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COLLECTOR WELLS FOR SMALL-SCALE IRRIGATION:
Siting, Construction, Testing and Operation of a Collector Well at the Lowveld Research Station, Chiredzi.

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EXECUTIVE SUMMARY

In 1988 the British Geological Survey (BGS) and the British Institute of Hydrology (IH) began a collaborative project aimed at developing limited groundwater resources for small-scale irrigation. The overall objective of the study is to determine the feasibility and sustainability of small-scale irrigation from the extensive, shallow aquifers associated with crystalline basement rocks. This is to be done by combining methods of high-efficiency, low-cost irrigation with the use of collector wells to develop the water resources of the weathered zone of the basement rocks. The study follows on naturally from and brings together recent work by IH on the former and BGS on the latter.

The Lowveld Research Station at Chiredzi in southern Zimbabwe was chosen as the focus of the study. The station has itself been carrying out research on improving irrigation efficiency for a number of years. Exploratory drilling to locate a suitable well site on the station was undertaken in October and November 1988, and construction of the well from February to April 1989. The well was completed to 12 m, tested, the laterals were constructed and the well was retested at 1 l/sec. Construction of the laterals had been effective, and improved the yield by 150%. The total cost of the completed well, comprising exploratory drilling, construction and testing and completion works was Z$19,000.

A permanent pump was installed and the well has been providing water for irrigation experiments since June 1989. A programme of hydrogeological observations at and around the well has been initiated. The well is providing adequate water for the experiments, at only 4% of the installed pumping capacity, which is itself significantly lower than the estimated long-term yield of the well. The potential exists for irrigating a considerably larger area, using efficient irrigation techniques, although this would in practice be limited by the capacity of human- or animal-powered pumps.

The collector well at Chiredzi is thus highly successful, even in a considerably drier area than any of the other wells in Zimbabwe. Hydrogeological conditions at the site are favourable, with deep weathering and a shallow water table. The well is constructed in dolerite intruded into Precambrian gneisses, with strong linear NNE-SSW structural trends. It is possible that local water levels are affected by recharge from the irrigated sugar estates to the south, from the irrigation canal or from storage reservoirs at LVRS. Consideration must be given to the extent to which these favourable conditions are unique, or can be replicated elsewhere in the region.

The next stage of the project is to establish gardens using the combination of collector wells and efficient irrigation at sites in communal lands in southern Zimbabwe. A site has been selected at Tamwa Kraal in Chivi Communal Lands, and a collector well has been constructed. The results from that and any subsequent sites will be the subject of future reports within this project.

Further work will be carried out in 1991 to investigate the question of localised recharge. This will include the construction of additional water level monitoring points to enable a water table contour map to be drawn to indicate the principal directions of groundwater flow and the collection of water samples for chemical and stable isotope analyses. Monitoring of the performance of the well at Chiredzi will continue.

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1. INTRODUCTION

1.1 Objectives of Project

In 1988 the British Geological Survey (BGS) and the UK Institute of Hydrology (IH) began a project aimed at developing limited groundwater resources for small-scale irrigation. The project is based at the Lowveld Research Station (LVRS), close to the town of Chiredzi in south-east Zimbabwe. Since October 1988 the field programme has been a collaborative activity between BGS, IH and LVRS. Funding for the equipment and UK staff inputs to the project has come from the Engineering Division of the UK Overseas Development Administration (ODA).

The overall objective of the study is to determine the feasibility and sustainability of small-scale irrigation from the extensive, shallow aquifers associated with crystalline basement rocks. Within the overall programme, the specific objectives of the hydrogeological component of the study are:

(a) to further investigate cheaper means of well construction,

(b) to locate sites for collector wells in the Chiredzi area of the Lowveld of Zimbabwe, and confirm their suitability by limited exploratory drilling,

(c) to construct and test 2-4 collector wells in the Chiredzi area,

(d) to continue data collection from new and existing wells to obtain information on the long-term safe yields of such wells,

(e) to collect and review further information on the regolith aquifer to improve techniques and bring down the cost of siting.

1.2 Scope of Report

The present report describes the hydrogeological work at the LVRS site from October 1988 to June 1990. This comprises the siting, construction, testing and operation of a collector well to provide water for irrigation experiments. These have been carried out by IH and LVRS and are the subject of separate reports. Some of the material included here has been summarised previously in various overseas visit reports (Chilton, 1989, 1990; Herbert, 1989) but is assembled here with additional interpretation and discussion to form the first technical report on the hydrogeological component of the project.

1.3 Background

Limited water availability is the main constraint to agricultural production in semi-arid areas. Better rainfed farming methods can improve crop production, but rainfed farming cannot guarantee continuous crop production because of the extreme unreliability of rainfall. Dependable crop production can only be achieved during periods of drought by use of irrigation. However, in much of Africa large irrigation schemes have proved to be expensive, inefficient and difficult for government or parastatal organisations to manage. Small-scale irrigation, on the other hand, should be relatively inexpensive, relatively efficient and can be managed by the farmers themselves. Used together with improved rainfed farming practices, small-scale irrigation has the potential for improving sustainability of agriculture in semi-arid areas by increasing and diversifying crop production and hence improving nutritional standards.

Large areas of semi-arid Africa are underlain by crystalline basement rocks. Shallow, often quite localised aquifers occur in the weathered zone and in the fractured bedrock. The average sustained yields of boreholes and wells are small because of the low to moderate permeability of the weathered material and because of discontinuity and low storativity in the fractured bedrock. Recharge rates vary greatly on a local scale according to soils, geomorphology, slope, geological structure and other factors, but are likely to be in excess of what can be conveniently and economically abstracted by conventional wells and boreholes for domestic supply purposes.

BGS has been carrying out research since 1983 on the design and use of horizontal drilling equipment for enhancing the yields of hand-dug wells located in these aquifers. Field work has been undertaken in Malawi and Zimbabwe (Wright et al., 1984; Wright et al., 1988) and in Sri Lanka (Ball et al., 1989). A technique has been developed which involves drilling horizontal boreholes, up to 30 m in length from the base of 2 m diameter dug wells. The results have demonstrated that abstraction by such "collector wells" from extensive, low permeability aquifers at moderately high discharge rates and low pumping heads is sufficient to meet demands for small-scale irrigation.

When water supplies for irrigation are limited, as is likely to be the case with the exploitation of basement aquifers, it is vital that water is used efficiently for irrigation to be economically viable. The methods of pumping and farming should also be suitable for use by farmers living in the rural areas. LVRS has been carrying out research for a number of years on methods of low-cost, high efficiency irrigation which are appropriate for use in semi-arid Africa. IH has a long history of research on crop water use and since 1982 has been working specifically on high-efficiency irrigation methods, with field studies in Sri Lanka and Mauritius (Foster et al., 1989; Batchelor et al., 1989). The present project therefore represents a natural bringing together into one project of the relevant research experience of BGS, IH and LVRS.

2. SITE LOCATION AND DESCRIPTION

The Lowveld Research Station is located in south-east Zimbabwe at latitude 21°01'S and longitude 31°34'E. The station is situated between the main A10 Ngundu to Chisumbanje road and the railway, approximately 15 km from Chiredzi town (Figure 1), and at an altitude of 430 m.

The climate of this part of the lowveld is semi-arid. Annual rainfall averages 450 mm, but ranges from 250 mm to 750 mm. Most of the annual rainfall results from high intensity storms during the period November to April.

This part of the lowveld has a number of large sugar estates which depend on irrigation water from Lake Kyle, Lake Macdougall, Bangala Dam and other smaller dams. The rest of the land is mainly given over to cattle ranching on a large scale; the historical land distribution means that the nearest communal lands are approximately 40 km from LVRS.

The geology of the area around Chiredzi was described by Swift et al. (1953). The immediate area around LVRS is underlain by paragneisses of the Beit Bridge Group of early Precambrian age (Figure 1). These form an interbedded series of mainly acid granulites with some schists, marbles and argillaceous rocks. Intrusive into these are orthogneisses, which range in composition from acid

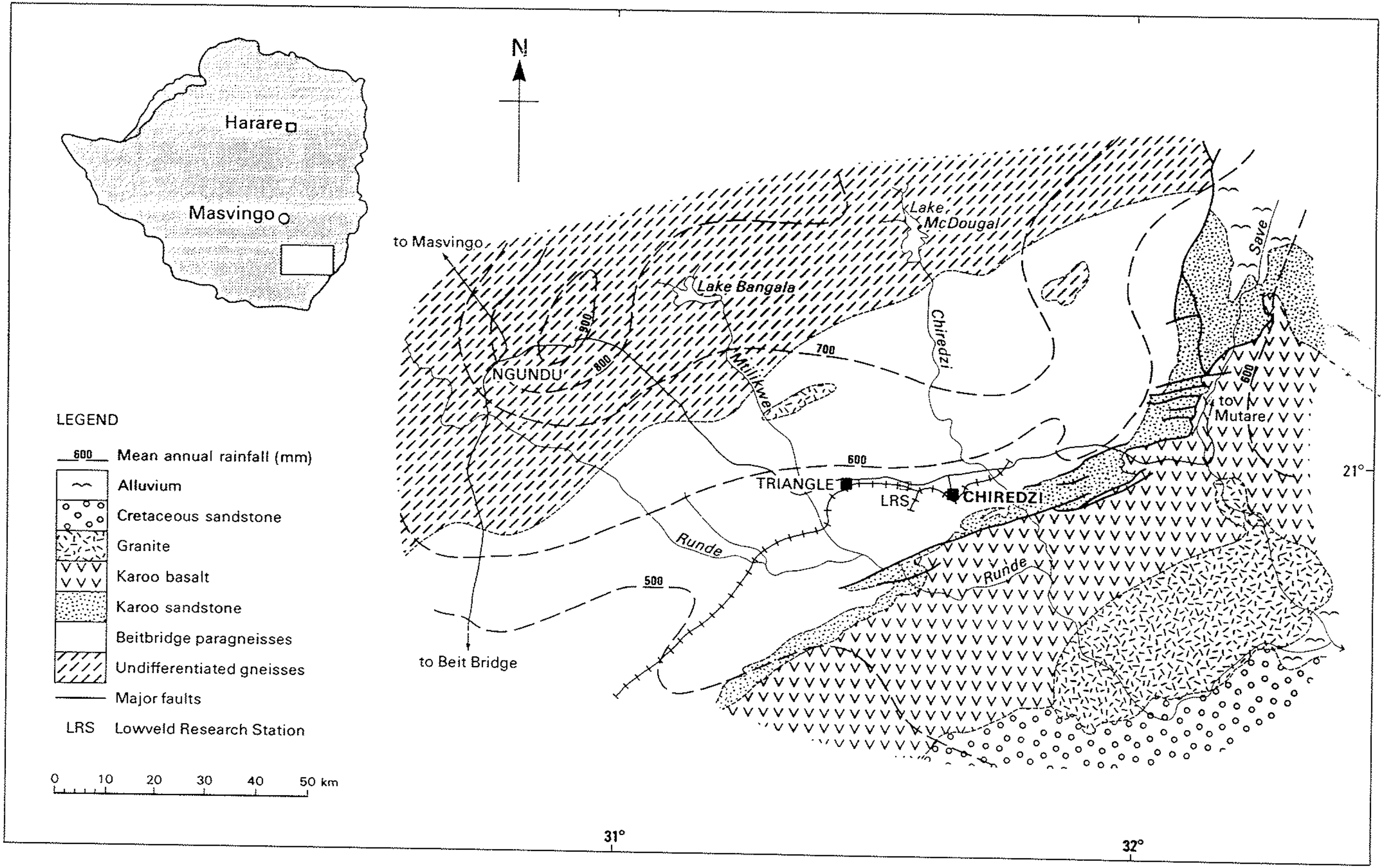

Figure 1. General location of Lowveld Research Station.

to ultrabasic. This combination of rock types forms the Basement complex, which has been subjected to deep-seated metamorphism. They have a dominant NE-SW structural trend, which is followed by the numerous intrusive dolerite dykes. The area has then been subjected to a prolonged period of erosion.

3. WELL SITING INVESTIGATIONS

The selection of the site for the collector well within the boundary of LVRS was based on the results of exploratory drilling. Nine exploratory boreholes were completed with a lightweight Holman air hammer investigation drilling rig loaned from the Ministry of Energy and Water Resources Development (MEWRD). The drilling was carried out in late 1988 under the supervision of Peter Rastall, the BGS contract driller in Zimbabwe.

3.1 Exploratory Drilling

Exploratory drilling sites were selected around the station, on land that was not already in use for cultivation trials. The locations of the nine exploratory boreholes are shown in Figure 2 and the information obtained is summarised in Table 1.

The first borehole in the SW corner of the station produced very good results from heavily weathered, blocky igneous rocks. The depth of weathering appeared to be about 30 m. Pumping for 140 minutes at 0.7 l/sec produced a drawdown of only 1 metre. The analysis of the test pumping of this borehole (Appendix 1) suggest a transmissivity of 20 m^2/day or more; relatively high for such a basement area. This first site was, therefore, too favourable, and would support yields sufficient for small-scale irrigation from a borehole, without requiring the construction of a collector well.

At the second site, pumping at only 0.2 l/sec drew the water level down to pump suction at 19 m in only 14 minutes. This site was considered marginal for a collector well. This point (October 1988) coincided with a joint BGS/IH visit to Chiredzi during which the results of boreholes 1 and 2 were reviewed and a programme of further drilling prepared:

(a) Two additional boreholes (no's 8 and 9) near to no. 2 and close to the entrance road (Figure 2).

(b) One borehole (no. 10) in the south east corner of the station.

(c) A line of four boreholes (no's 11 to 14) up the slope from the north-south drainage channel which traverses the station.

Boreholes 8 and 9 (Table 1) encountered weathered gneiss. Borehole 9 was dry to 17 m. Borehole 8 produced a yield of 0.25 l/sec for a drawdown of 7 m, giving a transmissivity of between 1 and 2 m^2/d (Appendix 1). The soil in this area of the station appeared to be shallow and there were larger, angular blocks of schist and gneiss at shallow depth. This was confirmed by the digging of a number of pits, and this part of the station was therefore ruled out.

The line of boreholes close to the vlei indicated water levels and weathering depths suitable for collector well construction (Table 1). Boreholes 12 and 13 were test pumped and produced moderate drawdowns for yields of 0.4 l/sec. Transmissivities of 10 m^2/d and 2 m^2/d respectively are indicated from analysis of the test pumping (Appendix 1). Four pits were also dug (Figure 2) to confirm the soil depth in this part of the LVRS site.

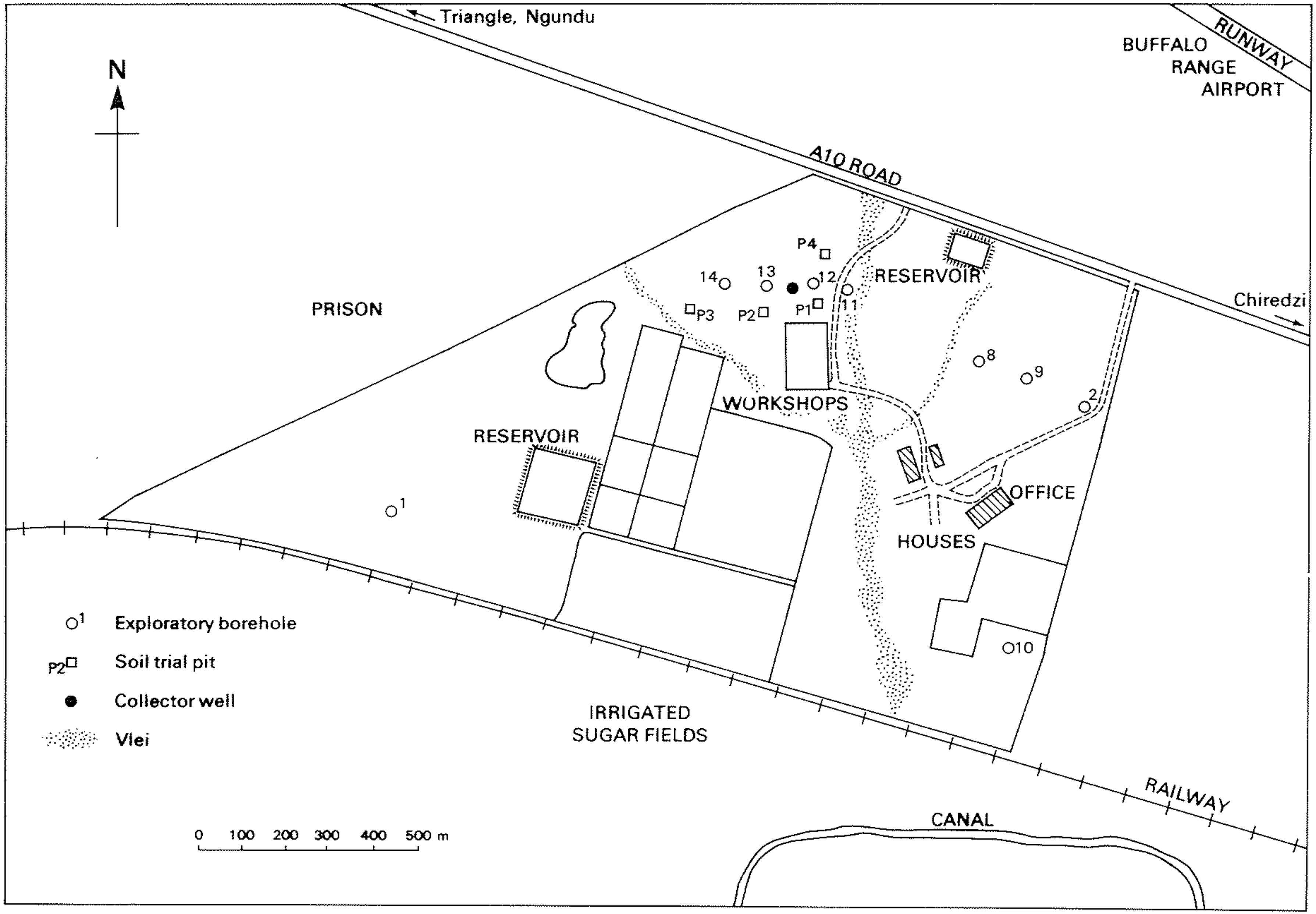

Figure 2. Location of exploratory boreholes and trial pits, Lowveld Research Station.

Table 1 Results of Exploratory Drilling at Lowveld Research Station, Chiredzi

Borehole Number	Depth (m)	Water Struck (m)	Rest Water Level (m)	Tested Yield (l/sec)	Duration of Pumping (min)	Final Drawdown (m)	Specific Capacity (l/sec/m)	Transmissivity (m^2/day)	Lithology
1	51.0	13.0 16.0	6.95	0.67	140	1.04	0.64	20	0-2 dark brown soil, 2-22 weathered dolerite, 22-43 less weathered, 43-51 hard, fractured dolerite
2	55.0	16.0 29.0	9.95	0.22	14	8.51	0.025	0.5	0-2 reddish brown topsoil, 2-13 weathered pinkish gneiss, 13-30 fine grained rock, hard (basalt?) 30-55 hard pegmatitic gneiss
8	25.0	10.0	8.0	0.2	220	7.14	0.03	1.4	0-1 reddish brown soil, 1-25 brown weathered pegmatite rock
9	17.0	dry	dry	-	-	-	-	-	0-2 topsoil and pegmatitic rock fragments, 2-16 fractured quartzitic and pegmatitic rock, 16-17 fresh, hard pegmatite
10	24.0	24.0	7.2	-	-	-	-	-	0-2 brown sandy topsoil, 2-18 coarse grained weathered pegmatite, 18-24 weathered dolerite?
11	16.0	8.75	3.15	-	-	-	-	-	0-1 dark brown soils, 1-16 fractured dolerite
12	26.0	8.5 10.0	4.3	0.4	120	2.20	0.18	8-10	0-1 brownish topsoil, 1-26 soft weathered pegmatitic gneiss
13	25.0	8.0 18.0	4.6	0.4	120	7.45	0.05	2	0-1 reddish brown soil, 1-12 weathered dolerite, 12-25 fractured dolerite
14	25.0	20.0	5.1	-	-	-	-	-	0-1 brown soil, 1-25 fractured and weathered pegmatitic gneiss

Lithological logs, S Sowa and S Sunguro, MEWRD, November 1988

Table 2 Results of Soil Trial Pits

Pit No.	Soil Depth (m)	Underlying Rock
1	0.60	Red, broken rock
2	0.40	Red weathered granite
3	0.60	Red, very weathered granite
4	0.40	Weathered granite

Water samples were collected during the test pumping for partial chemical analysis at the MEWRD laboratory in Harare. The results (Table 3) indicate low levels of overall mineralisation, with the exception of site 1.

