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COLLECTOR WELLS FOR SMALL-SCALE IRRIGATION: Construction and Testing of a Well at Tamwa/Sihambe/Dhobani Kraals and Further Work at Chiredzi

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Cover Photograph: *Garden members irrigating vegetables at Tamwa/Sihambe/Dhobani Kraals during the 1992 drought in southern Zimbabwe.*

EXECUTIVE SUMMARY

In 1988 the British Geological Survey (BGS) and the Institute of Hydrology (IH) began a collaborative project aimed at developing limited groundwater resources for small-scale irrigation. The overall objective of the study has been to determine the feasibility and sustainability of small-scale irrigation from the extensive, shallow aquifers associated with the weathering of crystalline basement rocks. This has been done by combining methods of high-efficiency, low-cost irrigation with the use of collector wells to abstract water from these aquifers. The study brought together in a single project appropriate recent experience of IH on the former and BGS on the latter.

Two collector wells have been constructed in southern Zimbabwe. The first at the Lowveld Research Station was completed in 1989 and the second in Chivi Communal Lands in 1991. Construction of the laterals was particularly effective at the former, improving the yield by 150%. In contrast, construction of the laterals improved the yield by only 10% at the second site, reflecting the highly variable and unpredictable nature of the weathered basement aquifer. The cost of the first collector well, complete with pump was Z$19,000, and the second, complete with two Bush pumps was Z$28,000.

The collector well at Chiredzi has been operated since mid-1989 by an electric pump to provide water for trials of methods of increasing irrigation efficiency at the Research Station, initially at very low abstraction rates and more recently at higher rates to provide for irrigation of vegetable cultivation in the current drought. The second well, with its two handpumps, has provided domestic water for up to 1200 people and water for an irrigated garden for 46 families. This has provided an opportunity to test the economic, social and institutional aspects of small-scale irrigated gardens, which are reported on separately. Initial economic analysis of the results of vegetable cultivation in the scheme suggest internal rates of return (IRR) in the range 20-33%.

The performance of both wells has been monitored since completion, and the 1992 drought has provided a severe test of their sustainability. Practically no recharge occurred in the 1991-92 rainy season, and water levels in both wells have fallen significantly. Abstraction at Chiredzi had risen from April 1992 to 7,000-10,000 l/d, and 20,000 l/d in the heaviest pumping, compared to an installed capacity of 27,000 l/d and estimated safe yield of 65,000 l/d. At Tamwa/Sihambe/Dhobani Kraals, initial abstractions of perhaps 5,000 l/d in 1991 increased to 12,000 to 15,000 l/d by March 1992 but, using the results of the monitoring, abstraction has been controlled by the users at about 10,000 l/d to help maintain domestic supplies and more limited cultivation until the 1992-93 rainy season.

The possibility that enhanced local recharge by infiltration of surface water helped to make the Chiredzi site a favourable one has been investigation. Water level information, groundwater chemistry and stable isotopes together confirm a local source of recharge from surface water originating from Lake Kyle. Further, the isotopic and hydrochemical data point to infiltration from the irrigated plots on the station rather than the irrigated sugarcane cultivation immediately to the south.

The opportunity has been taken to review the performance of the wells constructed in previous phases of the collector well programme. Some continue to operate to provide vital domestic water supplies to local schools and communities. However, others remain unused since completion, emphasising the need for institutional arrangements for their use to be formalised from the beginning.

Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 Background

Agriculture in semi-arid areas has developed in response to an unpredictable climate, and limited water availability is the main constraint to agricultural production. In these regions, farmers often compensate for the unreliable rainfall by cultivating large areas. With increasing population densities, this practice is becoming more difficult and overgrazing and soil erosion are now reducing the ability of the land to support agricultural production.

Better rainfed farming methods can improve crop production, but rainfed farming cannot guarantee crops because of the unreliability of the rainfall. This has been seen dramatically in the current drought in southern Africa; in southern Zimbabwe there are no rainfed crops this year. Dependable crop production can only be achieved in such extreme drought periods by the use of irrigation. However, large irrigation schemes have proved to be expensive, inefficient and difficult for government or parastatal organisations to manage. In addition, they do not integrate well with existing rainfed farming systems and can produce a range of socio-economic, health-related and environmental problems. Small-scale irrigation, in contrast, can be relatively inexpensive, more efficient and can be managed by the farmers themselves, along with their traditional farming systems. 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.

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.

