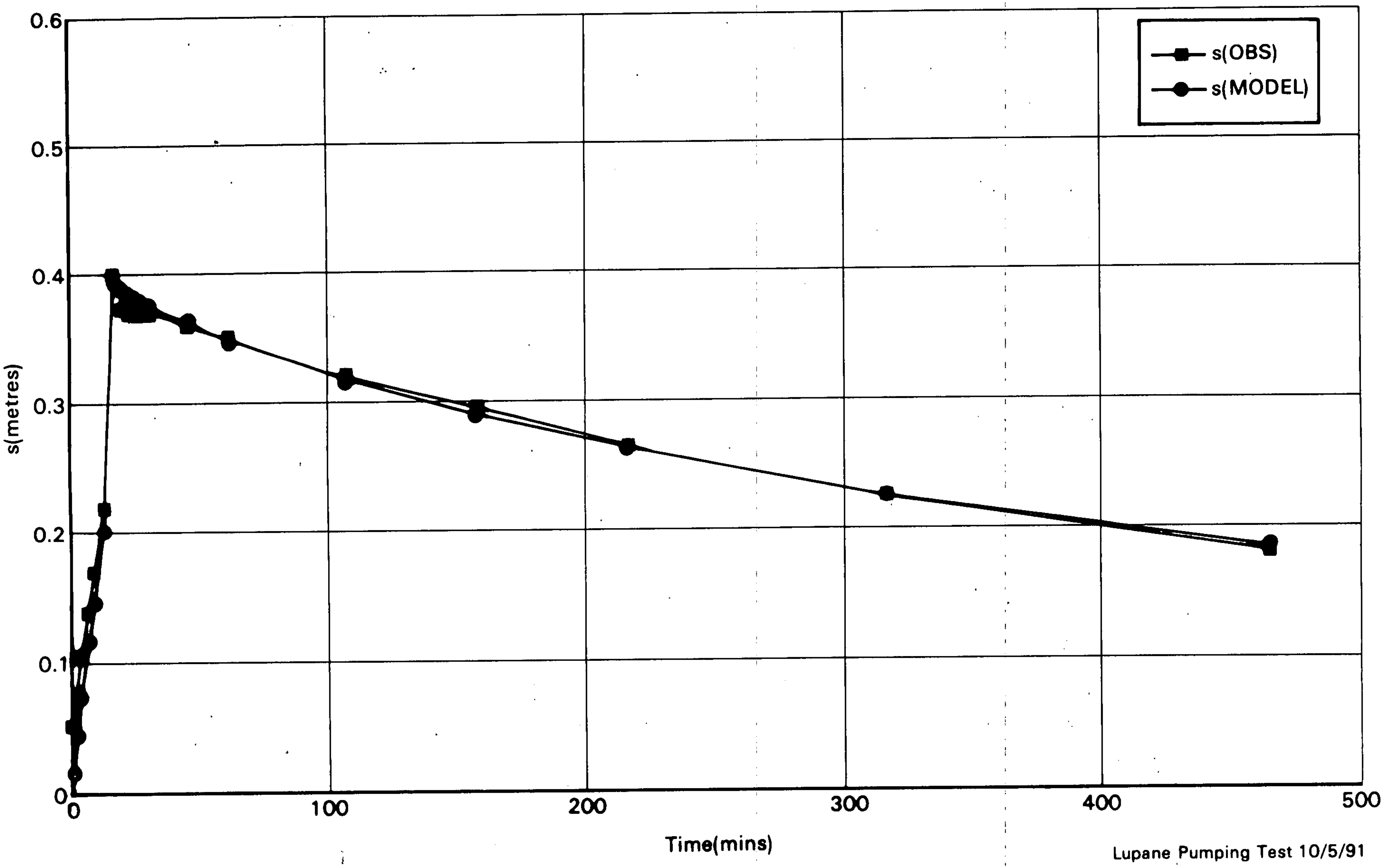


Fig. 5. Sketch map showing direction of laterals drilled at Lupane.

Fig. 6. Comparison of observed and predicted drawdowns.