Table 3 Chemical Analysis from Exploratory Boreholes

Borehole Number	Electrical Conductivity	pH	Ca	Mg	Na	Cl	SO_4	NO_3	Alkalinity
1	-	7.4	215	18	-	1200	150	3.6	611
2	1250	7.4	62	57	-	4	11	0.9	766
8	-	8.0	57	108	-	152	25	4.5	871
12	-	7.4	62	39	-	25	34	31.5	496
13	-	7.3	70	66	-	39	28	4.5	511

Taking account of the water levels in boreholes 11 to 14, and allowing adequate irrigation command area down slope of the well, the well site was chosen approximately midway between boreholes 12 and 13 (Figure 2).

3.2 Borehole Logging

Following geophysical logging at sites within Masvingo Province as part of the BGS Basement Aquifer Project, additional logging was undertaken at Chiredzi. A suite of geophysical logs was run, with the principal objective of locating permeable horizons and obtaining information on the degree of weathering. Methods of investigating the degree of weathering by using a number of cross-plot interpretative techniques had been developed in the BGS Basement Aquifer Project (Wright et al., 1989). Recent advances in this respect use the Briggs cube method of lithological reconstruction from log responses, which is briefly described in Appendix 2.

The logs run at Chiredzi comprised spontaneous potential, natural gamma, neutron-neutron porosity, caliper, micro normal and micro inverse and short, medium and long normal resistivity. The logs are shown in Figure 3. Inspection of the caliper logs suggests considerable fracturing from 13 to 31 m, and the greater counts on the gamma log suggest associated increased mineralisation. This is confirmed by the resistivity and neutron porosity logs, which show characteristic low resistivity and sharp variations in porosity associated with the fractures. Below 31 m the logs indicate a more massive formation with increasing resistivity and lower porosity. At 46 m a massive, permeable fracture is encountered.

Lithological reconstruction using the Briggs cube method produces the log shown on the left side of Figure 3. This indicates the major lithological boundary to be encountered at 37.2 m. This boundary is detected by a sharp increase in normal resistivities, accompanied by a sharp reduction in bulk porosity on the neutron log. Further investigation of the log responses by cross-plot techniques confirms this boundary. Cross-plotting neutron porosity against normal resistivity (Figure 4) suggests that weathering persists to 33.5 m below ground, compared to 37.2 m directly from the logs and 43 m from the drilling records. This difference probably arises because the geophysical and drilling logs locate the top and bottom respectively of the transition from weathered to largely unweathered rock. The logging suggests the transition zone extends from 37.2 to 42.3 m, and thus does correspond with the drilling results.

The spontaneous potential log exhibits variations which can be correlated with fractures or lithological changes. Large negative excursions indicate zones of increased permeability at 12-13 m, 18-20 m, 20-24 m, 29 m and 38-40 m, within and lastly at the boundary of the weathered zone.

4. WELL CONSTRUCTION

4.1 Well Shaft Construction

Construction of the well at Chiredzi commenced on 10 February 1989, using four locally employed labourers and one foreman and supervised by the BGS contract driller. The ground consisted of weathered but hard and blocky dolerite with vertical foliation and joints and many thin quartz veins. The material was harder to dig than might have been expected from the exploratory drilling, but excellent progress was maintained. Water was encountered at 5.2 m. The hole stood open until the first Armco lining material was inserted when the well had reached 7 m. The Armco lining comprises bolted, segmented, 3 mm thick corrugated, galvanised steel plates, 60 m of which were imported from the UK for this project. No major problems were encountered with the digging and the well was completed to 12 m on 5 April. Two pumping tests were carried out on the completed well. These are described in section 5 of this report.

Samples of the excavated material were retained for lithological description (Table 4). Samples of the angular rock fragments showing weathering were returned to BGS for thin section petrographical description. Two samples were sectioned. Both are highly weathered quartz dolerites made up of intergrown laths of labradorite, orthopyroxene with exsolution lamellae, clinopyroxene, opaque iron oxide and minor amounts of biotite. Quartz occurs as interstitial grains and, less commonly as a granophyric mesostasis. Both samples showed extensive alteration to hydrated iron oxides and brown-stained clay minerals.

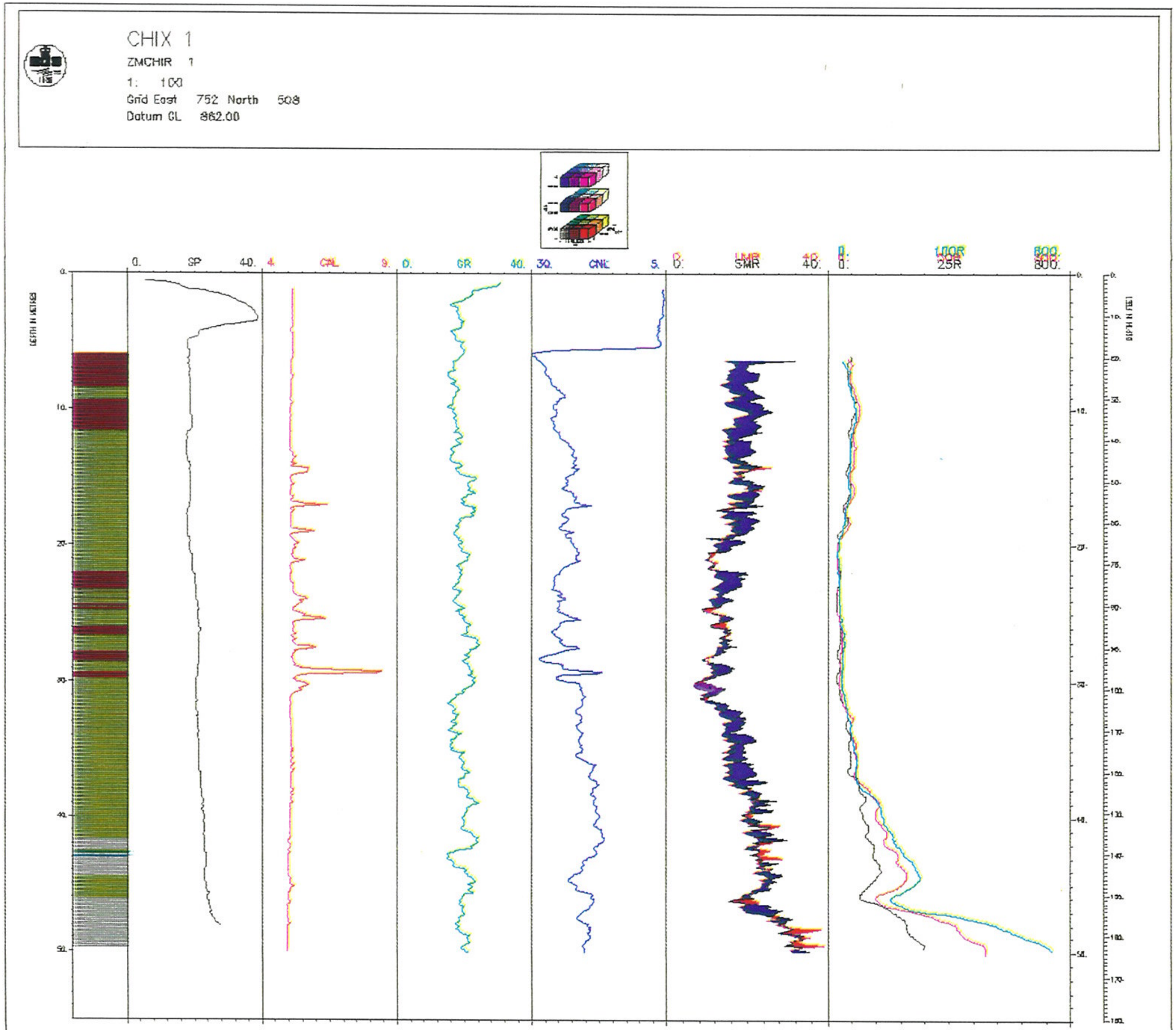

Figure 3. Downhole Geophysical Logs for Exploratory Borehole 1.

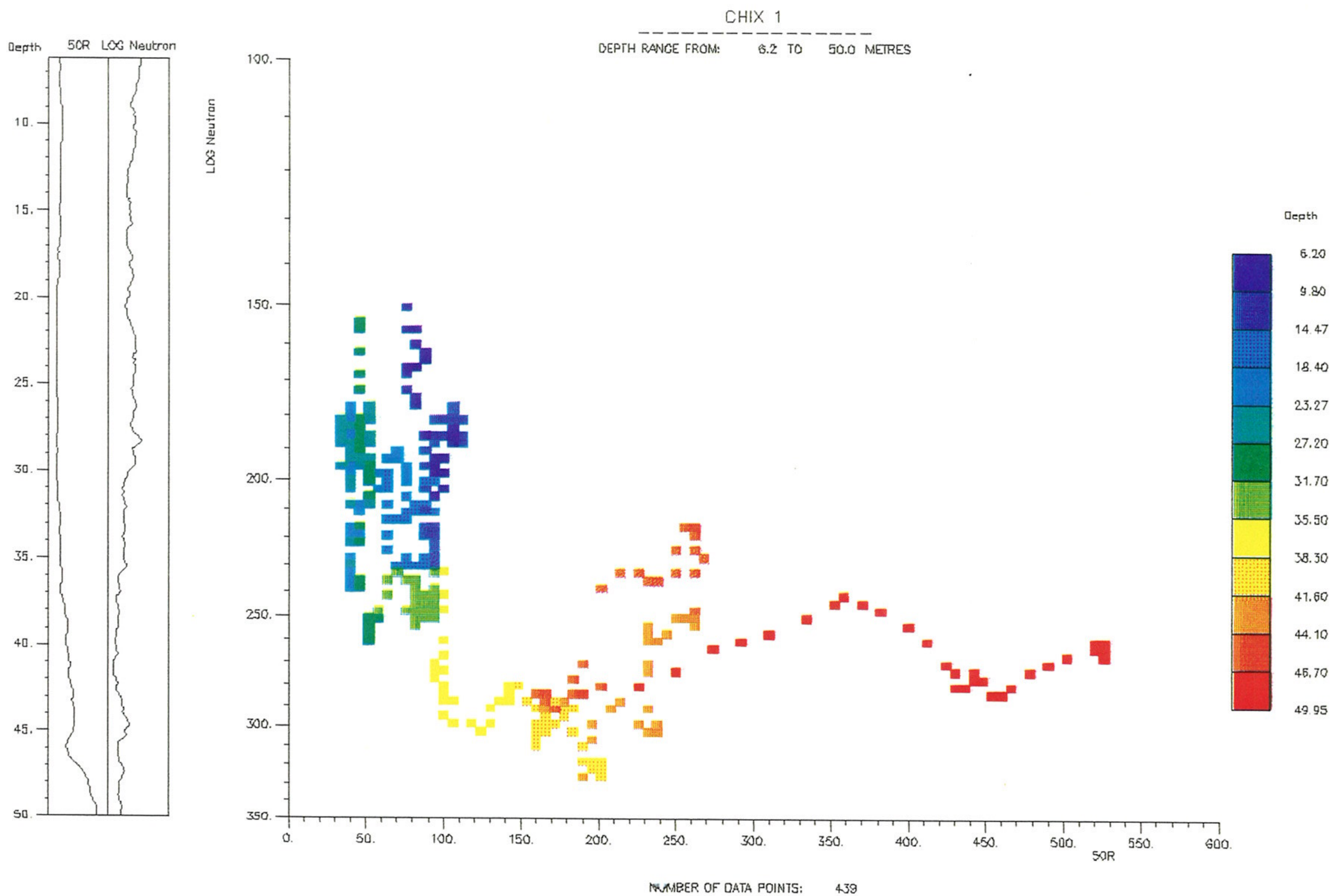

Figure 4. Cross Plot of Neutron Porosity against Normal Resistivity for Borehole 1.

Table 4 Lithological Description of Collector Well Samples

Depth (m)	Description
1	Fragments of creamy-pink concretionary material. Very little clay or sandy material.
2	Large (up to 10 cm), hard, angular fragments of ?dolerite with reddish-brown iron stained, weathered joint faces.
3	Hard, angular fragments of weathered rock with quartz veins. Yellow-red mottling due to weathering.
4	As above. Many thin quartz veins in the rock fragments. The weathered minerals appear yellow-buff and brownish white.
5	As above.
6	As above.
7	Much smaller fragments (1 cm) of weathered igneous rock. Some sand.
8	Mixture of small and large rock fragments. Surfaces of fragments are less weathered and greyer in colour.
9	Mostly small fragments as above.
10	Large and small angular fragments of weathered rock.
11	As above.
12	Small (1-2 cm) hard, angular grey fragments of igneous rock, less weathered, fresher grey on surface, less yellow or buff colouring.

4.2 Radial Drilling

The radial drilling was carried out between 22 and 25 April 1989. Four horizontal laterals were constructed in order, starting from NE, through NW, SW and SE (Figure 5). The first was 29 m long and passed through hard gneiss with bands of quartz and dolerite, and produced an inflow of about 1 l/sec. The second encountered very hard, unbroken rock at 10 m, was dry and was terminated at 10 m. The third is 30 m long, was dry for the first 5 m in hard granitic gneiss and then passed into a more broken dolerite with a considerable amount of clay and yielded very little water. The last lateral encountered a fault only 1.5 m from the well which produced significant water inflow. The lateral was extended to 20 m through alternate hard and soft dolerite layers with little additional water inflow, and completed to 30 m in a very hard, fresh rock.

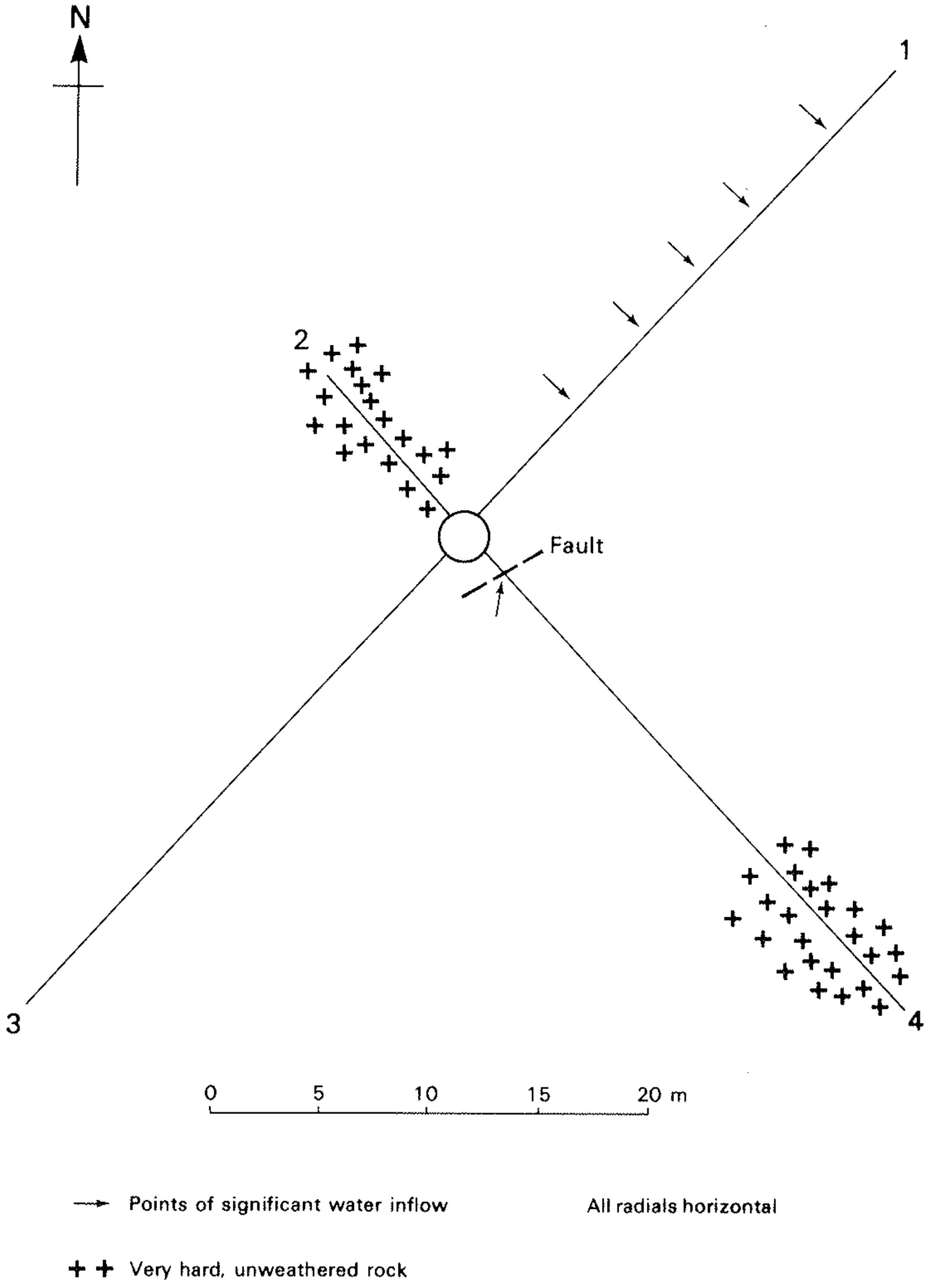

Figure 5. Layout of laterals at Chiredzi collector well.

4.3 Well Completion Works

After the radials were completed, further test pumping was performed and is described in section 5. The well was completed with a brick parapet and a permanent, sturdy access ladder and well cover with brackets to hold an autographic float water-level recorder. The well-head was completed with a 2 m deep sanitary seal and concrete apron around the well, as shown in Figure 6, a cross-section showing the as-built final construction of the well. The well was completed by the installation of a locally-purchased electric centrifugal pump, mounted on a float in the well (Figure 7). The pump is capable of producing 1.2 l/sec and delivers water to the adjacent 18,000 litre irrigation header tank (Figure 8).

5. WELL TESTING

5.1 Before Radial Drilling

Two pumping tests were carried out on the completed well.

	4 April	18 April
Static water level	5.06 m	5.33 m
Duration of pumping	90 mins	100 mins
Pump discharge rate	0.78 l/sec	5.58 l/sec
Final water level (bd)	5.73 m	12.30 m
Final drawdown	0.76 m	5.97 m
25% recovery	105 mins	195 mins
50% recovery	260 mins	-
75% recovery	-	-

The tests were analysed by the nomogram method developed by Barker and Herbert (1989) and the "50% recovery method" of Herbert and Kitching (1981), to give the following transmissivities (T, m^2/d) and storage coefficient (S):

		4 April	18 April	
		T	T	S
Barker and Herbert	25%	-	2.2	0.56
	50%	-	-	-
	75%	-	-	-
Herbert and Kitching	50%	5.5	3.6	

The results of the test of 4 April fall outside the range of values for which the nomogram is applicable.