Since 1983, the British Geological Survey (BGS) has been carrying out research 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; 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 support small-scale irrigation. When water supplies are limited, it is vital that the water is used efficiently. The Institute of Hydrology (IH) has a long history of research on crop water use and the Lowveld Research Station (LRS) at Chiredzi has also been carrying out research on methods of low-cost, efficient irrigation. The present programme of work therefore represents the natural bringing together of the relevant experience of BGS, IH and LRS.

1.2 Objectives of Study

Thus, in 1988 BGS and IH began a project aimed at developing limited groundwater resources for small-scale irrigation. The project is based at and carried out in collaboration with the Lowveld Research Station (LRS), situated close to Chiredzi in southern Zimbabwe. Funding for equipment and UK staff inputs from both BGS and IH has come from the Engineering Division of the UK Overseas Development Administration (ODA). The overall objectives of the study are to determine the feasibility and sustainability of small-scale irrigation from the shallow aquifers associated with crystalline basement rocks, and to assess simple, low-cost irrigation methods that can be used to improve water efficiency in small irrigated gardens. Within the overall programme, the specific objectives of the hydrogeological component of the study were:

(a) to further investigate cheaper methods of well construction

(b) to construct and test 2-4 collector wells in southern Zimbabwe

(c) obtain information on the long-term safe yields of collector wells by observing the performance of wells constructed in the present project and reviewing as far as possible the performance of wells constructed in earlier projects

(d) to improve techniques and bring down the cost of siting collector wells.

1.3 Scope of Report

The present report describes hydrogeological activities in the project from June 1990 to June 1992. These comprise the construction and testing of a collector well in Chivi Communal Area and further work at LRS Chiredzi to investigate possible local sources of enhanced recharge. This was a recommendation of the earlier report on the hydrogeological component of the study (Chilton et al, 1990), which also described in full the construction and testing of the collector well at LRS, Chiredzi. The parallel studies by IH over the same period are described by Lovell et al (1992). That work assesses the effectiveness of different irrigation practices and possible problems which might result from irrigation with more saline groundwater, and describes the first on-farm trials based on the collector well at Tamwa/Sihambe/Dhobani Kraals in the Chivi Communal Area.

2. COLLECTOR WELLS FOR COMMUNAL GARDENS

2.1 Siting Criteria

Having established a successful collector well at LRS, Chiredzi, the principal objective of the next phase of the programme was to construct and operate one or two collector wells at sites away from LRS. This would test the feasibility of using the combination of collector wells and efficient irrigation techniques to develop and sustain the cultivation of small gardens. In this way the project would be able to examine the institutional, administrative and economic aspects of collector well-based small-scale irrigation, in addition to hydrogeological and agronomic aspects. Sites would be required, therefore, where groundwater and soil conditions are suitable and where there is community interest in gardens and a need for vegetables. The selection criteria used to help identify these potential sites are listed below.

Geographical

(a) Within a Communal Area of Natural Regions IV and V that receive low and erratic annual rainfall.

(b) On a basement complex rock or other problem aquifer where extraction of water can be improved by use of the collector well principle.

(c) In an area presently without reliable water, that is, an area remote from dams, perennial rivers, or adequate and reliable groundwater. Villages which already have handpumps for domestic supply could be included.

(d) Soils are suitable for horticultural production.

Hydrogeological

(e) Where groundwater is found 12 metres or less below ground level, 15 metres if permeable material is found immediately beneath.

(f) The groundwater found is of a quality suitable for irrigation and domestic use.

(g) Wells can be dug by hand.

Socioeconomic and Agricultural

(h) The village group, found to be in need of vegetables, shows a strong interest in developing a community vegetable garden, and a willingness and ability to adopt new crop production techniques.

(i) The village group agrees to allocate an area of land for use as a community garden and collector well site, the area henceforth to be available for the community and not overly influenced by one single party.

(j) Perhaps a history of gardening exists in the area, but previous gardens were abandoned for legitimate reasons (e.g. water at present is insufficient for both domestic and garden use; distant riverside cultivation no longer permitted; gardeners displaced by a land issue with the land "owner").

(k) Though vegetables will primarily be grown for home consumption, access to a market should exist for surplus to be sold locally.

(l) A site chosen should ideally be one of several potential sites in the region, allowing other schemes to be developed following success of the first scheme.

2.2 Location of Sites

A preliminary list of possible general areas for collector well sites in communal lands and resettlement schemes was made during the October 1988 visit (Table 1). Visits have been made to several of these and detailed notes on six locations were included as an appendix in Lovell et al (1990). Apart from Tamwa/Sihambe/Dhobani Kraals, groundwater investigations were carried out in Sangwe and at two locations in the Nyahombe Resettlement Scheme. The latter are briefly described here for possible future reference and so that the information is not lost. Further work may be carried out in Sangwe, so the information will be retained for inclusion in a later report.