Lupane Pumping Test 10/5/91

Fig. 7. Comparison of recovery of levels, pre and post drilling of laterals, at Lupane.

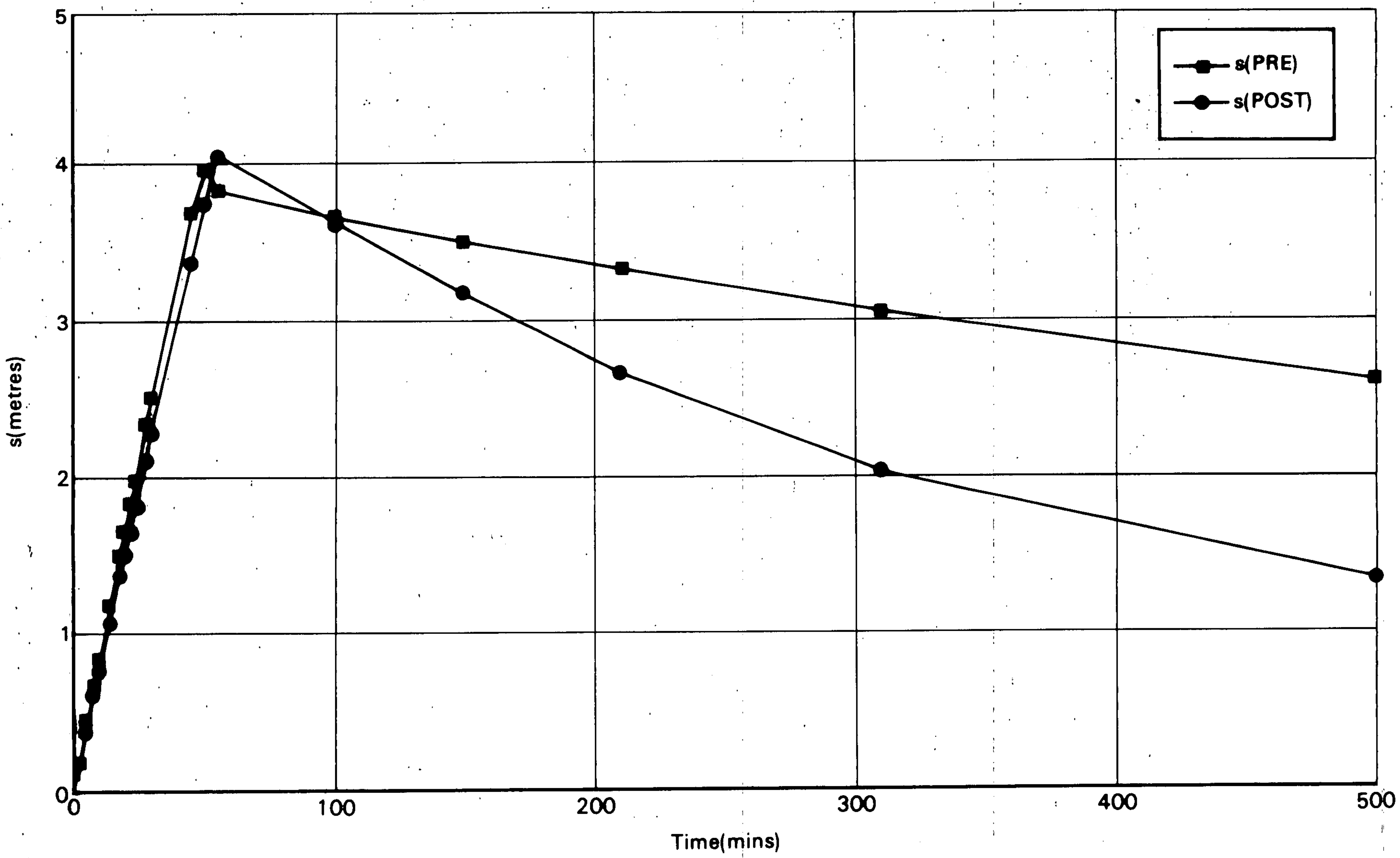


FIG 8.SELECTING OPTIMUM DEVELOPMENT FOR ALLUVIAL PLAINS.