5.2 After Radial Drilling

After the radials have been completed, the standard procedure is to carry out a test in which the water level is drawn down to pump suction, followed by a longer-term test at a lower pumping rate which simulates the possible operating schedule of the well. The former is compared with the similar test performed on the well before the laterals are constructed, and the latter is used to assess the long-term sustainable yield of the well.

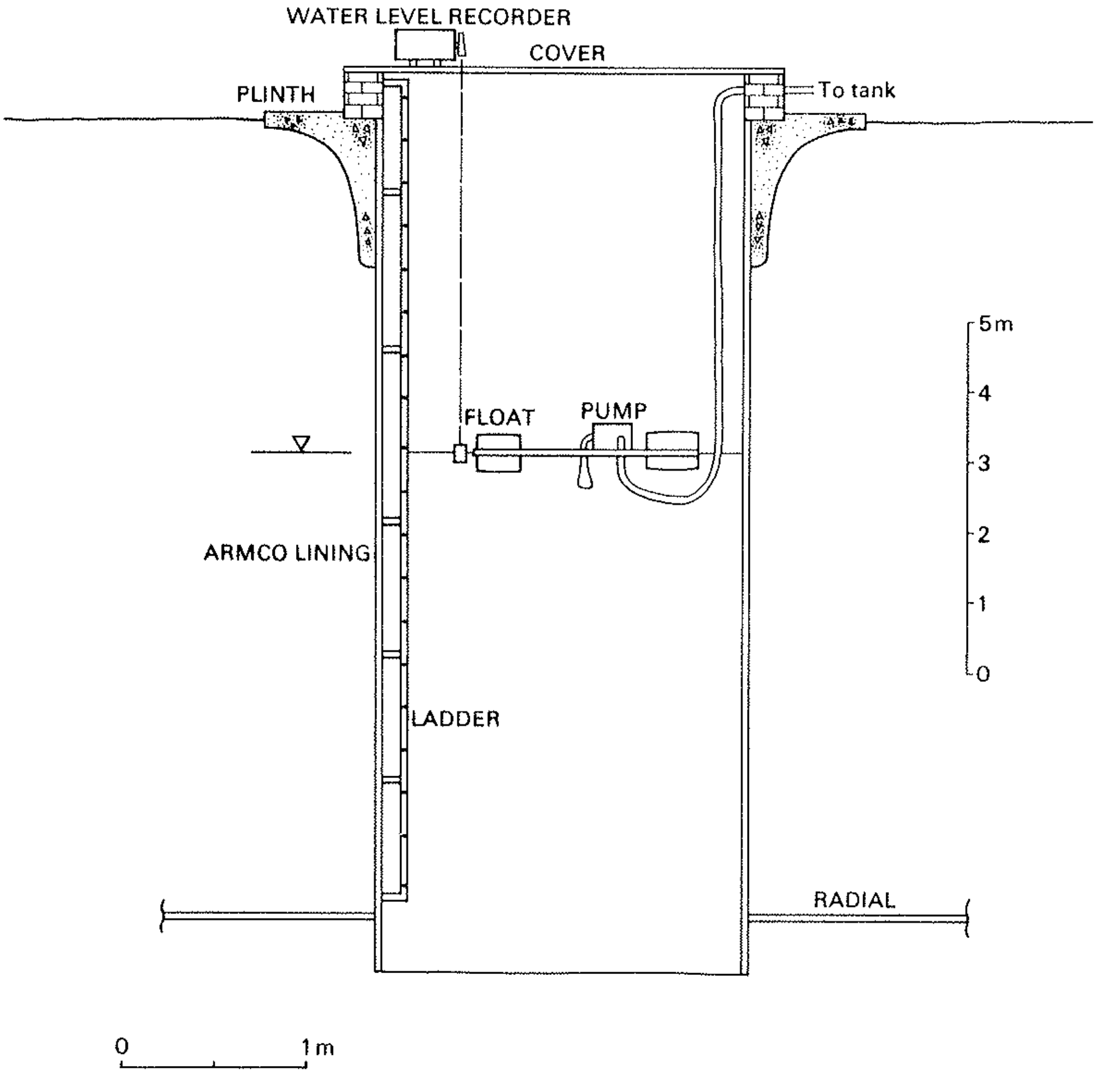

Figure 6. Section showing construction of Chiredzi collector well.

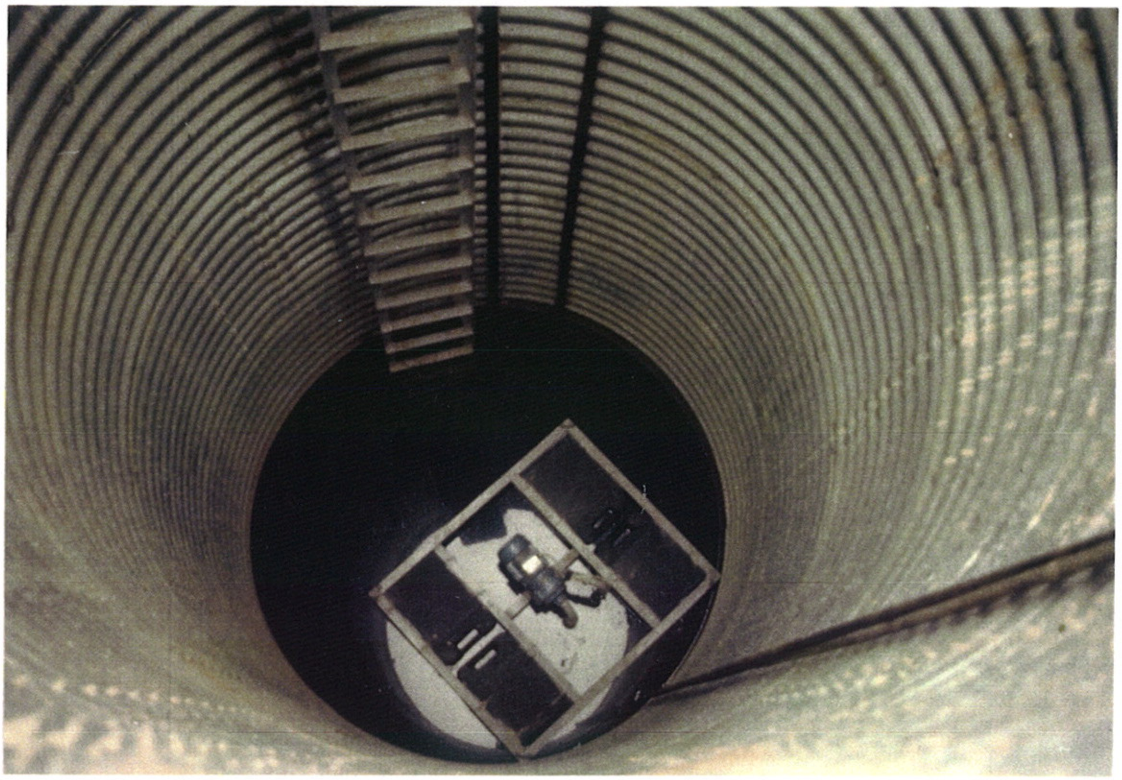

Figure 7. View of Collector Well Showing Pump Mounted on Float.

Figure 8. View Showing Well Headworks and Irrigation Header Tank.

	4 May	3 June
Static water level	5.38 m	5.21 m
Duration of pumping	130 mins	240 mins
Pump discharge rate	5.58 l/sec	1.23 l/sec
Final water level (bd)	12.43 m	7.49 m
Final drawdown	7.05 m	2.28 m
25% recovery	69 mins	60 mins
50% recovery	175 mins	147 mins
75% recovery	365 mins	-

Recovery from 12.0 m to 10.0 m took 94 minutes, compared to 240 minutes for the depth interval before the laterals were drilled. This represents an increase of inflow from 0.44 l/sec before the drilling of the laterals to 1.1 l/sec afterwards, an improvement in yield of 150%.

The tests were analysed in the same way, to give the following transmissivities, (T, m^2/d) and storage coefficients (S):

		4 May		3 June	
		T	S	T	S
Barker and Herbert	25%	0.5	-	3.7	0.56
	50%	1.4	0.56	9.3	0.1
	75%	8.6	0.18	-	-
Herbert and Kitching	50%	7.0		7.1	

The increasing transmissivity implies a degree of partial penetration by the collector well, and the reducing storage coefficient suggests leaky aquifer conditions. The 75% recovery results are therefore most representative of the aquifer characteristics (Wright, 1988). The calculated transmissivities fall within the range (2-10 m^2/d) of the two nearest exploratory boreholes (Table 1).

The long-term test was carried out from 9 to 16 May, following a strict daily regime of three two-hour pumping periods, separated by three hour rest periods. The pump discharge rate was 0.98 l/sec, and pump suction was set at 12.0 m below ground level. Water levels in the neighbouring exploratory boreholes were measured at the beginning and end of each day. Water samples were collected for full chemical analysis close to the beginning and end of the long-term test. The water level information is summarised in Tables 5 and 6 and Figure 9.

The drawdown in the well during the cyclic pumping can be considered in two parts (Wright et al., 1988). The drawdown from beginning to end of pumping each day is fairly constant (Table 5) and averages 1.47 m in this case. In addition, there is an overall, gradual fall in water levels, measured at the beginning of each day's pumping (Table 5 and Figure 9). If these water levels are ploted against log of time since pumping started, the plot is linear and can be extrapolated to predict the drawdown after a prolonged period of pumping at that discharge rate, for example to the end of a dry season.

Table 5 Water Levels in Collector Well at Beginning and End of Each Pumping Period.

Date	06.00	08.00	11.00	13.00	16.00	18.00
9 May	5.34	6.38	5.72	6.65	5.85	6.75
10 May	5.49	6.72	5.92	6.98	6.07	7.05
11 May	5.57	6.76	5.98	7.01	6.13	7.10
12 May	5.70	6.73	5.98	6.97	6.10	7.02
13 May	5.60	6.78	6.02	6.98	6.13	7.10
14 May	5.67	6.77	6.05	7.02	6.17	7.13
15 May	5.68	6.80	6.08	7.08	6.21	7.15
16 May	5.67	6.84	6.09	7.12	6.22	7.19
17 May	-	5.65				

Table 6 Water Levels in Exploratory Boreholes at the Beginning and End of Each Day.

Date and Time		11	12	13	14
9 May	06.00	-	-	-	-
	17.30	3.41	5.10	5.38	5.69
10 May	06.30	3.43	4.96	5.32	5.70
	17.30	3.43	5.31	5.50	5.71
11 May	06.30	3.45	5.01	5.36	5.72
	17.30	3.43	5.32	5.51	5.76
12 May	06.30	3.43	5.01	5.37	5.71
	17.30	3.41	5.31	5.50	5.70
13 May	06.30	3.44	5.04	5.38	5.73
	17.30	3.42	5.34	5.53	5.74
14 May	06.30	3.48	5.10	5.44	5.80
	17.30	3.46	5.38	5.58	5.79
15 May	06.30	3.48	5.12	5.45	5.79
	17.30	3.46	5.49	5.58	5.79
16 May	06.30	3.43	5.12	5.45	5.79
	17.30	3.40	5.39	5.58	5.77
17 May	08.00	3.41	5.58?	5.44	5.79

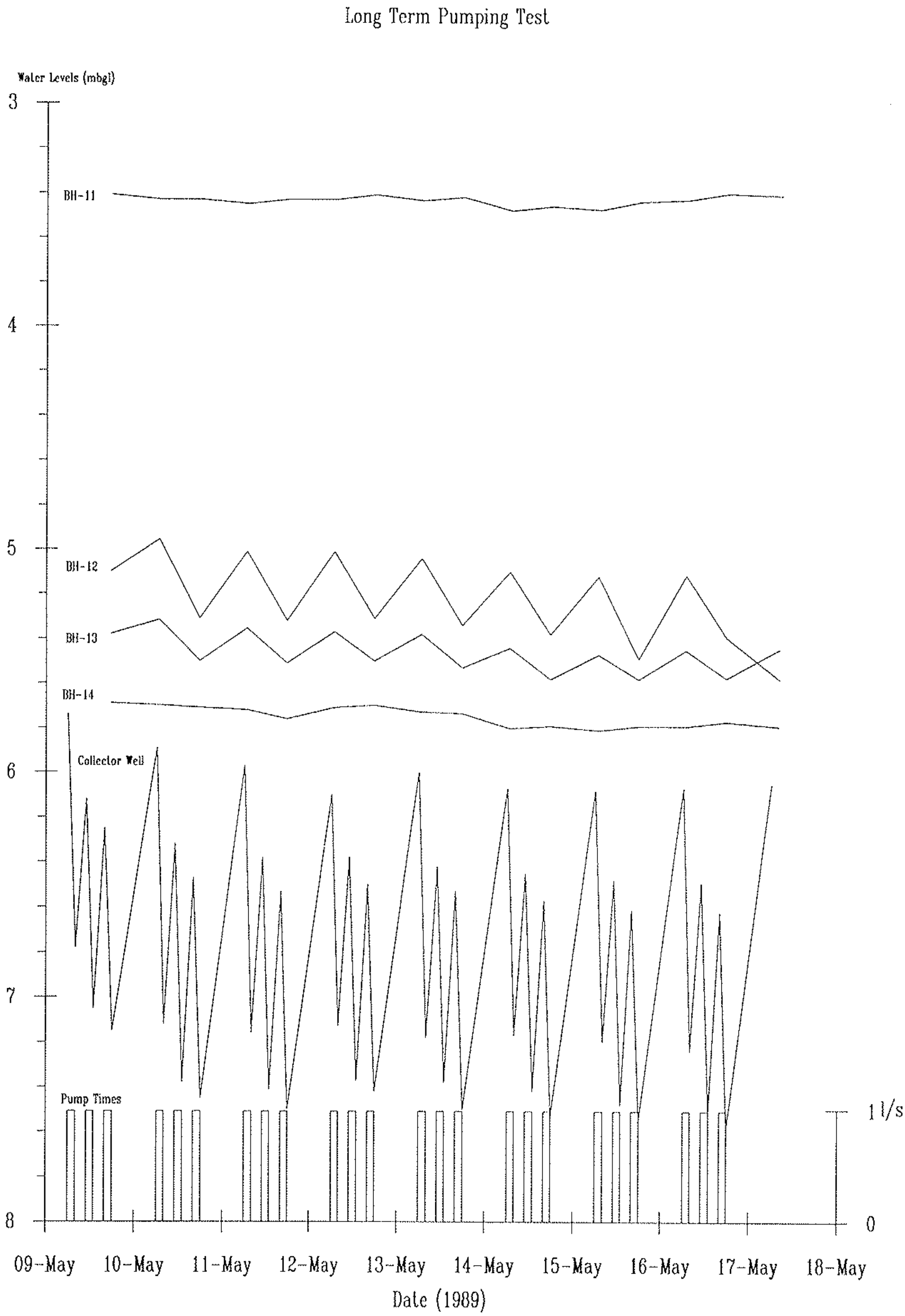

Figure 9. Pumping periods and water levels in long-term test.

Thus, if the background drawdown at the pumping test rate of Q_0 is S_{200} after 200 days, and the extra drawdown during the daily pumping regime is S_E and if the available drawdown in the well is S_A then the long-term safe discharge Q_s is given by:

$$Q_s = Q_0.S_A/(S_{200} + S_E)$$

In this case:

$$Q_s = 0.98 \times (11.5 - 5.3)/(0.58 + 1.47) = 2.97 \text{ l/sec}$$

This figure is, of course, only an approximate one. Drawdowns can be considered as roughly proportional to discharge, and the straight line extrapolation is subject to error (Figure 10). This extrapolation also assumes that no adverse hydrogeological boundary conditions are encountered during pumping.

In addition, the standard Jacob method has been applied to the long-term test, using the semi-log plot. The transmissivity obtained (Figure 10) is twice as high as that obtained from the exploratory boreholes (Table 1) and the short-term tests, which may confirm the 'leaky' nature of the aquifer, although other explanations are also possible. This phenomenon has been widely observed (Wright et al., 1988). The transmissivity obtained from this analysis of the long-term test may provide a better estimate of the 'regional' transmissivity.

6. WELL COSTS

6.1 Costs of Well Siting

The collector well site at LVRS, Chiredzi was selected on the basis of the exploratory drilling. No geophysical exploration was carried out, and the cost of siting is thus the cost of exploratory drilling. Nine boreholes were drilled at the research station using a Holman lightweight air hammer rig and crew borrowed from MEWRD.

It is not easy to isolate and provide an accurate figure for the drilling costs, principally because of the way such activities are accounted for in MEWRD. Nevertheless, an estimate is given, based on the cost of the crew and the time taken, together with the costs of fuel and other consumables and the cost of casing left in the observation boreholes (Table 7). All costs are quoted in Zimbabwe Dollars, at approximately 3.5 to the pound sterling.

To this must be added consumables in the form of two 110 mm button drilling bits for the rig at Z$700 each. The labour, fuel and casing costs are the actual costs incurred. The plant and vehicle costs and the test pumping are estimated on the basis of an eight-hour working day and hire charges for rig, truck, compressor and pump of Z$25 per hour. In fact the rig and compressor were loaned by MEWRD free of charge for this work, and the vehicle and pump were provided by the earlier collector well project, so the direct cost of the exploratory drilling is less than the total given in Table 7 below.

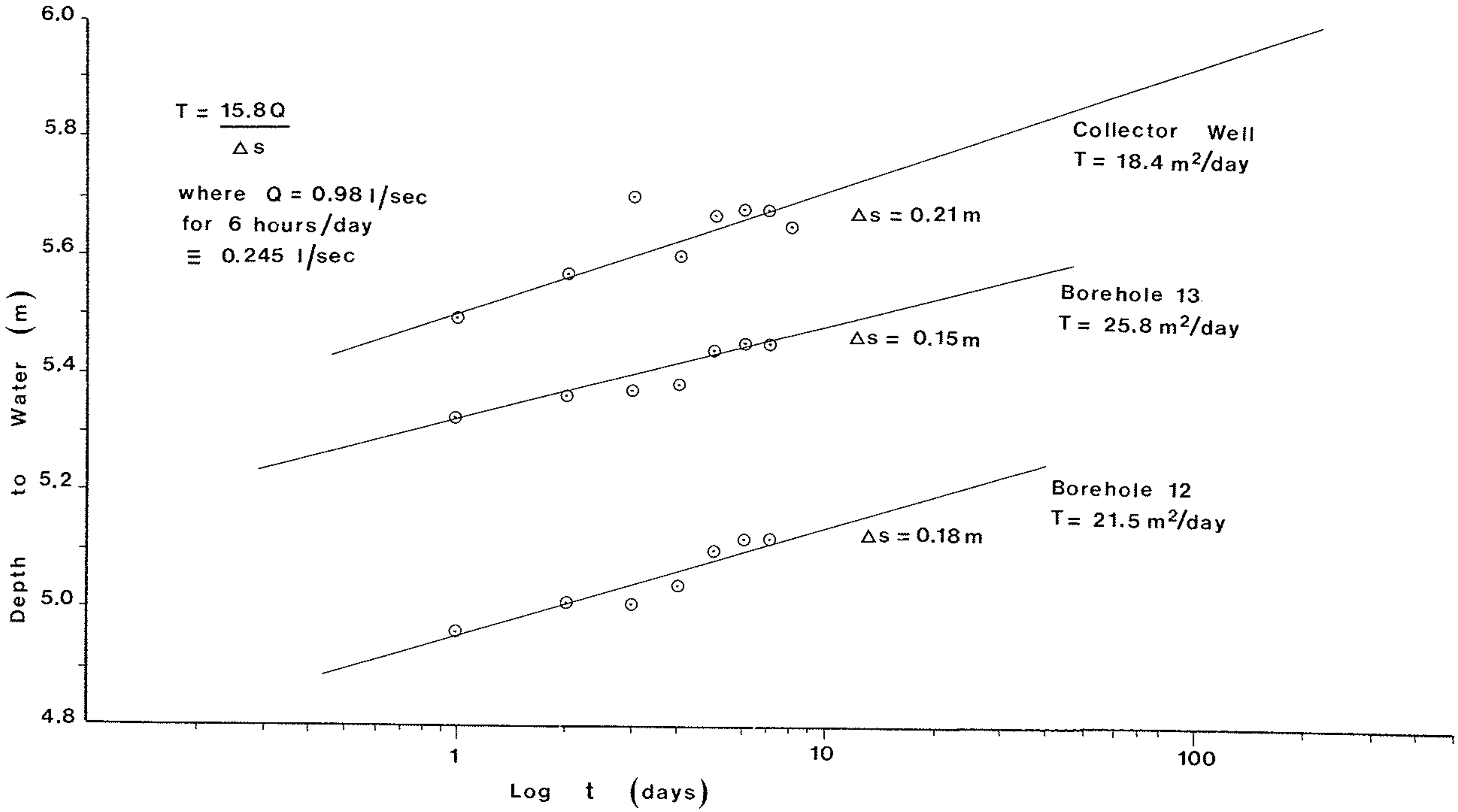

Figure 10. Water levels at beginning of first of daily pumping cycles.