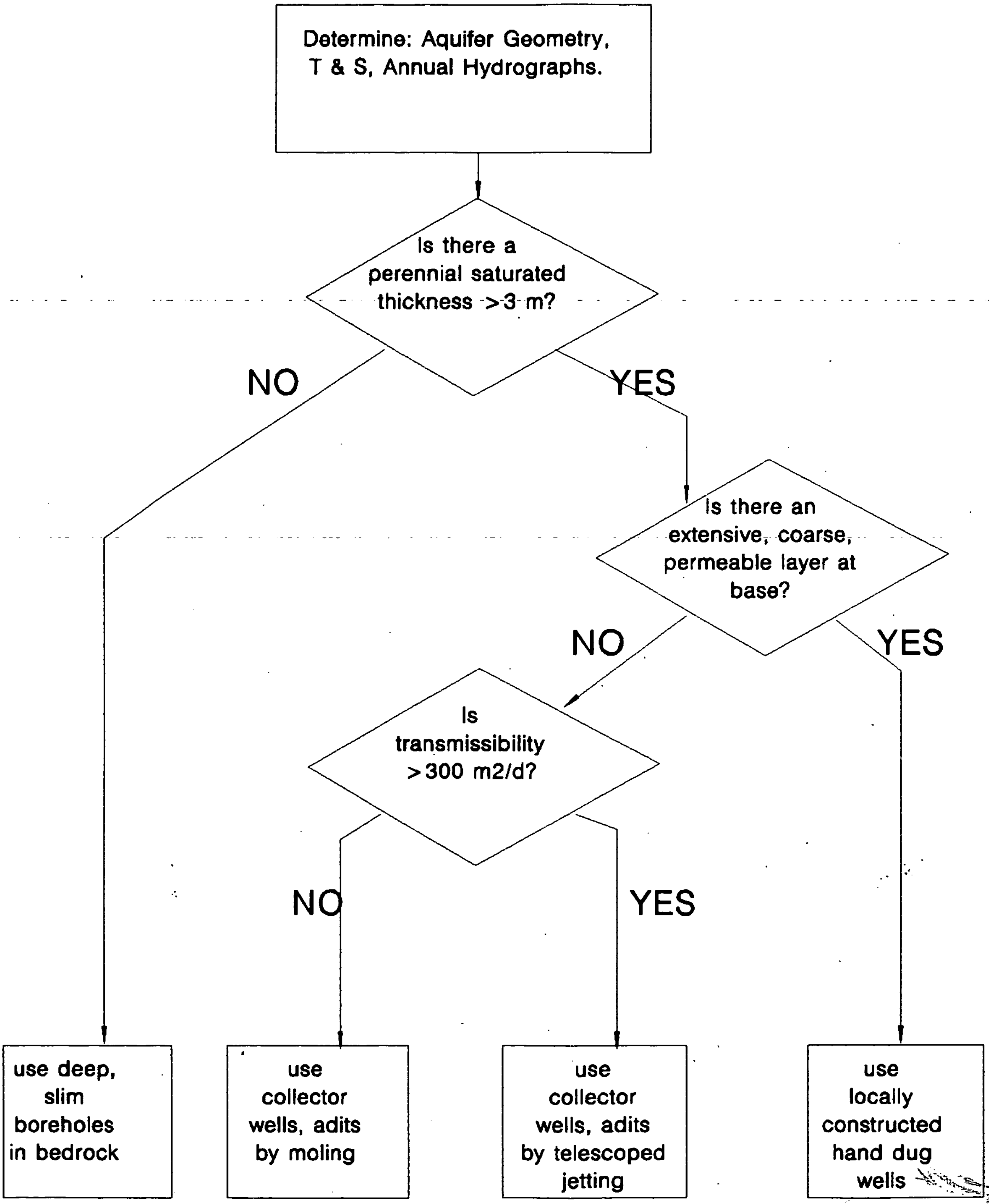


Table 1. Hydrogeochemical Data for Water Sample taken from the Bush Pump at Makusiya School, Southern Zimbabwe.

British Geological Survey
Hydrogeology Research Group

HYDROGEOCHEMICAL DATA
See coding instructions overleaf

Sequence No. 39 | 984

CARD 1
1 sequence no. 6: 890984
7 GB, overseas or Ireland: 2
8 Latitude (deg. min. sec. N/S): 21 16 00 N
Longitude (deg. min. sec. E/W) 22: 031 37 00 E
23 National/Irish Grid reference 34:
35 Country 44: ZIMBABWE
45 Locality 68: MAKUSIYA SCHOOL BUSH P
69 Well identity 78 (1:25000 sheet, Site No., Well):

CARD 2
1 sequence no. 6:
7 Date of sampling 12: 040789
13 Time 16: 0700
17 Date analysis completed 22:
23 Sampled by: 4
24 Sample source 25: 10
26 Filter: 1
27 Acid: 0
28 Sample condition 29: 01
30 Water use 31: 02
32 Source of analytical data 33:
34 Additional information 35: 00
36 Lithology / Stratigraphy 43:
44 Multiple aquifer 46:
47 Well lining 48:
50 Elevation (m) 55:
56 Well depth (m) 61:
62 Top depth (m) / Water level (m) 67:
68 Bottom depth (m) / Sample depth (m) 73:
74 Moisture content (g/kg dry) / Discharge (l/s) 79:

CARD 3
1 sequence no. 6:
7 Temperature (°C) 14:
15 pH (field) 22:
23 pH (lab) 30: 8.6
31 E_H (mV) 38:
39 O_2 46:
47 Sp. electrical cond. (μS/cm at 25°C) 54:
55 Density 62:
63 Units:
64 Project 1 67:
68 Project 2 71:
72 Project 3 75:

CARD 4
1 sequence no. 6:
7 Na 14: 166.
15 K 22: 1.2
23 Ca 30: 14.1
31 Mg 38: 46.0
39 Titration alkalinity as HCO_3 (field) 46:
47 Titration alkalinity as HCO_3 (lab.) 54: 637.
55 SO_4 62: 4.6
63 Cl 70: 40.8
71 Total oxidised nitrogen 78: -0.7

CARD 5
1 sequence no. 6:
7 Sr 14: 0.436
15 Ba 22: 0.052
23 B 30: 0.22
31 Si 38: 34.7
39 Li 46: -0.007
47 Fe (total) 54: -0.015
55 Mn 62: 0.018
63 F 70:
71 Br 78:

CARD 6
1 sequence no. 6:
7 I 14:
15 NO_2 - N 22:
23 NH_4 - N 30:
31 P (total) 38:
39 P (colorimetric) 46:
47 HS 54:
55 TDS 62:
63 TSS 70:

CARD 7
1 sequence no. 6:
7 CO_2 14:
15 TOC 22:
23 ^3H 30:
31 $d^{14}C$ 38:
39 $\delta^{13}C$(DIC) 46:
47 $\delta^{18}O(H_2O)$ 54:
55 $\delta^2H(H_2O)$ 62:
63 $\delta^{34}S(SO_4)$ 70:
71 $\delta^{18}O(SO_4)$ 78:

CARD 8
1 sequence no. 6:
7 Ag 14:
15 Al 22:
23 As 30:
31 Be 38:
39 Bi 46:
47 Ce 54:
55 Cd 62:
63 Co 70:
71 Cr 78:

CARD 9
1 sequence no. 6:
7 Cs 14:
15 Cu 22:
23 Eu 30:
31 Fe^{2+} 38:
39 Fe^{3+} 46:
47 Ga 54:
55 Ge 62:
63 Hg 70:
71 La 78:

CARD 10
1 sequence no. 6:
7 Mo 14:
15 Ni 22:
23 Pb 30:
31 Rb 38:
39 Sb 46:
47 Sc 54:
55 Se 62:
63 Sn 70:
71 Te 78:

CARD 11
1 sequence no. 6:
7 Ti 14:
15 Tl 22:
23 U 30:
31 V 38:
39 W 46:
47 Y 54:
55 Zn 62:
63 Zr 70:

t16c hy form nbaskr/gms

Comments

Table 2. Hydrogeochemical Data for Water Sample taken from BGS Exploratory Borehole 3 at Makusiya School, Southern Zimbabwe.