Table 7 Costs of Exploratory Drilling.

Borehole Number	Labour	Fuel	Rig, Truck Compressor	Casing	Test Pumping	Total
1	60	126	600	420	250	1456
2	120	150	1200	70	250	1790
8	60	126	600	-	250	1036
9	60	60	375	-	-	495
10	60	60	375	-	-	495
11	60	60	375	350	-	845
12	60	60	375	490	250	1235
13	60	60	375	210	250	955
14	60	60	375	210	-	705
	600	762	4650	1750	1250	9012

6.2 Well Construction Costs

Well construction was carried out by locally employed labourers and a foreman paid for from BGS project funds, and supervised by the BGS contract driller. A detailed summary of the direct costs of construction can be given. Table 8 lists the local costs incurred during the construction and testing period. They do not include the cost of the BGS contract driller.

Table 8 Local Costs of Well Construction, by Month

Month	Labour	Diesel	Misc.	Total
Feb	454	367	234	1055
Mar	1334	946	818	3098
Apr	867	713	50	1630
May	74	126	43	243
Totals	2729	2152	1145	6026

The personnel involved in the construction of the well comprise four casual labourers at Z$4.85 per day and one foreman at Z$350 per month. The monthly salary bill includes considerable amounts of overtime for working at weekends and on public holidays. Most of the diesel cost is for the use of the MEWRD compressor which was loaned free of charge for this work. If it had been necessary to hire a compressor, the rate would have been Z$25 per hour, and the total cost of the compressor use would have been several thousand dollars. In a large development project in which numbers of collector well installations were to be produced, provision of a compressor would be included in the capital expenditure at the beginning of the project. Assuming a working life of ten years, provision of spares at 5% per annum, the construction of nine collector wells per annum and an annual interest rate of 5%, then the present values of the cost of compressor per well is Z$440 (Herbert, 1989). This figure is used in the present cost estimate.

Well costs can also be broken down by operation (Table 9). The total direct costs of construction, testing and equipping the collector well at LVRS Chiredzi are therefore about Z$14,500, to which must be added the direct costs of siting of Z$4400. The total cost of the completed well is therefore about Z$19,500 which includes the allowance of Z$440 for the compressor.

This compares with costs of Z$24,000 to Z$28,000 for 2 m diameter wells of brick caisson construction (Wright et al., 1988). Detailed costs for the two collector wells at Wenimbi and Gutu are not available, but it is likely that they were below Z$25,000. Neither previous cost estimates for these wells nor those for Chiredzi include the costs of BGS staff on the project. Even allowing for possible non-inclusion of some costs, it would appear that construction costs are being brought down, especially as the Chiredzi costs include permanent pumping plant.

At Chiredzi, about half the cost of well construction is in the imported Armco lining, of which 60 m were shipped to Zimbabwe for the project. Locally-produced, thin-wall culvert lining had been tried in the collector well at Chinkwiri, but proved to have insufficient strength to maintain its form during installation. If suitable Armco-type lining material could be obtained locally, then further cost savings might be achieved. Enquiries have been made to establish whether local provision of similar bolted segment lining is technically and economically feasible. Because of the high cost of importing steel plate, and the difficulty of obtaining foreign exchange facilities to do this, local supply appears unlikely. However, digging experience now shows that the Armco which was imported is probably over-specified, and some further cost savings could be made by using a 2 mm or 2.5 mm plate thickness.

7. WELL OPERATION

A programme of hydrogeological measurements is being carried out by LVRS, IH and BGS at and around the well. This is to help evaluate the feasibility of collector well-based irrigation by careful monitoring of the well's performance.

Table 9 Costs of Collector Well, Lowveld Research Station

	Well Construction	Short-term Testing and Lateral Drilling	Long-term Test	Installation of Permanent Pump
Salaries	1938	717	74	-
Diesel/Fuel	1333	693	126	-
Digging Tools and Equipment	525	-	-	-
Cement	196	-	-	-
Sand and Gravel	267	-	-	-
Boots and Hard Hats	130	-	-	-
Armco Lining (12 m @ Z$626/m)	7512	-	-	-
Electric Pump	-	-	-	751
Delivery Pipes, Hoses and Fittings	-	-	-	455
Ladder	-	-	-	147
Pump Float	-	-	-	182
	11930	1410	200	1535

Table 10 Hydrogeological Monitoring Programme at Chiredzi

Measurement	Frequency	From Date	Remarks
Water levels in collector well	Continuous	6/89	Float recorder. Weekly chart.
Well discharge	As operated	6/89	Meter from 12/89. Pumping time logs. Volume to tank as occasional check.
EC, chloride of well discharge	Monthly	11/89	At end of a pumping period
Water levels in exploratory boreholes	Weekly	10/88	-
Chloride in rainfall	Aggregate over month	4/90	Analysis at BGS.
EC, chloride of canal water	Monthly	6/89	
Full chemical analysis of well water	Infrequent	5/89	Analysis at BGS
Full chemical analysis of canal water	Infrequent	6/89	Analysis at BGS
Stable isotopes	Infrequent	-	Analysis at BGS

Monitoring of water levels in the exploratory boreholes at LVRS now provides data over two rainy seasons (Figure 11). In the early part of 1989, water levels in boreholes 11 to 14 decline somewhat, probably in response to the dewatering of the collector well during construction. This is followed by more extreme fluctuations in April and May (Figure 11), caused by the dewatering for construction of the laterals, and the test pumping. Water levels appear to then recover through the remainder of 1989. The peak and steep decline in early 1990 may be a seasonal response to the 1989-90 rainfall (Figure 11). Although this is seen in borehole 1, it is not apparent in boreholes 8 and 10, which appear to show no seasonal responses. Monitoring as outlined in Table 10 will continue for the duration of the project.

Operation of the well to provide water for irrigation trials commenced in June 1989. Table 11 shows the volume of groundwater abstracted in each weekly period since operation began. Figure 12 shows the water level in the collector well over this period, together with abstraction volumes taken from Table 11 and weekly rainfall at Chiredzi.

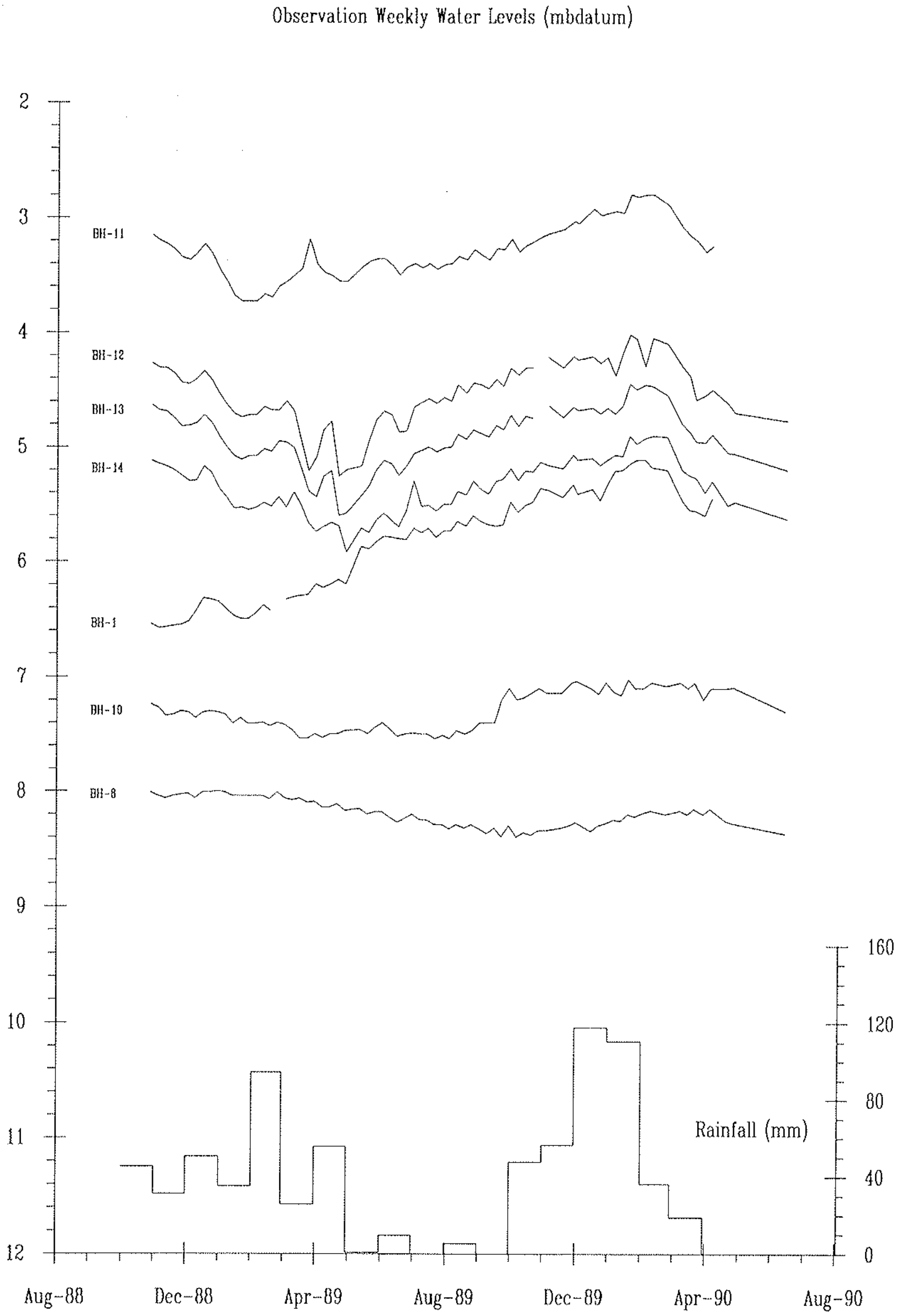

Figure 11. Water levels in exploratory boreholes and rainfall at LVRS.

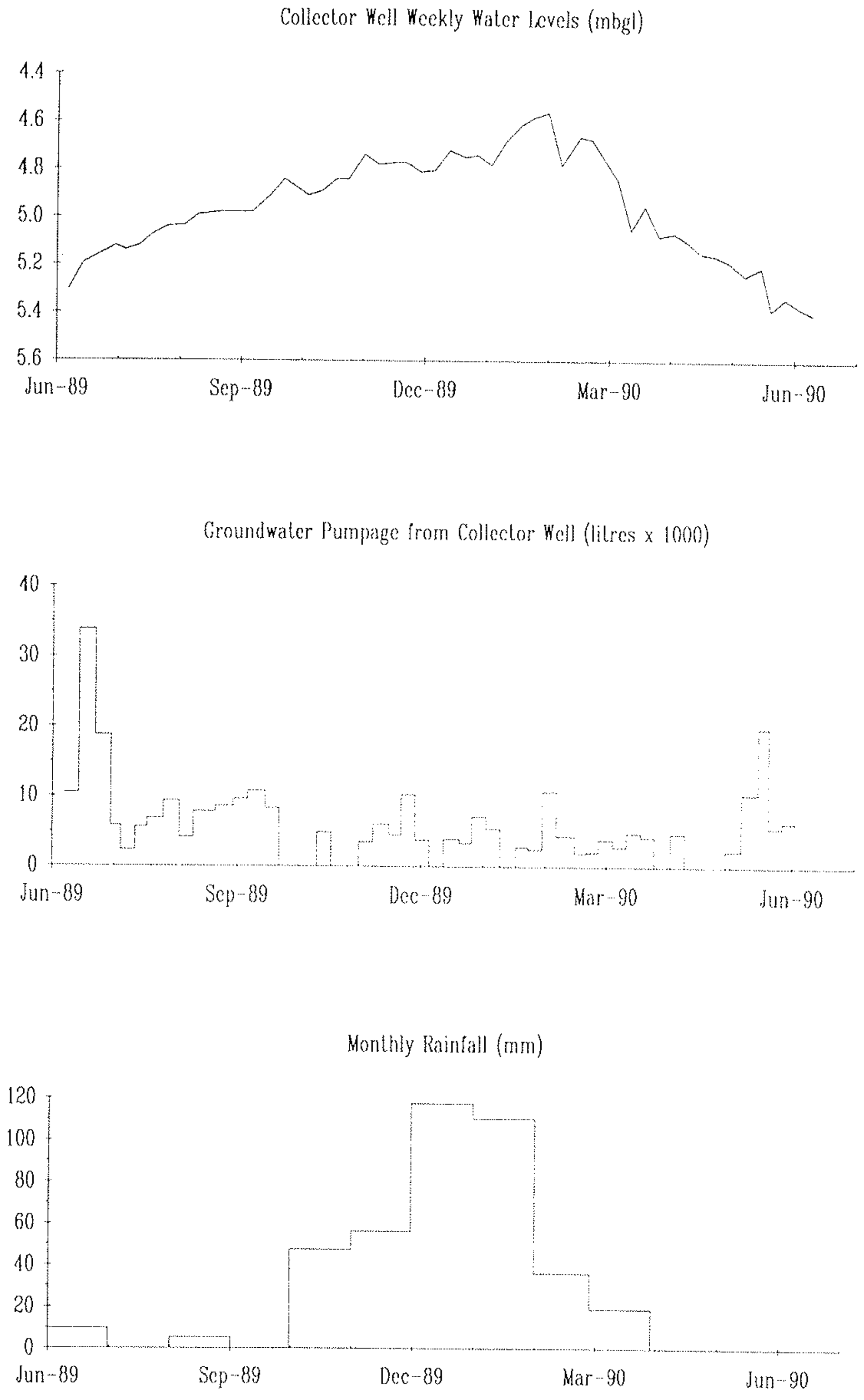

Figure 12. Collector well pumpage, water level, and rainfall at LVRS.

Table 11 Groundwater Pumpage from Collector Well

Trace No.	Dates	Times Pumped	Volume (litres)	Trace No.	Dates	Times Pumped	Volume (litres)
	1989				1990		
1	7/6 - 14/6	2	10,450	28	3/1 - 10/1	1	5,380
2	14/6 - 22/6	5	33,900	29	10/1 - 18/1	-	nil
3	22/6 - 30/6	3	18,750	30	18/1 - 24/1	1	2,870
4	30/6 - 5/7	1	5,850	31	24/1 - 31/1	1	2,475
5	5/7 - 12/7	1	2,350	32	31/1 - 7/2	3	10,735
6	12/7 - 20/7	2	5,650	33	7/2 - 16/2	1	4,430
7	20/7 - 26/7	3	6,850	34	16/2 - 22/2	1	2,040
8	26/7 - 3/8	4	9,350	35	22/2 - 28/2	1	2,130
9	3/8 - 10/8	2	4,150	36	28/2 - 7/3	1	3,860
10	10/8 - 21/8	3	7,800	37	7/3 - 14/3	1	2,900
11	21/8 - 30/8	4	8,600	38	14/3 - 21/3	2	4,840
12	30/8 - 6/9	2	9,600	39	21/3 - 28/3	1	4,240
13	6/9 - 14/9	2	10,800	40	28/3 - 5/4	-	nil
14	14/9 - 22/9	2	8,300	41	5/4 - 12/4	1	4,790
	22/9 - 4/10	- - no chart - -		42	12/4 - 18/4	-	nil
15	4/10 - 11/10	0	nil	43	18/4 - 25/4	-	nil
16	11/10 - 18/10	1	4,900	44	25/4 - 2/5	-	nil
17	18/10 - 24/10	0	nil	45	2/5 - 10/5	1	2,400
18	24/10 - 1/11	0	nil	46	10/5 - 18/5	2	10,410
19	1/11 - 8/11	1	3,550	47	18/5 - 23/5	3	19,880
20	8/11 - 16/11	2	6,050	48	23/5 - 30/5	1	5,610
21	16/11 - 22/11	1	4,510	49	30/5 - 6/6	2	6,360
22	22/11 - 29/11	2	10,250				
23	29/11 - 6/12	1	3,850				
*24	6/12 - 13/12	0	nil				
25	13/12 - 21/12	1	3,950				
26	21/12 - 27/12	1	3,400				
27	27/12 - 3/1	2	7, 150				

* meter installed 8/12

Abstraction from the well averages only 850 l/d over this period. This is much less than the estimated safe yield (approximately 65,000 l/d) and the present installed pumping capacity (22,000 l/d), reflecting the extremely efficient water use of the irrigated cultivation trials. Currently about 0.4 ha is being irrigated (Batchelor et al., 1990) from the well, clearly the potential is there to irrigate a considerably larger area. Monitoring of water levels and abstraction will continue (Table 10) to the end of the project.

The results of chemical analyses of water drawn from the collector well are shown in Table 12. Water from the well plots as high salinity hazard (750-2250 μS/cm, USDA, 1954) and low sodium hazard (sodium adsorption ratio, SAR 1.8).

Table 12 Summary of Chemical Analyses at Chiredzi

Location	Date	EC ($\mu S/cm$)	Na	K	Ca	Mg	Alkalinity as HCO_3	SO_4	Cl	NO_3-N	Si	Sr	Fe
Collector Well (long test)	09.05.89	-	76	0.7	62	58	628	30.2	31.0	3.4	26.4	0.35	0.02
"	16.05.89	-	76	0.8	61	59	621	25.2	33.3	5.0	27.3	0.35	0.02
Collector Well (20 mins pumping)	03.06.89	997	79	0.7	73	59	651	26.0	33.0	4.8	27.5	0.38	0.02
(220 mins pumping)	03.06.89	978	78	0.7	70	59	631	25.2	33.5	4.6	27.6	0.38	0.02
Collector Well	06.04.90	-	86	1.0	68.7	66.4	604	41.3	60.5	0.5	-	-	-
Canal	06.06.90	78	6.6	2.3	5.5	2.7	41	3.0	4.5	0.08	6.7	0.04	0.37
	06.04.90	-	5.9	3.0	4.9	2.0	34	4.2	6.0	0.5	-	-	-

all figures in mg/l unless stated

8. PRELIMINARY CONCLUSIONS AND FUTURE WORK

The principal outcome of the hydrogeological component of the study to date is that a highly successful well has been constructed at LVRS Chiredzi. The well has operated for a year at about 4% of the installed capacity, and 1½% of the estimated long term yield. If irrigation were carried out with the same high efficiency, up to 30 ha could theoretically be watered from the one well, although practical considerations of water distribution and limitations imposed by the use of manual or animal-powered pumps mean that this would not be achieved. Nevertheless, there is clearly considerable scope for extending the area under investigation.

With an average annual rainfall of about 450 mm, the Chiredzi area is considerably drier than any of the other successful collector well locations in Zimbabwe. Consideration must be given, therefore, to the extent to which the local hydrogeological conditions at LVRS might be unique, or might be replicated elsewhere in the region and if so how further good sites might be identified. The local hydrogeological factors favourable to well construction, i.e. deep weathering, moderate to good hydraulic conductivity and shallow water levels, relate to both geology and groundwater recharge conditions.

The area around Chiredzi is underlain by paragneisses of the Beit Bridge Group of early Precambrian age. This is the first collector well site in these rocks. They form part of the Limpopo Mobile Belt with dominantly ENE-WSW structural trends, parallel to which are intruded numerous dolerite dykes. The depth of weathering at LVRS, based on the results of the exploratory drilling (Table 1), is considerable, usually 20 to 30 m. A depth of weathering of at least 35 m is also suggested by the geophysical logging of borehole 1.

The collector well itself is constructed in weathered dolerite. This is evident from visual examination of the excavated material and from thin sections. Some of the exploratory boreholes (Table 1) encountered basement gneiss and others are drilled in the dolerite. Doleritic intrusions are clearly small but plentiful in this area. From the limited test pumping results obtained from these boreholes, there is no clear correlation between performance and geology. The best borehole (no. 1, Table 1) is in the dolerite and the second best (no. 12) is in the gneiss. Turning to the well itself, information from the construction of the laterals also suggests the importance of local geological factors. The hardest rock was encountered in laterals 2 and 4 (Figure 5) at right angles to the main structural trend, and much of the water inflow was in lateral 1 parallel to the trend.

Thus local geological factors are probably important in determining collector well performance. Both rock type and structural features, joints and lineations, may affect the depth and nature of weathering. Information obtained from Chiredzi will be put together with that from other collector well sites and exploratory drilling in the region and the results of parallel research on borehole and well siting being carried out by BGS Keyworth in a general review of collector well siting criteria. Particular consideration will be given to controls on the depth of weathering.

Water levels at Chiredzi are less than 10 m below ground at all sites drilled (Table 1). In the region of the collector well, they are within 5 m of the ground surface, and thus highly favourable for a well. Records of rural water supply boreholes constructed in the Lowveld, some limited exploratory drilling early in the project away from LVRS show that water levels are often much deeper. It has been suggested that the high water levels at LVRS Chiredzi may result from enhanced recharge from the irrigated sugar estates to the south. Certainly the irrigated land and the canal is close (Figure 2) and has received Lake Kyle water for many years. It is possible that the storage reservoirs on the station (Figure 2) might also act as a source of recharge, although this seems less likely as they are small and probably heavily silted. The canal itself is lined.

A further possible source of localised recharge is the vlei which runs north-south through the station, and is said to collect excess runoff from the airfield and the main road in very heavy rain. The line of exploratory boreholes 11 to 14 (Figure 2) was located at right angles to the vlei. Depth to water increases with topography away from the vlei (Table 1).

Further work will be carried out in 1991 to investigate the question of localised recharge. It is planned to construct a number of additional, shallow, water table monitoring points. By levelling in the whole local network, a water table contour map will indicate the principal directions of groundwater flow and presence of any recharge mounds caused by localised sources of infiltration. Secondly, samples of local groundwater, regional groundwater and possible surface water recharge sources will be collected for detailed chemical and stable isotope analysis to try to determine if these sources of recharge could be important.

The next principal objective of the project is to establish gardens using the combination of collector wells and efficient irrigation at sites in communal lands. A site has been selected at Tamwa Kraal in Chivi Communal Lands and a collector well has been constructed. The results from that and any subsequent sites, and the continuing monitoring and additional work at Chiredzi will be the subject of future reports within this project. Additional hydrogeological activities may include modelling of the test pumping results from the collector wells.

ACKNOWLEDGEMENTS

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APPENDIX 1 Results of Test Pumping of Exploratory Boreholes

Borehole Number	Transmissivity (m^2/d) Drawdown	Recovery
1	20.9	53.3
1	20.3	-
2	0.53	0.52
8	1.41	1.36
12	9.4	10.2
12	8.1	10.2
13	2.15	2.34

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 15mm A.G.L.
PUMPING RATE: 0.6666667 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0003
WELL NO.: BH/1
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 6.95m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
2	9	0	0.00	6.950	0.000	0.6667
2	9	3	2.50	7.090	0.140	0.6667
2	9	3	3.00	7.120	0.170	0.6667
2	9	4	3.50	7.160	0.210	0.6667
2	9	4	4.00	7.190	0.240	0.6667
2	9	5	4.50	7.220	0.270	0.6667
2	9	5	5.00	7.240	0.290	0.6667
2	9	6	6.00	7.330	0.380	0.6667
2	9	7	7.00	7.370	0.420	0.6667
2	9	8	8.00	7.390	0.440	0.6667
2	9	9	9.00	7.420	0.470	0.6667
2	9	10	10.00	7.420	0.470	0.6667
2	9	12	12.00	7.470	0.520	0.6667
2	9	14	14.00	7.490	0.540	0.6667
2	9	16	16.00	7.500	0.550	0.6667
2	9	18	18.00	7.510	0.560	0.6667
2	9	20	20.00	7.540	0.590	0.6667
2	9	22	22.00	7.540	0.590	0.6667
2	9	24	24.00	7.560	0.610	0.6667
2	9	26	26.00	7.590	0.640	0.6667
2	9	28	28.00	7.620	0.670	0.6667
2	9	30	30.00	7.650	0.700	0.6667
2	9	32	32.00	7.650	0.700	0.6667
2	9	35	35.00	7.690	0.740	0.6667
2	9	40	40.00	7.700	0.750	0.6667
2	9	45	45.00	7.680	0.730	0.6667
2	9	50	50.00	7.750	0.800	0.6667
2	10	0	60.00	7.820	0.870	0.6667
2	10	10	70.00	7.850	0.900	0.6667
2	10	20	80.00	7.880	0.930	0.6667
2	10	30	90.00	7.890	0.940	0.6667
2	10	40	100.00	7.910	0.960	0.6667
2	11	0	120.00	7.960	1.010	0.6667
2	11	20	140.00	7.990	1.040	0.6667
						VALUE USED 0.6667

BRITISH GEOLOGICAL SURVEY

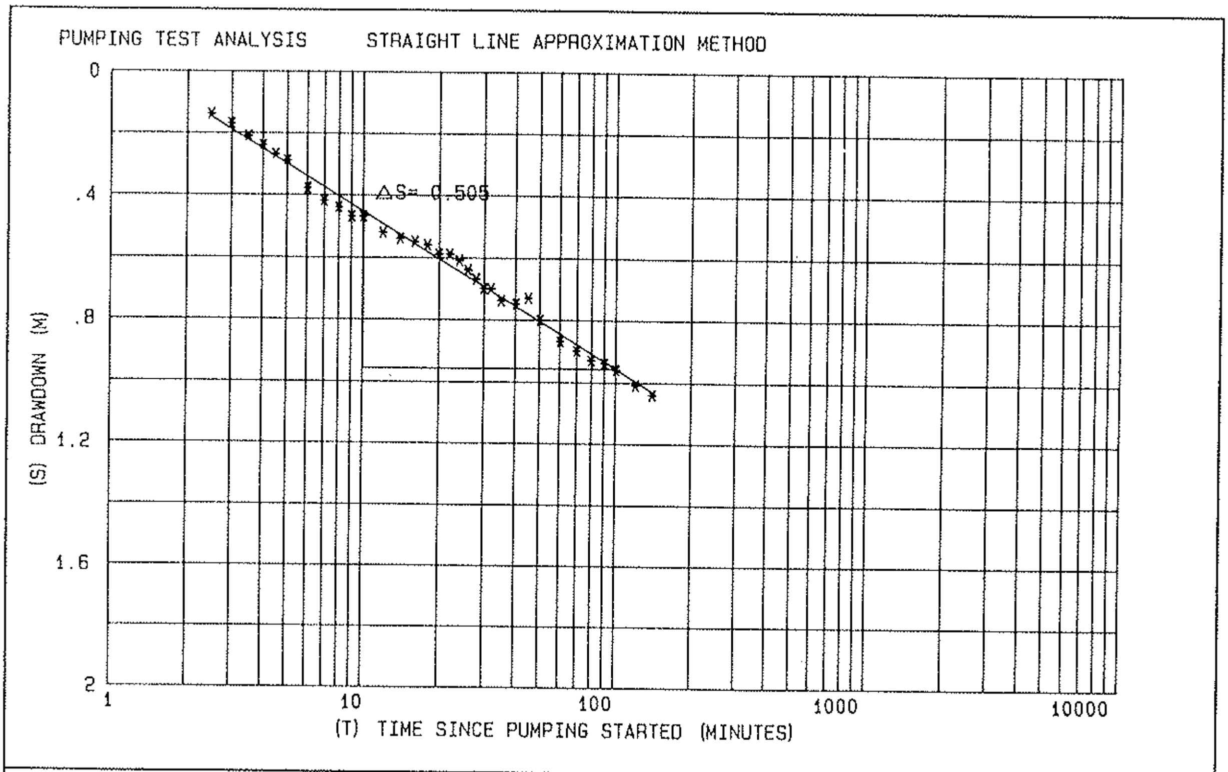
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 15mm A.G.L.
PUMPING RATE: 0.6666667 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0003
WELL NO.: BH/1
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 6.95m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t′ (MIN)	t/t′	(m)	(m)
2	11	21	140.50	0.50	281.00	7.530	0.580
2	11	21	141.00	1.00	141.00	7.480	0.530
2	11	22	141.50	1.50	94.33	7.430	0.480
2	11	22	142.00	2.00	71.00	7.410	0.460
2	11	23	142.50	2.50	57.00	7.390	0.440
2	11	23	143.00	3.00	47.67	7.380	0.430
2	11	24	143.50	3.50	41.00	7.375	0.425
2	11	24	144.00	4.00	36.00	7.370	0.420
2	11	25	144.50	4.50	32.11	7.370	0.420
2	11	25	145.00	5.00	29.00	7.365	0.415
2	11	26	146.00	6.00	24.33	7.360	0.410
2	11	27	147.00	7.00	21.00	7.350	0.400
2	11	28	148.00	8.00	18.50	7.350	0.400
2	11	29	149.00	9.00	16.56	7.340	0.390
2	11	30	150.00	10.00	15.00	7.330	0.380
2	11	32	152.00	12.00	12.67	7.315	0.365
2	11	34	154.00	14.00	11.00	7.300	0.350
2	11	36	156.00	16.00	9.75	7.290	0.340
2	11	38	158.00	18.00	8.78	7.270	0.320
2	11	40	160.00	20.00	8.00	7.265	0.315
2	11	42	162.00	22.00	7.36	7.260	0.310
2	11	44	164.00	24.00	6.83	7.250	0.300
2	11	46	166.00	26.00	6.38	7.245	0.295
2	11	48	168.00	28.00	6.00	7.230	0.280
2	11	50	170.00	30.00	5.67	7.230	0.280
2	11	52	172.00	32.00	5.38	7.220	0.270
2	11	55	175.00	35.00	5.00	7.210	0.260
2	12	0	180.00	40.00	4.50	7.195	0.245
2	12	5	185.00	45.00	4.11	7.180	0.230
2	12	10	190.00	50.00	3.80	7.175	0.225
2	12	20	200.00	60.00	3.33	7.150	0.200
2	12	30	210.00	70.00	3.00	7.130	0.180
2	12	40	220.00	80.00	2.75	7.120	0.170
2	12	50	230.00	90.00	2.56	7.100	0.150
2	13	0	240.00	100.00	2.40	7.090	0.140

BRITISH GEOLOGICAL SURVEY



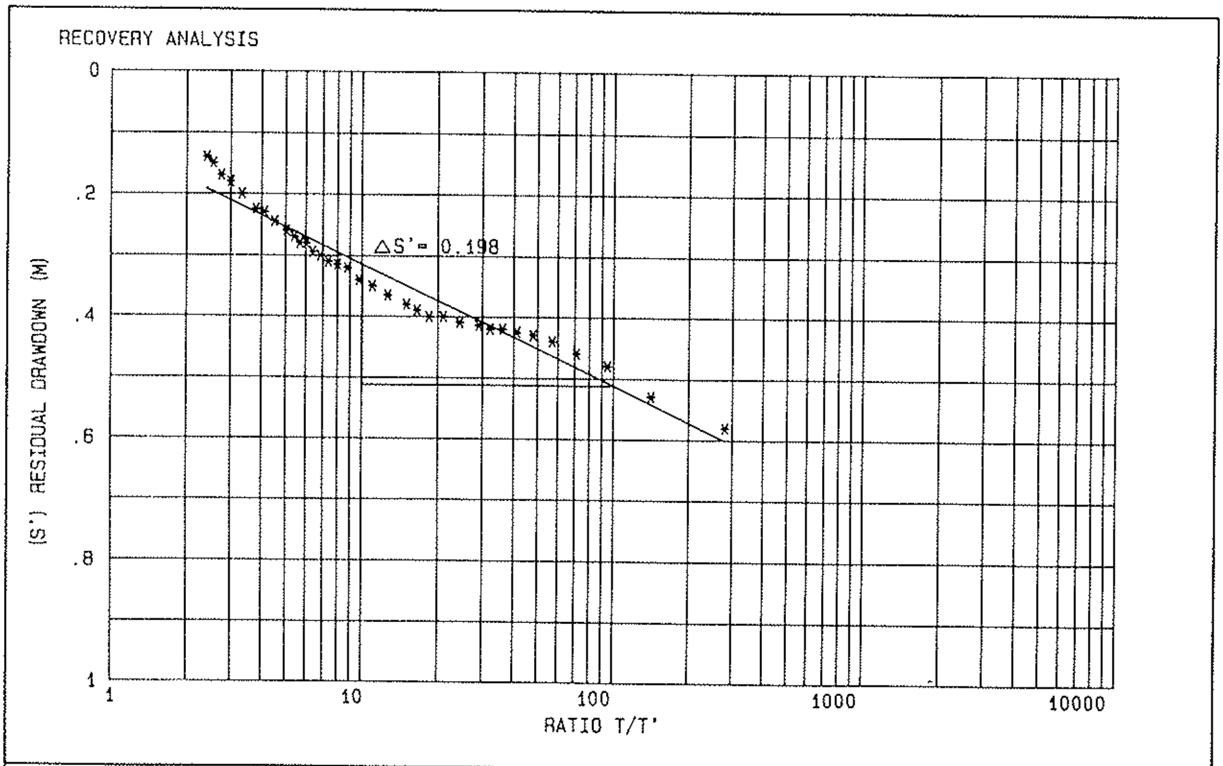
PROJECT: ZIMBABWE
FILE: 0003
LOCATION: CHIREDZI

WELL NO.: BH/1
Q= .6666667 L/S
S.W.L.= 6.95m

ΔS= 0.505 M
T= 20.909 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 1



PROJECT: ZIMBABWE
FILE: 0003
LOCATION: CHIREDZI

WELL NO.: BH/1
Q= .6666667 L/S
S.W.L.= 6.95m

ΔS'= 0.198 M
T= 53.325 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 2

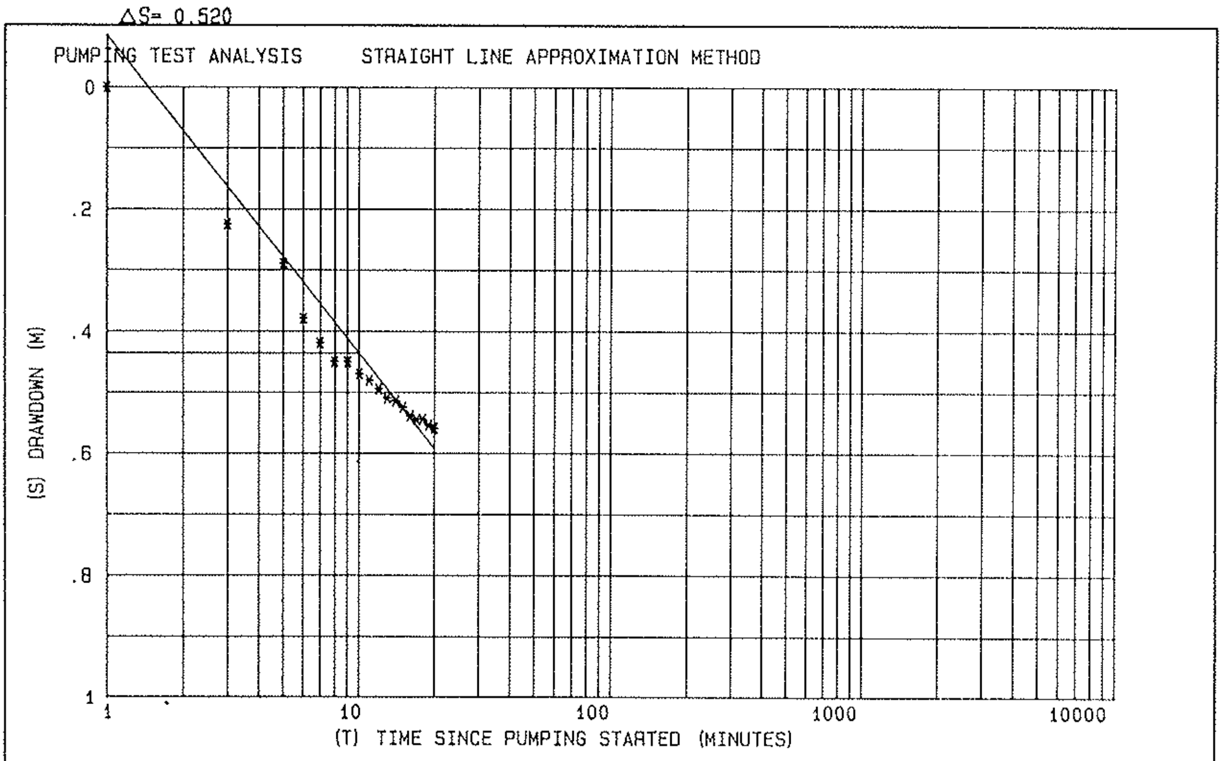
PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 30mm A.G.L.
PUMPING RATE: 0.6666667 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0002
WELL NO.: BH/1
ELEV. OF DATUM POINT:
STATIC WATER LEVEL:
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
1	14	1	1.00	7.820	0.000	0.6667
1	14	2	2.00	7.810	-0.010	0.6667
1	14	3	3.00	8.045	0.225	0.6667
1	14	4	4.00	7.765	-0.055	0.6667
1	14	5	5.00	8.110	0.290	0.6667
1	14	6	6.00	8.200	0.380	0.6667
1	14	7	7.00	8.240	0.420	0.6667
1	14	8	8.00	8.270	0.450	0.6667
1	14	9	9.00	8.270	0.450	0.6667
1	14	10	10.00	8.290	0.470	0.6667
1	14	11	11.00	8.300	0.480	0.6667
1	14	12	12.00	8.315	0.495	0.6667
1	14	13	13.00	8.330	0.510	0.6667
1	14	14	14.00	8.335	0.515	0.6667
1	14	15	15.00	8.345	0.525	0.6667
1	14	16	16.00	8.360	0.540	0.6667
1	14	17	17.00	8.365	0.545	0.6667
1	14	18	18.00	8.365	0.545	0.6667
1	14	19	19.00	8.375	0.555	0.6667
1	14	20	20.00	8.380	0.560	0.6667
						VALUE USED 0.6667

BRITISH GEOLOGICAL SURVEY



PROJECT: ZIMBABWE
FILE: 0002
LOCATION: CHIREDZI

WELL NO.: BH/1
Q= .6666667 L/S
S.W.L.=

ΔS= 0.520 M
T= 20.319 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 1

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2222222 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0007
WELL NO.: BH/2
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 10.69m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
14	8	0	0.00	10.690	0.000	0.2222
14	8	1	1.00	11.960	1.270	0.2222
14	8	2	1.50	12.450	1.760	0.2222
14	8	2	2.00	12.940	2.250	0.2222
14	8	3	2.50	13.340	2.650	0.2222
14	8	3	3.00	13.680	2.990	0.2222
14	8	4	3.50	14.020	3.330	0.2222
14	8	4	4.00	14.470	3.780	0.2222
14	8	5	4.50	14.950	4.260	0.2222
14	8	5	5.00	15.180	4.490	0.2222
14	8	6	6.00	15.810	5.120	0.2222
14	8	7	7.00	16.390	5.700	0.2222
14	8	8	8.00	16.880	6.190	0.2222
14	8	9	9.00	17.240	6.550	0.2222
14	8	10	10.00	17.620	6.930	0.2222
14	8	12	12.00	18.500	7.810	0.2222
14	8	14	14.00	19.200	8.510	0.2222
						VALUE USED 0.2222