British Geological Survey
Hydrogeology Research Group

HYDROGEOCHEMICAL DATA

See coding instructions overleaf

Sequence No. 39 | 985

CARD 1

1 sequence no. 6	7 GB, overseas or Ireland	8 Latitude (deg. min. sec. N/S) Longitude (deg. min. sec. E/W) 22	23 National/Irish Grid reference 34	35 Country 44
890985	2	211600N0313700E		ZIMBABWE

45 Locality 68	69 Well identity (1:25000 sheet, Site No., Well) 78
MAKUSIYA SCHOOL BH3	

CARD 2

1 sequence no. 6	7 Date of sampling 12	13 Time 16	17 Date analysis completed 22	23 Sampled by	24 Sample source 25	26 Filter	27 Acid	28 Sample condition 29
	080789	1030		4	10	1	0	01

30 Water use 31	32 Source of analytical data 33	34 Additional information 35	36 Lithology	Stratigraphy 43	44 Multiple aquifer 46	47 Well lining 48	50 Elevation (m) 55
09		00					

56 Well depth (m) 61	62 Top depth (m) Water level (m) 67	68 Bottom depth (m) Sample depth (m) 73	74 Moisture content (g/kg dry) Discharge (l/s) 79

CARD 3

1 sequence no. 6	7 Temperature (°C) 14	15 pH (field) 22	23 pH (lab) 30	31 E_H (mV) 38	39 O_2 46
			8.4		
	47 Sp. electrical cond. (µS/cm at 25°C) 54	55 Density 62	63 Units	64 Project 1 67	68 Project 2 71
	72 Project 3 75				

CARD 4

1 sequence no. 6	7 Na 14	15 K 22	23 Ca 30	31 Mg 38	39 Titration alkalinity as HCO_3 (field) 46
	36.2	0.9	38.1	48.8	
	47 Titration alkalinity as HCO_3 (lab.) 54	55 SO_4 62	63 Cl 70	71 Total oxidised nitrogen 78	
	452.	2.9	29.5	0.7	

CARD 5

1 sequence no. 6	7 Sr 14	15 Ba 22	23 B 30	31 Si 38	39 Li 46
	0.406	0.088	0.04	32.0	-0.007
	47 Fe (total) 54	55 Mn 62	63 F 70	71 Br 78	
	-0.015	0.101			

CARD 6

1 sequence no. 6	7 I 14	15 NO_2-N 22	23 NH_4-N 30	31 P (total) 38	39 P (colorimetric) 46
	47 HS 54	55 TDS 62	63 TSS 70		

CARD 7

1 sequence no. 6	7 CO_2 14	15 TOC 22	23 ^3H 30	31 $d^{14}C$ 38	39 $\delta^{13}C$(DIC) 46
	47 $\delta^{18}O(H_2O)$ 54	55 $\delta^2H(H_2O)$ 62	63 $\delta^{34}S(SO_4)$ 70	71 $\delta^{18}O(SO_4)$ 78	

CARD 8

1 sequence no. 6	7 Ag 14	15 Al 22	23 As 30	31 Be 38	39 Bi 46
	47 Ce 54	55 Cd 62	63 Co 70	71 Cr 78	

CARD 9

1 sequence no. 6	7 Cs 14	15 Cu 22	23 Eu 30	31 Fe^{2+} 38	39 Fe^{3+} 46
	47 Ga 54	55 Ge 62	63 Hg 70	71 La 78	

CARD 10

1 sequence no. 6	7 Mo 14	15 Ni 22	23 Pb 30	31 Rb 38	39 Sb 46
	47 Sc 54	55 Se 62	63 Sn 70	71 Te 78	

CARD 11

1 sequence no. 6	7 Ti 14	15 Tl 22	23 U 30	31 V 38	39 W 46
	47 Y 54	55 Zn 62	63 Zr 70		

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Comments

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