BRITISH GEOLOGICAL SURVEY

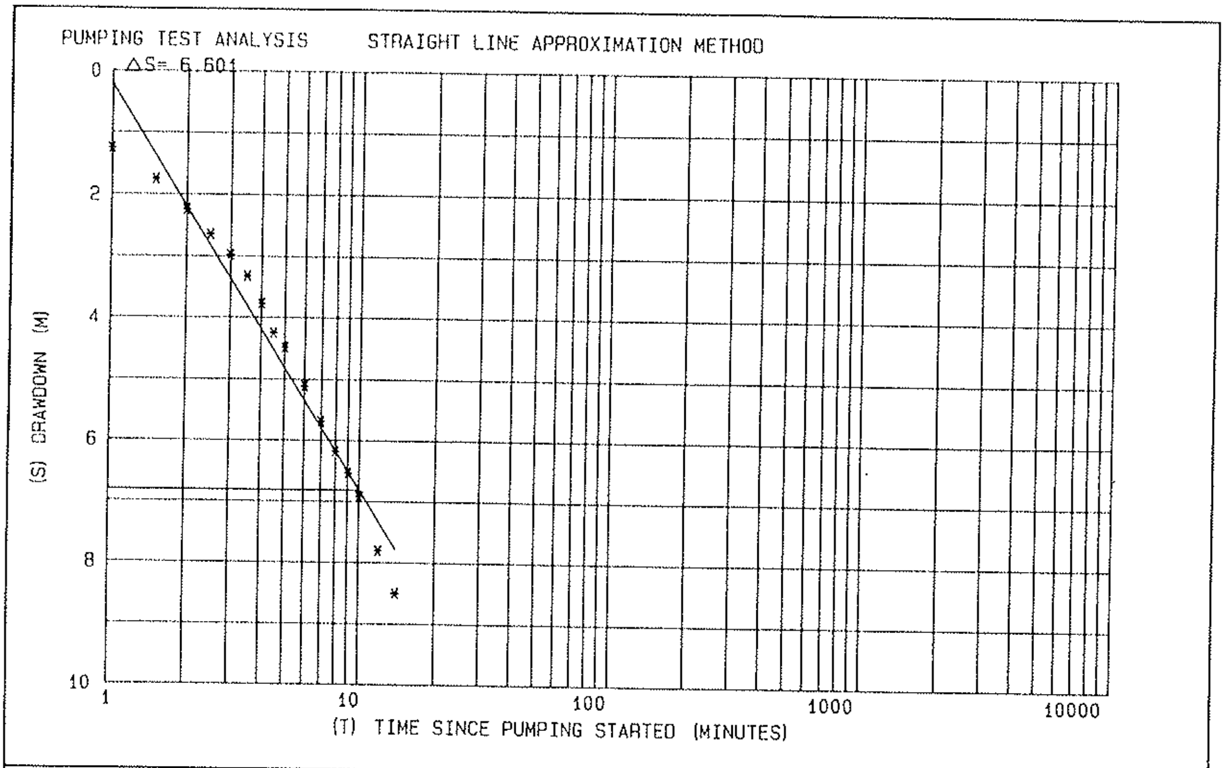
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2222222 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0007
WELL NO.: BH/2
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 10.69m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t' (MIN)	t/t'	(m)	(m)
14	8	14	14.00	0.00	0.00	19.200	8.510
14	8	15	14.50	0.50	29.00	18.820	8.130
14	8	15	15.00	1.00	15.00	18.290	7.600
14	8	16	15.50	1.50	10.33	17.820	7.130
14	8	16	16.00	2.00	8.00	17.430	6.740
14	8	17	16.50	2.50	6.60	16.920	6.230
14	8	18	17.50	3.50	5.00	15.820	5.130
14	8	18	18.00	4.00	4.50	15.540	4.850
14	8	19	18.50	4.50	4.11	15.290	4.600
14	8	19	19.00	5.00	3.80	14.950	4.260
14	8	20	20.00	6.00	3.33	14.400	3.710
14	8	21	21.00	7.00	3.00	14.000	3.310
14	8	22	22.00	8.00	2.75	13.750	3.060
14	8	23	23.00	9.00	2.56	13.550	2.860
14	8	24	24.00	10.00	2.40	13.320	2.630
14	8	26	26.00	12.00	2.17	13.040	2.350
14	8	28	28.00	14.00	2.00	12.820	2.130
14	8	30	30.00	16.00	1.88	12.550	1.860
14	8	32	32.00	18.00	1.78	12.340	1.650
14	8	34	34.00	20.00	1.70	12.160	1.470
14	8	36	36.00	22.00	1.64	12.020	1.330
14	8	38	38.00	24.00	1.58	11.900	1.210
14	8	40	40.00	26.00	1.54	11.800	1.110
14	8	44	44.00	30.00	1.47	11.690	1.000
14	8	46	46.00	32.00	1.44	11.520	0.830
14	8	49	49.00	35.00	1.40	11.400	0.710
14	8	54	54.00	40.00	1.35	11.300	0.610
14	8	59	59.00	45.00	1.31	11.210	0.520
14	9	4	64.00	50.00	1.28	11.160	0.470
14	9	14	74.00	60.00	1.23	11.100	0.410
14	9	24	84.00	70.00	1.20	11.000	0.310
14	9	34	94.00	80.00	1.18	10.940	0.250
14	9	44	104.00	90.00	1.16	10.880	0.190
14	9	54	114.00	100.00	1.14	10.840	0.150
14	10	14	134.00	120.00	1.12	10.790	0.100
14	10	34	154.00	140.00	1.10	10.750	0.060
14	10	54	174.00	160.00	1.09	10.720	0.030
14	11	14	194.00	180.00	1.08	10.700	0.010

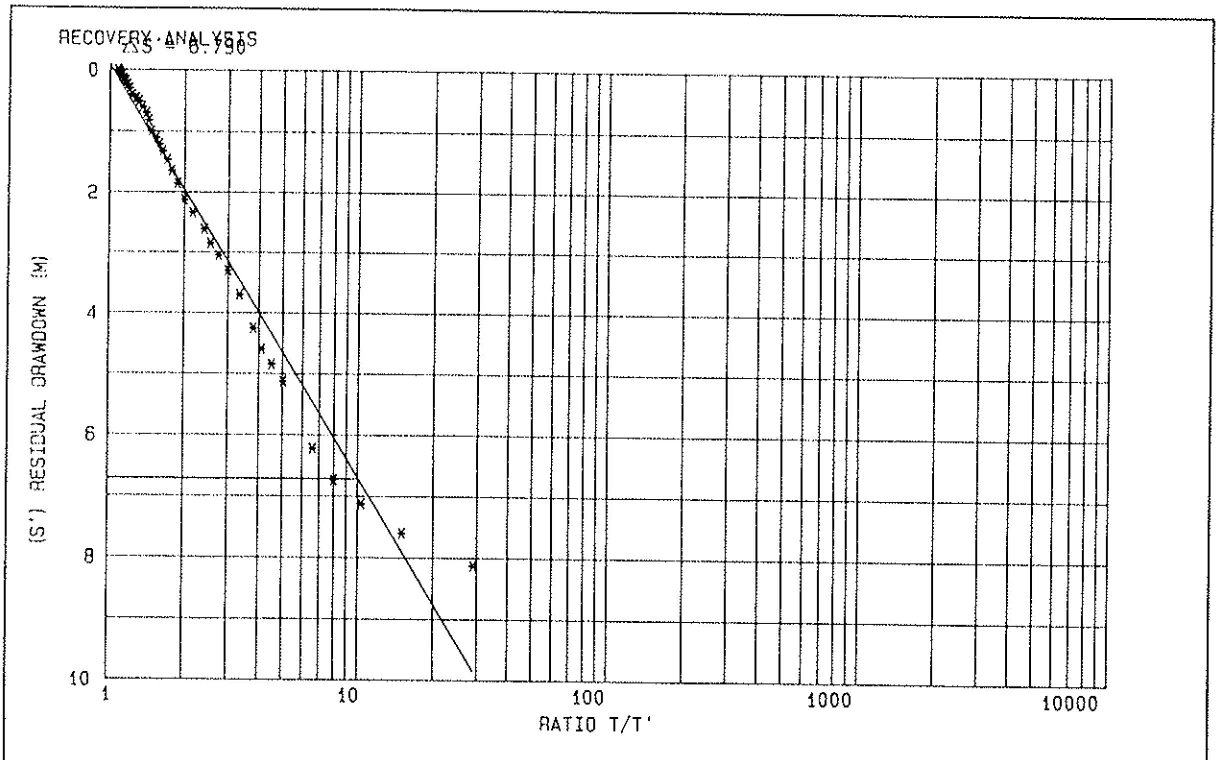
BRITISH GEOLOGICAL SURVEY



PROJECT: ZIMBABWE FILE: 0007 LOCATION: CHIREDZI	WELL NO.: BH/2 Q= .2222222 L/S S.W.L.= 10.69m	ΔS= 6.601 M T= 0.533 M2/DAY S=

BRITISH GEOLOGICAL SURVEY

FIGURE 1



PROJECT: ZIMBABWE FILE: 0007 LOCATION: CHIREDZI	WELL NO.: BH/2 Q= .2222222 L/S S.W.L.= 10.69m	ΔS'= 6.790 M T= 0.518 M2/DAY S=

BRITISH GEOLOGICAL SURVEY

FIGURE 2

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2439024 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0001
WELL NO.: BH/8
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 8.52m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
22	7	30	0.00	8.520	0.000	0.2439
22	7	31	0.50	9.320	0.800	0.2439
22	7	31	1.00	9.800	1.280	0.2439
22	7	32	1.50	10.150	1.630	0.2439
22	7	32	2.00	10.430	1.910	0.2439
22	7	33	2.50	10.670	2.150	0.2439
22	7	33	3.00	10.920	2.400	0.2439
22	7	34	3.50	11.120	2.600	0.2439
22	7	34	4.00	11.340	2.820	0.2439
22	7	35	4.50	11.500	2.980	0.2439
22	7	35	5.00	11.640	3.120	0.2439
22	7	36	6.00	11.930	3.410	0.2439
22	7	37	7.00	12.170	3.650	0.2439
22	7	38	8.00	12.370	3.850	0.2439
22	7	39	9.00	12.530	4.010	0.2439
22	7	42	12.00	13.030	4.510	0.2439
22	7	44	14.00	13.250	4.730	0.2439
22	7	46	16.00	13.400	4.880	0.2439
22	7	48	18.00	13.570	5.050	0.2439
22	7	50	20.00	13.670	5.150	0.2439
22	7	52	22.00	13.770	5.250	0.2439
22	7	54	24.00	13.800	5.280	0.2439
22	7	56	26.00	13.870	5.350	0.2439
22	7	58	28.00	13.910	5.390	0.2439
22	8	0	30.00	13.980	5.460	0.2439
22	8	2	32.00	14.000	5.480	0.2439
22	8	5	35.00	14.070	5.550	0.2439
22	8	10	40.00	14.150	5.630	0.2439
22	8	15	45.00	14.300	5.780	0.2439
22	8	20	50.00	14.390	5.870	0.2439
22	8	30	60.00	14.440	5.920	0.2439
22	8	40	70.00	14.480	5.960	0.2439
22	8	50	80.00	14.680	6.160	0.2439
22	9	0	90.00	14.870	6.350	0.2439
22	9	10	100.00	14.960	6.440	0.2439
22	9	50	140.00	15.130	6.610	0.2439
22	10	10	160.00	15.440	6.920	0.2439
22	10	30	180.00	15.850	7.330	0.2439
22	10	50	200.00	15.660	7.140	0.2439
22	11	10	220.00	15.660	7.140	0.2439
						VALUE USED 0.2439

BRITISH GEOLOGICAL SURVEY

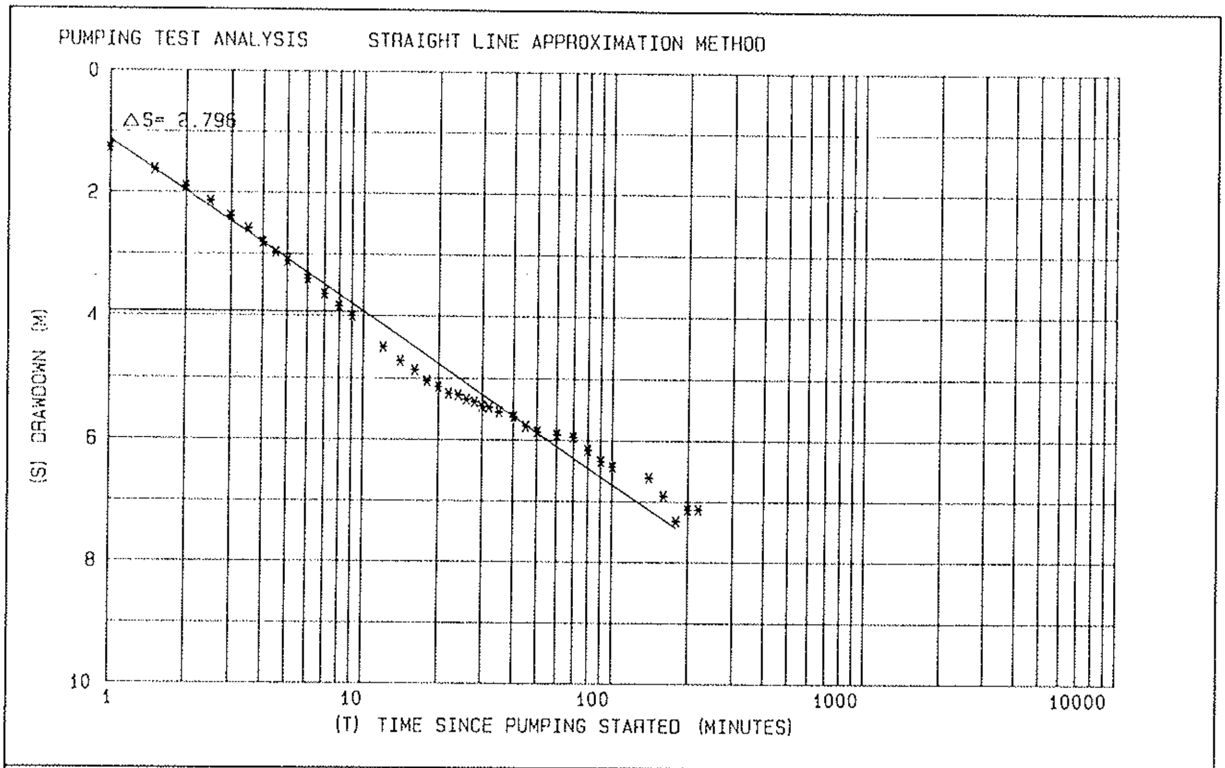
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2439024 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0001
WELL NO.: BH/8
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 8.52m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t′ (MIN)	t/t′	(m)	(m)
22	11	10	220.00	0.00	0.00	15.660	7.140
22	11	11	220.50	0.50	441.00	14.320	5.800
22	11	11	221.00	1.00	221.00	13.740	5.220
22	11	12	221.50	1.50	147.67	13.190	4.670
22	11	12	222.00	2.00	111.00	12.630	4.110
22	11	13	222.50	2.50	89.00	12.130	3.610
22	11	13	223.00	3.00	74.33	11.790	3.270
22	11	14	224.00	4.00	56.00	11.120	2.600
22	11	15	224.50	4.50	49.89	10.940	2.420
22	11	15	225.00	5.00	45.00	10.680	2.160
22	11	16	226.00	6.00	37.67	10.370	1.850
22	11	17	227.00	7.00	32.43	10.190	1.670
22	11	18	228.00	8.00	28.50	9.910	1.390
22	11	19	229.00	9.00	25.44	9.770	1.250
22	11	20	230.00	10.00	23.00	9.640	1.120
22	11	22	232.00	12.00	19.33	9.470	0.950
22	11	24	234.00	14.00	16.71	9.320	0.800
22	11	26	236.00	16.00	14.75	9.240	0.720
22	11	30	240.00	20.00	12.00	9.120	0.600
22	11	32	242.00	22.00	11.00	9.070	0.550
22	11	34	244.00	24.00	10.17	9.020	0.500
22	11	36	246.00	26.00	9.46	9.000	0.480
22	11	38	248.00	28.00	8.86	8.970	0.450
22	11	40	250.00	30.00	8.33	8.950	0.430
22	11	42	252.00	32.00	7.88	8.930	0.410
22	11	45	255.00	35.00	7.29	8.900	0.380
22	11	50	260.00	40.00	6.50	8.870	0.350
22	11	55	265.00	45.00	5.89	8.830	0.310
22	12	0	270.00	50.00	5.40	8.800	0.280
22	12	10	280.00	60.00	4.67	8.740	0.220
22	12	20	290.00	70.00	4.14	8.680	0.160
22	12	30	300.00	80.00	3.75	8.620	0.100
22	12	40	310.00	90.00	3.44	8.560	0.040

BRITISH GEOLOGICAL SURVEY



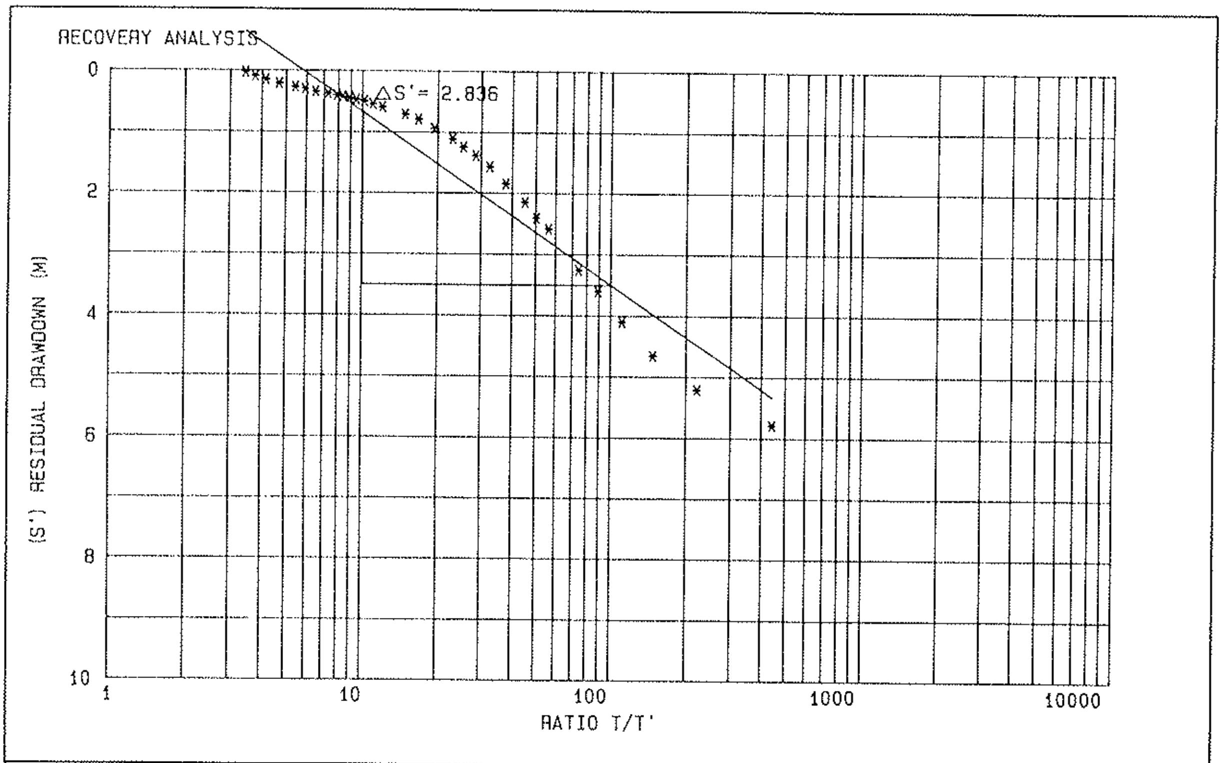
PROJECT: ZIMBABWE
FILE: 0001
LOCATION: CHIREDZI

WELL NO.: BH/8
Q= .2439024 L/S
S.W.L.= 8.52m

△S= 2.796 M
T= 1.382 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 1



PROJECT: ZIMBABWE
FILE: 0001
LOCATION: CHIREDZI

WELL NO.: BH/8
Q= .2439024 L/S
S.W.L.= 8.52m

△S'= 2.836 M
T= 1.362 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 2

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.400 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0004
WELL NO.: BH/12
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.75m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
24	13	0	0.00	4.750	0.000	0.4000
24	13	1	0.50	5.390	0.640	0.4000
24	13	1	1.00	5.630	0.880	0.4000
24	13	2	1.50	5.830	1.080	0.4000
24	13	2	2.00	5.950	1.200	0.4000
24	13	3	2.50	6.050	1.300	0.4000
24	13	3	3.00	6.120	1.370	0.4000
24	13	4	3.50	6.180	1.430	0.4000
24	13	4	4.00	6.230	1.480	0.4000
24	13	5	4.50	6.260	1.510	0.4000
24	13	5	5.00	6.300	1.550	0.4000
24	13	6	6.00	6.340	1.590	0.4000
24	13	7	7.00	6.380	1.630	0.4000
24	13	8	8.00	6.420	1.670	0.4000
24	13	9	9.00	6.440	1.690	0.4000
24	13	10	10.00	6.460	1.710	0.4000
24	13	14	14.00	6.520	1.770	0.4000
24	13	16	16.00	6.540	1.790	0.4000
24	13	18	18.00	6.560	1.810	0.4000
24	13	20	20.00	6.570	1.820	0.4000
24	13	22	22.00	6.575	1.825	0.4000
24	13	24	24.00	6.595	1.845	0.4000
24	13	26	26.00	6.600	1.850	0.4000
24	13	28	28.00	6.610	1.860	0.4000
24	13	30	30.00	6.625	1.875	0.4000
24	13	32	32.00	6.640	1.890	0.4000
24	13	35	35.00	6.670	1.920	0.4000
24	13	45	45.00	6.720	1.970	0.4000
24	13	50	50.00	6.750	2.000	0.4000
24	14	0	60.00	6.790	2.040	0.4000
24	14	10	70.00	6.830	2.080	0.4000
24	14	20	80.00	6.860	2.110	0.4000
24	14	30	90.00	6.870	2.120	0.4000
24	14	40	100.00	6.890	2.140	0.4000
24	15	0	120.00	6.950	2.200	0.4000
						VALUE USED 0.4000

BRITISH GEOLOGICAL SURVEY

PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.400 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0004
WELL NO.: BH/12
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.75m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t′ (MIN)	t/t′	(m)	(m)
24	15	1	120.50	0.50	241.00	6.380	1.630
24	15	1	121.00	1.00	121.00	5.970	1.220
24	15	2	121.50	1.50	81.00	5.790	1.040
24	15	2	122.00	2.00	61.00	5.640	0.890
24	15	3	122.50	2.50	49.00	5.530	0.780
24	15	3	123.00	3.00	41.00	5.490	0.740
24	15	4	123.50	3.50	35.29	5.430	0.680
24	15	4	124.00	4.00	31.00	5.400	0.650
24	15	5	124.50	4.50	27.67	5.370	0.620
24	15	5	125.00	5.00	25.00	5.350	0.600
24	15	6	126.00	6.00	21.00	5.300	0.550
24	15	7	127.00	7.00	18.14	5.280	0.530
24	15	8	128.00	8.00	16.00	5.250	0.500
24	15	9	129.00	9.00	14.33	5.230	0.480
24	15	10	130.00	10.00	13.00	5.220	0.470
24	15	12	132.00	12.00	11.00	5.190	0.440
24	15	14	134.00	14.00	9.57	5.160	0.410
24	15	16	136.00	16.00	8.50	5.140	0.390
24	15	18	138.00	18.00	7.67	5.120	0.370
24	15	20	140.00	20.00	7.00	5.110	0.360
24	15	22	142.00	22.00	6.45	5.090	0.340
24	15	24	144.00	24.00	6.00	5.060	0.310
24	15	26	146.00	26.00	5.62	5.060	0.310
24	15	28	148.00	28.00	5.29	5.050	0.300
24	15	30	150.00	30.00	5.00	5.050	0.300
24	15	32	152.00	32.00	4.75	5.030	0.280
24	15	35	155.00	35.00	4.43	5.020	0.270
24	15	40	160.00	40.00	4.00	5.000	0.250
24	15	45	165.00	45.00	3.67	4.980	0.230
24	15	50	170.00	50.00	3.40	4.960	0.210
24	16	0	180.00	60.00	3.00	4.920	0.170
24	16	10	190.00	70.00	2.71	4.880	0.130
24	16	20	200.00	80.00	2.50	4.840	0.090
24	16	30	210.00	90.00	2.33	4.800	0.050
24	16	40	220.00	100.00	2.20	4.760	0.010

BRITISH GEOLOGICAL SURVEY

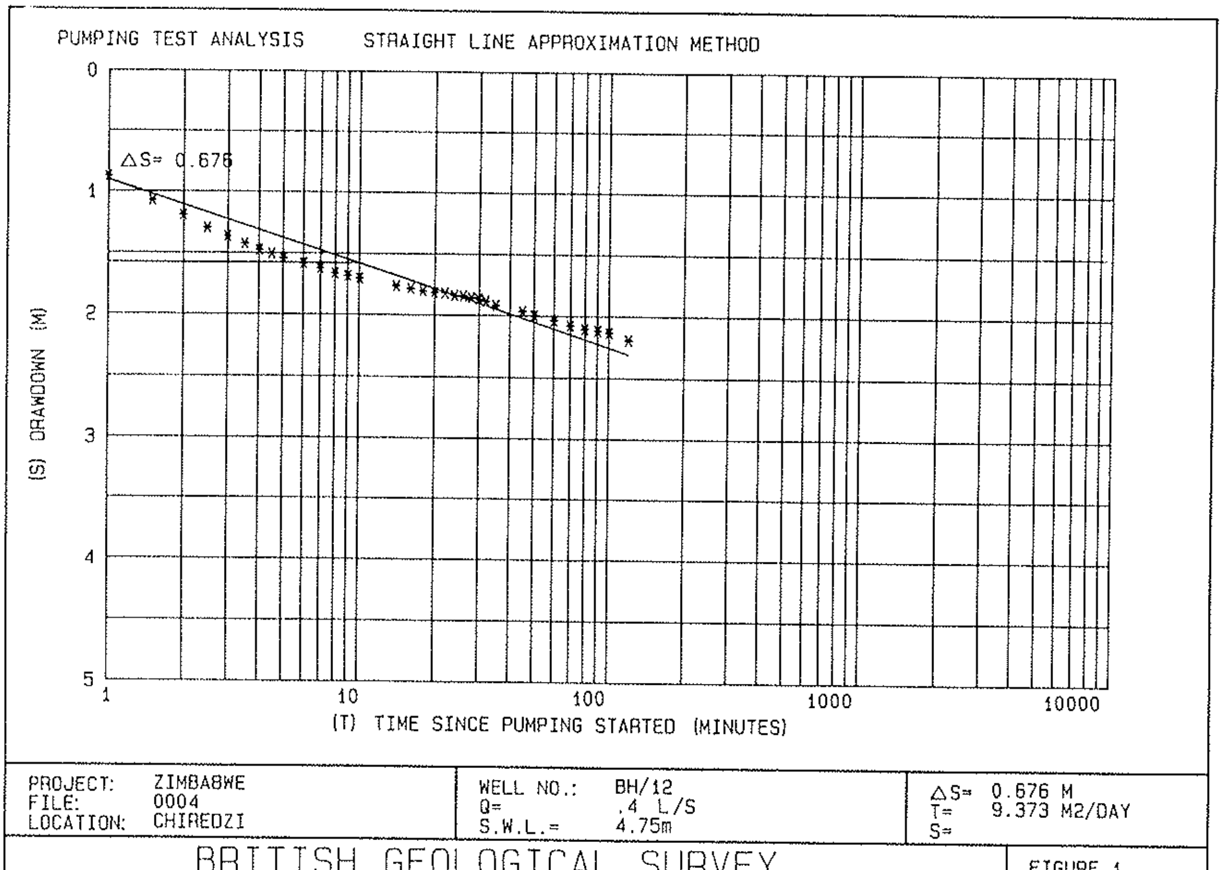


FIGURE 1

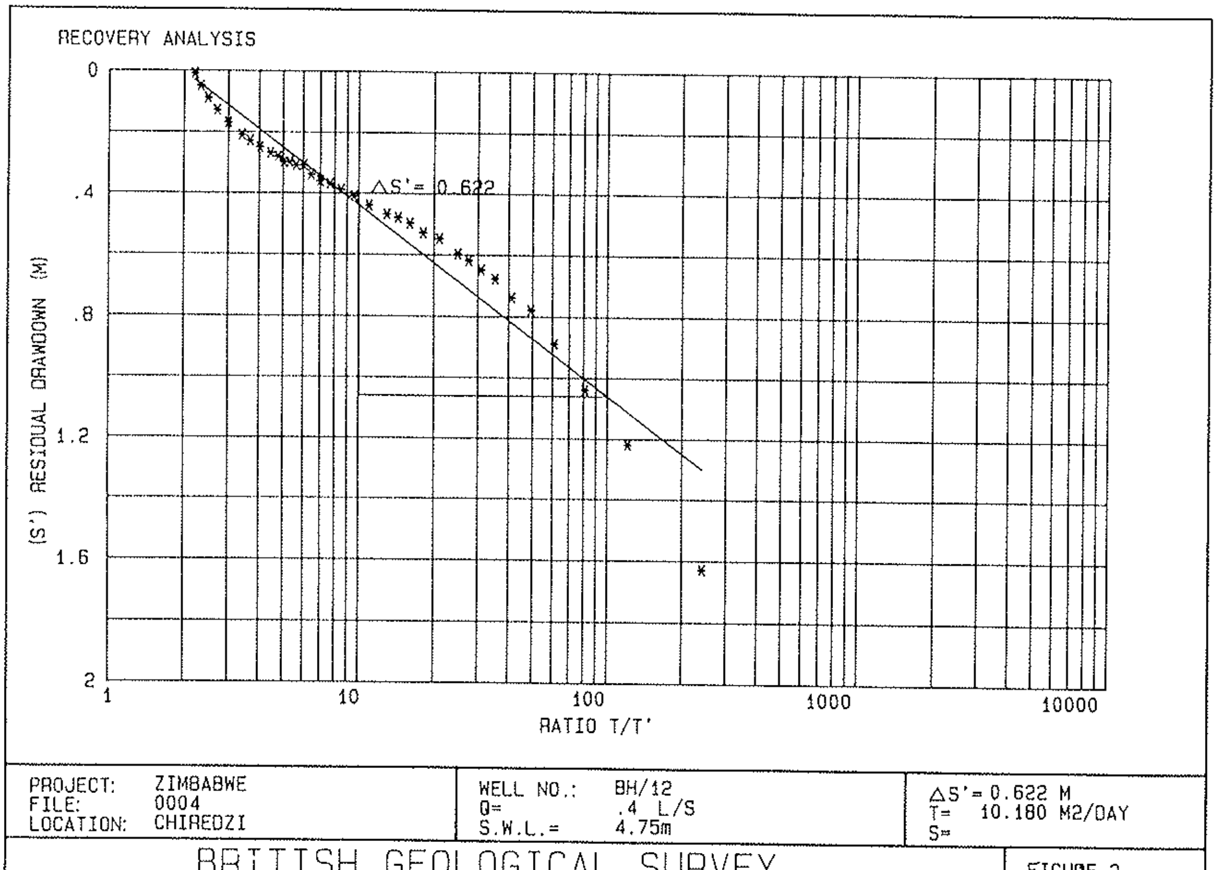


FIGURE 2

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2597403 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0005
WELL NO.: BH/12
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.74m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
24	9	0	0.00	4.740	0.000	0.2597
24	9	1	0.50	5.100	0.360	0.2597
24	9	1	1.00	5.240	0.500	0.2597
24	9	2	1.50	5.370	0.630	0.2597
24	9	3	3.00	5.550	0.810	0.2597
24	9	4	3.50	5.590	0.850	0.2597
24	9	4	4.00	5.610	0.870	0.2597
24	9	5	4.50	5.630	0.890	0.2597
24	9	5	5.00	5.670	0.930	0.2597
24	9	6	6.00	5.700	0.960	0.2597
24	9	7	7.00	5.730	0.990	0.2597
24	9	8	8.00	5.750	1.010	0.2597
24	9	12	12.00	5.760	1.020	0.2597
24	9	14	14.00	5.780	1.040	0.2597
24	9	16	16.00	5.790	1.050	0.2597
24	9	18	18.00	5.805	1.065	0.2597
24	9	20	20.00	5.830	1.090	0.2597
24	9	22	22.00	5.810	1.070	0.2597
24	9	24	24.00	5.810	1.070	0.2597
24	9	26	26.00	5.810	1.070	0.2597
24	9	28	28.00	5.810	1.070	0.2597
						VALUE USED 0.2597

BRITISH GEOLOGICAL SURVEY

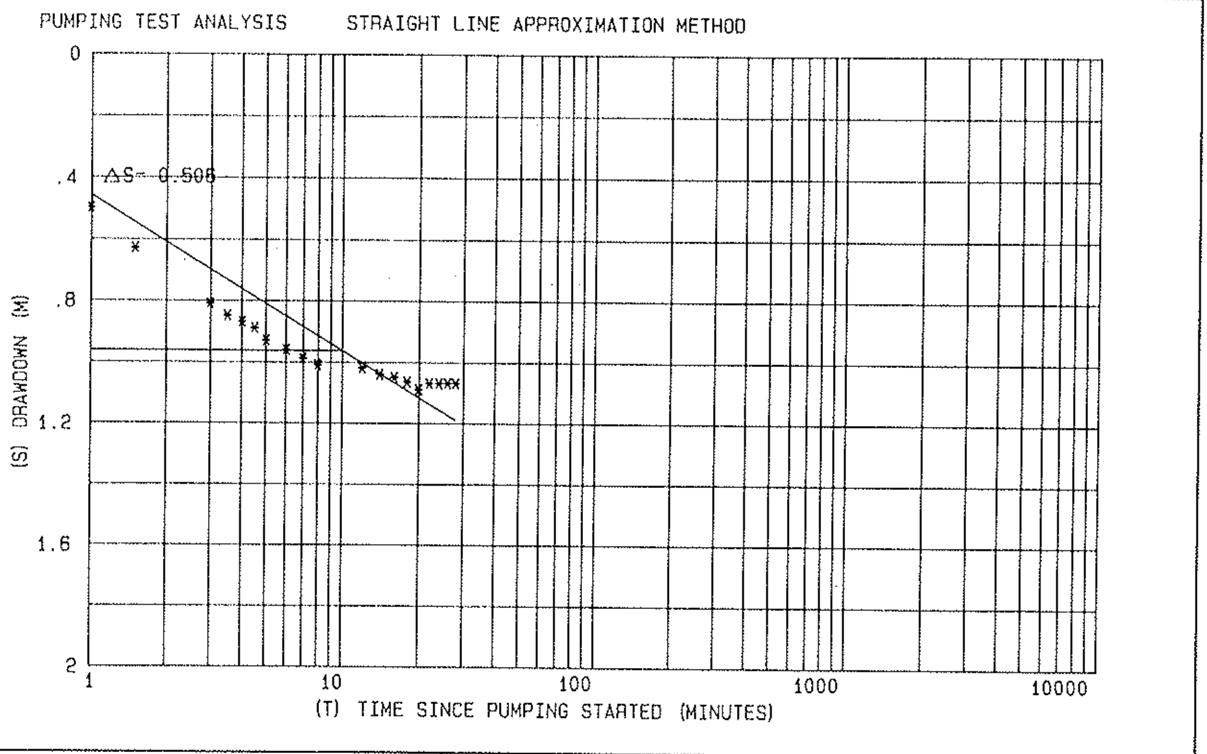
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.2597403 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0005
WELL NO.: BH/12
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.74m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t' (MIN)	t/t'	(m)	(m)
24	9	29	28.50	0.50	57.00	5.590	0.850
24	9	29	29.00	1.00	29.00	5.250	0.510
24	9	30	29.50	1.50	19.67	5.120	0.380
24	9	30	30.00	2.00	15.00	5.080	0.340
24	9	31	30.50	2.50	12.20	5.040	0.300
24	9	31	31.00	3.00	10.33	5.020	0.280
24	9	32	31.50	3.50	9.00	5.000	0.260
24	9	32	32.00	4.00	8.00	4.980	0.240
24	9	33	32.50	4.50	7.22	4.960	0.220
24	9	33	33.00	5.00	6.60	4.950	0.210
24	9	34	34.00	6.00	5.67	4.940	0.200
24	9	35	35.00	7.00	5.00	4.930	0.190
24	9	36	36.00	8.00	4.50	4.920	0.180
24	9	37	37.00	9.00	4.11	4.910	0.170
24	9	38	38.00	10.00	3.80	4.900	0.160
24	9	40	40.00	12.00	3.33	4.890	0.150
24	9	42	42.00	14.00	3.00	4.880	0.140
24	9	44	44.00	16.00	2.75	4.880	0.140
24	9	46	46.00	18.00	2.56	4.875	0.135
24	9	48	48.00	20.00	2.40	4.870	0.130
24	9	50	50.00	22.00	2.27	4.855	0.115
24	9	52	52.00	24.00	2.17	4.850	0.110

BRITISH GEOLOGICAL SURVEY



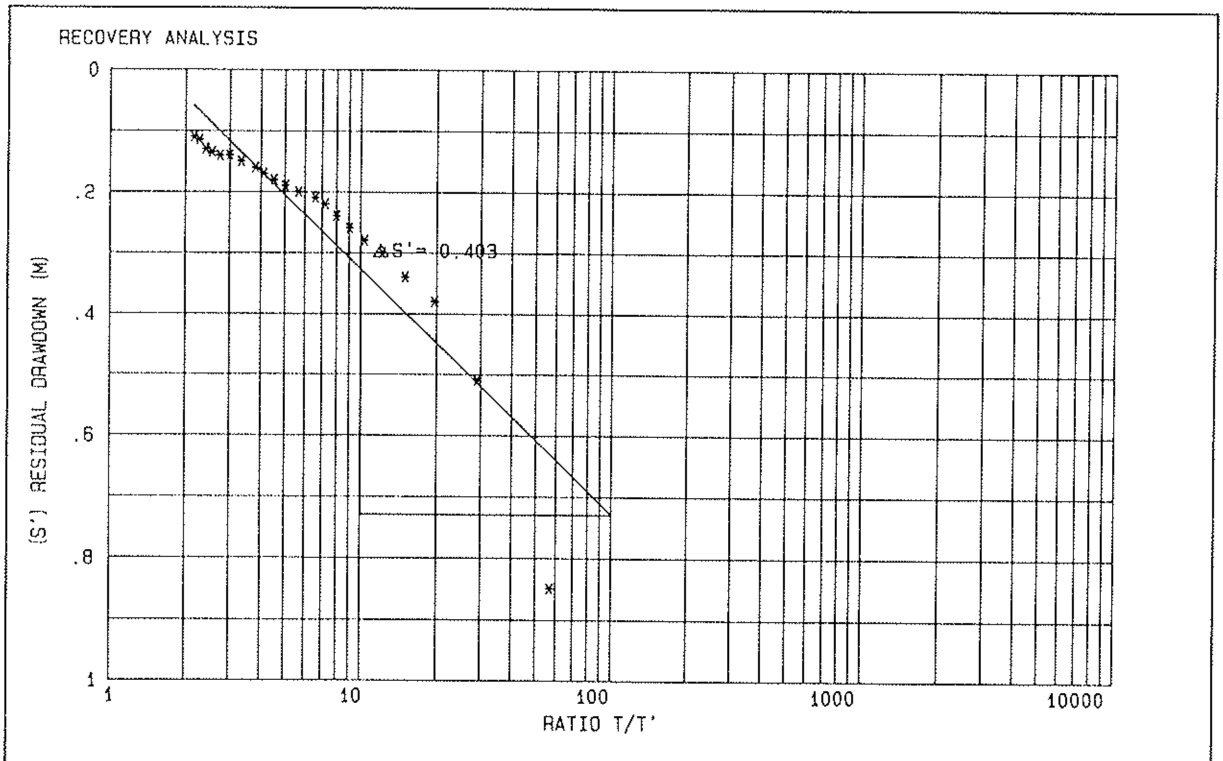
PROJECT: ZIMBABWE
FILE: 0005
LOCATION: CHIREDZI

WELL NO.: BH/12
Q= .2597403 L/S
S.W.L.= 4.74m

ΔS= 0.506 M
T= 8.125 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 1



PROJECT: ZIMBABWE
FILE: 0005
LOCATION: CHIREDZI

WELL NO.: BH/12
Q= .2597403 L/S
S.W.L.= 4.74m

ΔS'= 0.403 M
T= 10.209 M2/DAY
S=

BRITISH GEOLOGICAL SURVEY

FIGURE 2

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.400 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0006
WELL NO.: BH/13
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 5.17m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
25	10	30	0.00	5.170	0.000	0.4000
25	10	31	0.50	6.500	1.330	0.4000
25	10	31	1.00	7.110	1.940	0.4000
25	10	32	1.50	7.740	2.570	0.4000
25	10	32	2.00	8.270	3.100	0.4000
25	10	33	2.50	8.720	3.550	0.4000
25	10	33	3.00	9.050	3.880	0.4000
25	10	34	4.00	9.610	4.440	0.4000
25	10	35	4.50	9.830	4.660	0.4000
25	10	35	5.00	10.040	4.870	0.4000
25	10	36	6.00	10.310	5.140	0.4000
25	10	37	7.00	10.540	5.370	0.4000
25	10	38	8.00	10.680	5.510	0.4000
25	10	39	9.00	10.830	5.660	0.4000
25	10	40	10.00	10.970	5.800	0.4000
25	10	44	14.00	11.150	5.980	0.4000
25	10	46	16.00	11.320	6.150	0.4000
25	10	48	18.00	11.430	6.260	0.4000
25	10	50	20.00	11.520	6.350	0.4000
25	10	52	22.00	11.580	6.410	0.4000
25	10	54	24.00	11.620	6.450	0.4000
25	10	56	26.00	11.690	6.520	0.4000
25	10	58	28.00	11.720	6.550	0.4000
25	11	0	30.00	11.740	6.570	0.4000
25	11	2	32.00	11.760	6.590	0.4000
25	11	5	35.00	11.860	6.690	0.4000
25	11	10	40.00	11.970	6.800	0.4000
25	11	15	45.00	12.050	6.880	0.4000
25	11	20	50.00	12.140	6.970	0.4000
25	11	30	60.00	12.340	7.170	0.4000
25	11	40	70.00	12.430	7.260	0.4000
25	11	50	80.00	12.520	7.350	0.4000
25	12	0	90.00	12.580	7.410	0.4000
25	12	30	120.00	12.620	7.450	0.4000
						VALUE USED 0.4000

BRITISH GEOLOGICAL SURVEY

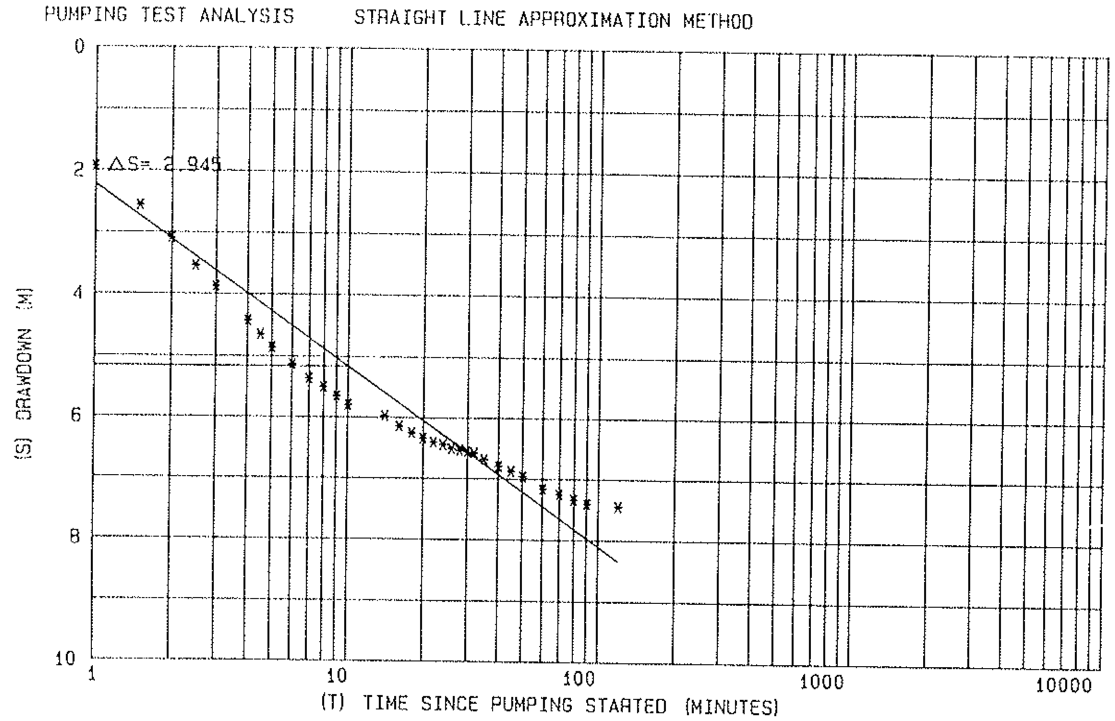
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: CHIREDZI
DATUM POINT: 60mm A.G.L.
PUMPING RATE: 0.400 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0006
WELL NO.: BH/13
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 5.17m
R = ----- FROM
SCREEN INTERVAL: TO

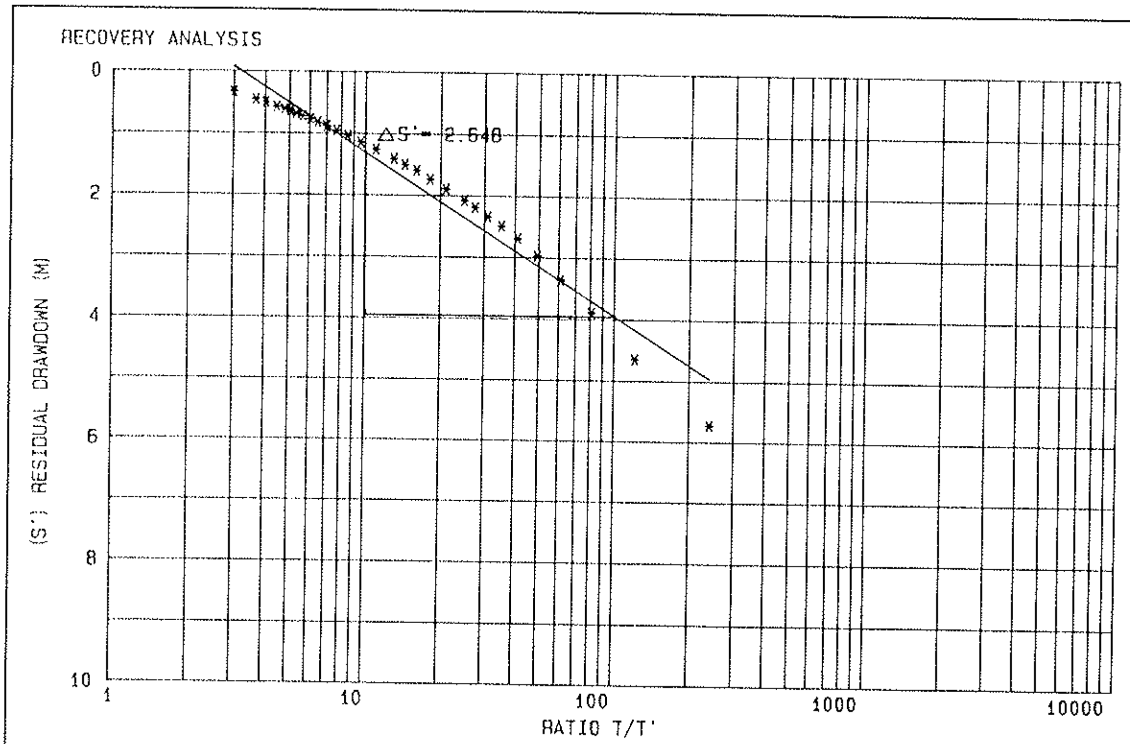
TIME			PUMPING STARTED	PUMPING ENDED	RATIO	WATER LEVEL	RESIDUAL DRAWDOWN
DY	HR	MN	t (MIN)	t′ (MIN)	t/t′	(m)	(m)
25	12	30	120.00	0.00	0.00	12.620	7.450
25	12	31	120.50	0.50	241.00	10.900	5.730
25	12	31	121.00	1.00	121.00	9.820	4.650
25	12	32	121.50	1.50	81.00	9.070	3.900
25	12	32	122.00	2.00	61.00	8.540	3.370
25	12	33	122.50	2.50	49.00	8.150	2.980
25	12	33	123.00	3.00	41.00	7.870	2.700
25	12	34	123.50	3.50	35.29	7.670	2.500
25	12	34	124.00	4.00	31.00	7.520	2.350
25	12	35	124.50	4.50	27.67	7.370	2.200
25	12	35	125.00	5.00	25.00	7.250	2.080
25	12	36	126.00	6.00	21.00	7.070	1.900
25	12	37	127.00	7.00	18.14	6.910	1.740
25	12	38	128.00	8.00	16.00	6.770	1.600
25	12	39	129.00	9.00	14.33	6.680	1.510
25	12	40	130.00	10.00	13.00	6.580	1.410
25	12	42	132.00	12.00	11.00	6.430	1.260
25	12	44	134.00	14.00	9.57	6.320	1.150
25	12	46	136.00	16.00	8.50	6.210	1.040
25	12	48	138.00	18.00	7.67	6.130	0.960
25	12	50	140.00	20.00	7.00	6.060	0.890
25	12	52	142.00	22.00	6.45	6.000	0.830
25	12	54	144.00	24.00	6.00	5.950	0.780
25	12	56	146.00	26.00	5.62	5.900	0.730
25	12	58	148.00	28.00	5.29	5.860	0.690
25	13	0	150.00	30.00	5.00	5.820	0.650
25	13	2	152.00	32.00	4.75	5.790	0.620
25	13	5	155.00	35.00	4.43	5.750	0.580
25	13	10	160.00	40.00	4.00	5.680	0.510
25	13	15	165.00	45.00	3.67	5.630	0.460
25	13	30	180.00	60.00	3.00	5.510	0.340

BRITISH GEOLOGICAL SURVEY



PROJECT: ZIMBABWE FILE: 0006 LOCATION: CHIREDZI	WELL NO.: BH/13 Q= .4 L/S S.W.L.= 5.17m	ΔS= 2.945 M T= 2.152 M2/DAY S=

BRITISH GEOLOGICAL SURVEY — FIGURE 1



PROJECT: ZIMBABWE FILE: 0006 LOCATION: CHIREDZI	WELL NO.: BH/13 Q= .4 L/S S.W.L.= 5.17m	ΔS' = 2.648 M T= 2.392 M2/DAY S=

BRITISH GEOLOGICAL SURVEY — FIGURE 2

APPENDIX 2

PN/90/13

BOREHOLE GEOPHYSICAL LOGGING AT THE LOWVELD RESEARCH STATION, CHIREDZI, SOUTHERN ZIMBABWE

INTRODUCTION

Following site investigation studies within the Masvingo Province of Southern Zimbabwe further borehole geophysical logging was undertaken at three sites at Chiredzi. These investigations were part of studies currently being implemented at the research station and consisted of a suite of borehole geophysical techniques.

The purpose of this investigation was to delineate the permeable horizons within the formations traversed and to indicate the different formations and their degree of weathering.

Of the three sites geophysically investigated two were away from the research station and one borehole was at the station. The designation of these boreholes was EXP3, EXP4 and EXP1 respectively.

The interpretation of the geophysical responses of the different logging techniques had previously been investigated in the BGS Basement Aquifer Project. Using a number of cross plot interpretative methods the degree of weathering of these granitic and gneissic formations had been delineated. Recent advances in interpretative techniques have included the Briggs cube as a graphical method for lithological construction from log responses.

This cube, consisting of 27 elements, was used initially to aid lithological construction from the natural gamma, sonic velocity and neutron porosity logs. From the different values of the logging parameters different hues of the cube represented the specific log response of the formations being investigated. In this case the parameters that are used are the normal resistivity, natural gamma radiation and borehole compensated neutron. Specific responses are obtained from different formations e.g. clay with low resistivity, high natural gamma response and low apparent porosity results in a blue cube colour as opposed to the characteristic hue for granite of off white. The full dynamic range of the cube is highly dependent on the choice of logging parameter range and careful selection of the amplitude of the resistivity, gamma and neutron will result in a lithological column that will adequately represent the observed lithology.

Further interpretation of the degree of weathering is obtained from the x-y-z cross plot of resistivity and neutron porosity against depth. The characteristic response obtained for an unfractured formation results in a initial shallow response of reducing porosity against increasing resistivity. This response then reaches a plateau where increasing resistivity does not indicate the corresponding reduction in porosity. The knee response to that of the plateau indicates the limit of weathering and by reference to the depth colour code the depth of weathering may be obtained. The existance of fracturing within the massive unweathered basement formation results in a neutron log response of increasing apparent porosity but without the expected large excursion in resistivity. This type response is a result of the spacial detection limits of the geophysical methods employed and is particularly characteristic of an unweathered fracture.

Where fracturing is associated with weathering, as a result of fluid flow through the permeable fracture, a characteristic response is obtained indicating the upper boundary of the fracture to be weathered whereas the lower horizon is unweathered. This results in a characteristic resistivity log response that shows a gradual reduction of formation resistivity at the upper boundary of the fracture and an abrupt increase in the resistivity at the base of the fracture. This results in a saw tooth log response which from previous studies in Malawi and Zimbabwe has been noted to be associated with water flow through the fracture.

INVESTIGATIONS AT CHIREDZI

Investigations in the Chiredzi area were undertaken at three sites and for the purpose of this report the borehole site EXP1 will be commented upon. The main information to be obtained from the logs will be the depth of weathering, indications of permeable fractures and any significant changes in water quality associated with specific horizons within the profile.

The suite of geophysical logging run was the following: spontaneous potential, natural gamma radiation, neutron-neutron porosity, 3 arm caliper, micro normal and micro inverse resistivity (2.5 cm and 5.0 cm), and short, medium and long normal resistivity. The results of this logging are presented in Figure 3.

Inspection of the logs indicates considerable fracturing to exist to about 31 m bgl from 13 m bgl. Inspection of other logging techniques over this horizon shows the horizon to be associated with increased mineralisation, as indicated on the natural gamma log (higher counts). Resistivities are reduced within fractured formations by the reduction of the total apparent resistivity by the saturating fluid, in this case fresh water. This characteristic response is noted on all resistivity logs indicating that fracturing is extensive and is not associated with drilling operations. The neutron porosity log exhibits large variations in indicated porosity values associated with these fractures.

Below 31 m the geophysical logs indicate that a more massive formation was penetrated with increasing resistivities and reducing porosity, however at 46 m a massive permeable fracture is encountered. This fracture exhibits the characteristic response of pronounced weathering above the fracture horizon with a sharp cut off at its lower boundary. Minor excursions in the caliper log may indicate this horizon to be composed of a number of fractures, however other logging techniques employed are incapable of resolving this into discrete fractures.

Lithological reconstruction by use of the Briggs cube has resulted in the litholog represented in Column 1 of Figure 3 and indicates the major lithological boundary to the more massive formation encountered at 37.2 m. This boundary is indicated by a sharp increase in normal resistivities and a step reduction in the bulk porosity of the neutron log.

Further investigation of the log responses utilising cross plot techniques verifies the above observations. Cross plotting neutron porosity against 50 cm normal resistivity with depth as the z axis is shown in Figure 4. This figure indicates a field associated with the weathered formation to exist to at least 35.5 m. Below this depth the neutron porosity is at a minimum value and resistivities increase with depth. Inspection of the drilling record shows the junction of less weathered dolerite to be at 43 m with geophysical methods placing the boundary slightly higher in the profile at 37.2 m. This discrepancy may be accounted for by the geophysical logs indicating the commencement of the reduction of weathering, whereas drilling operations would indicate gross lithological changes. The transitional formation change to the massive dolerite is noted to be from 37.2 m to 42.3 m from logging. This compares with the drilling record of 43 m.

Geophysical indications of permeable horizons are limited to a few methods, namely: spontaneous potential, fluid temperature and conductivity, flow metering and formation type responses. Investigation of the geophysical logs obtained for borehole EXP1 indicated several horizons to be productive either from the log responses or from type response.

The spontaneous potential log exhibits a number of variations which are able to be correlated with either fractures or lithological changes. Large negative excursions within the log profile are representative of indications of permeability. It is well documented that the development of streaming potentials within crystalline rocks may be indicated easily on the spontaneous potential log and that the development of these potentials is indicative of permeability. No values of permeability may be ascribed to the development of these potentials.

Observation of the spontaneous potential log showed variations to exist at the following horizons: 12-13 m, 18-20 m, 22-24 m, 29 m and 38-40 m. Correlation of these variations with the formations penetrated showed the majority of the SP excursions were within the weathered material with the 38-40 m level being located at the boundary of the weathered to competent dolerite.

Bulk porosity decreased with depth and apart from variation associated with fractures the neutron log generally indicated the formation to be of low overall porosity. The yield of this borehole was controlled by the fractures intersected by the borehole.

CONCLUSIONS

The borehole geophysical logging at the Research Station, Chiredzi, was undertaken at the end of a geophysical logging investigation within Masvingo Province for the Basement Aquifer Project. The dolerite formation encountered at Chiredzi had only been previous logged once within the above project, thus type responses for this formation were limited.

1. The cross plot of the neutron and resistivity with depth adequately delineates the depth of weathering, indicating the massive dolerite to be penetrated at 42 m. This formation boundary correlates with the drilling derived lithology.

2. The recent inclusion of the Briggs cube within the interpretation methods indicates the usefulness of the method to reconstruct the lithology from geophysical logs. The sensitivity of this method to the choice of log range requires care, however experience with this method indicates that it is capable of providing considerable information on the formations encountered.
3. Indications of the permeable horizons within the borehole were limited to the spontaneous potential log. Considerable information could have been obtained on the relative yields of different horizons of the borehole if standard fluid column logging had been undertaken during pump testing of this borehole.