Staff of LRS Chiredzi suggested that the first site for an irrigated garden should be in a resettlement scheme. Consequently, the first visits were made to the Nyahombe Resettlement Scheme, 80 km NW of LRS (Figure 1) in October 1989. The scheme just straddles the main A10 road (Figure 2) but primarily occupies a triangular area of land between the Tokwe and Runde Rivers. The underlying geology comprises granulite gneisses of the Limpopo Mobile Belt, which form prominent inselberg hills. Average rainfall ranges from perhaps 900 mm in the north of the Scheme to 700 mm in the south.

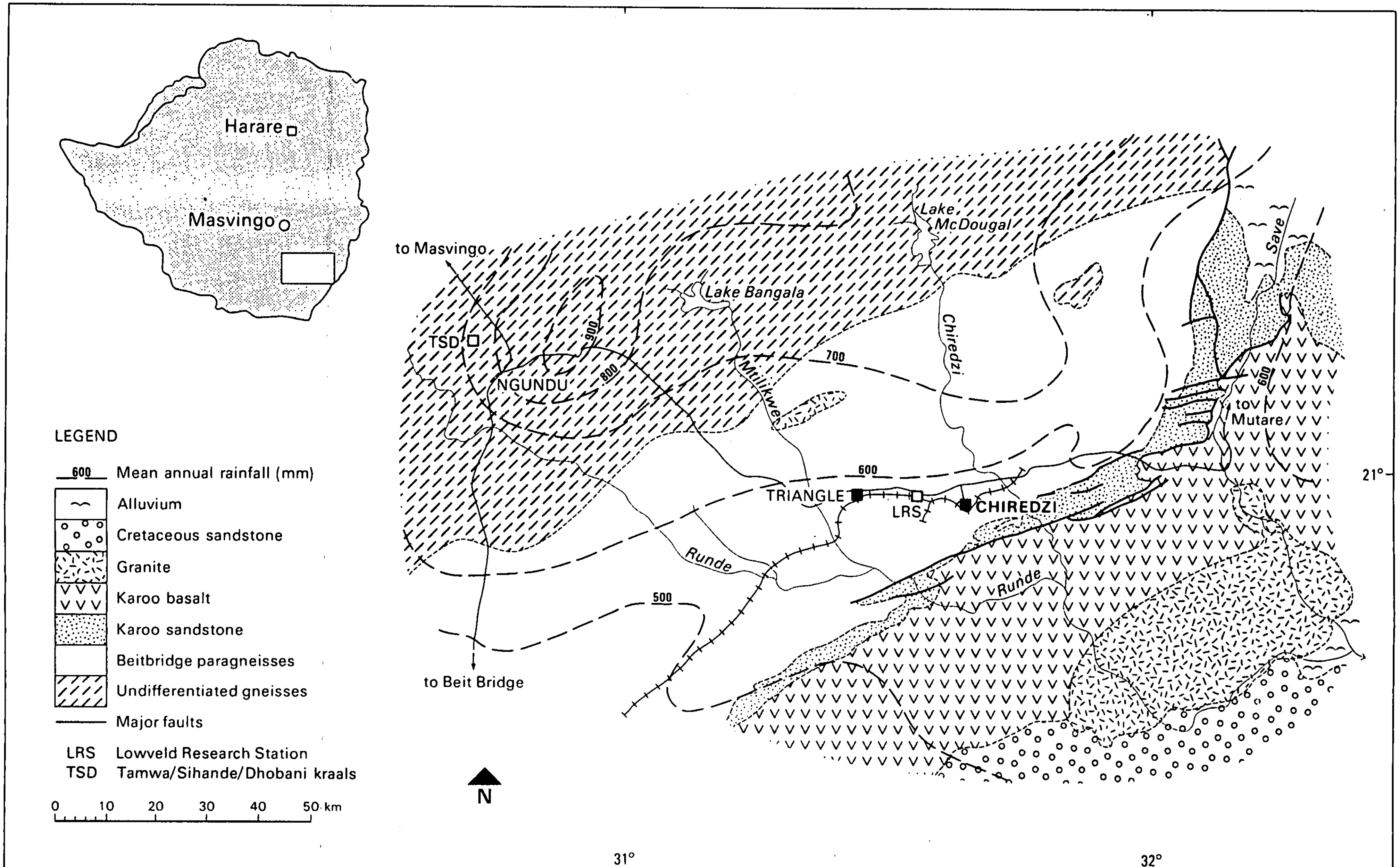


Figure 1. Location of collector well sites in southern Zimbabwe.

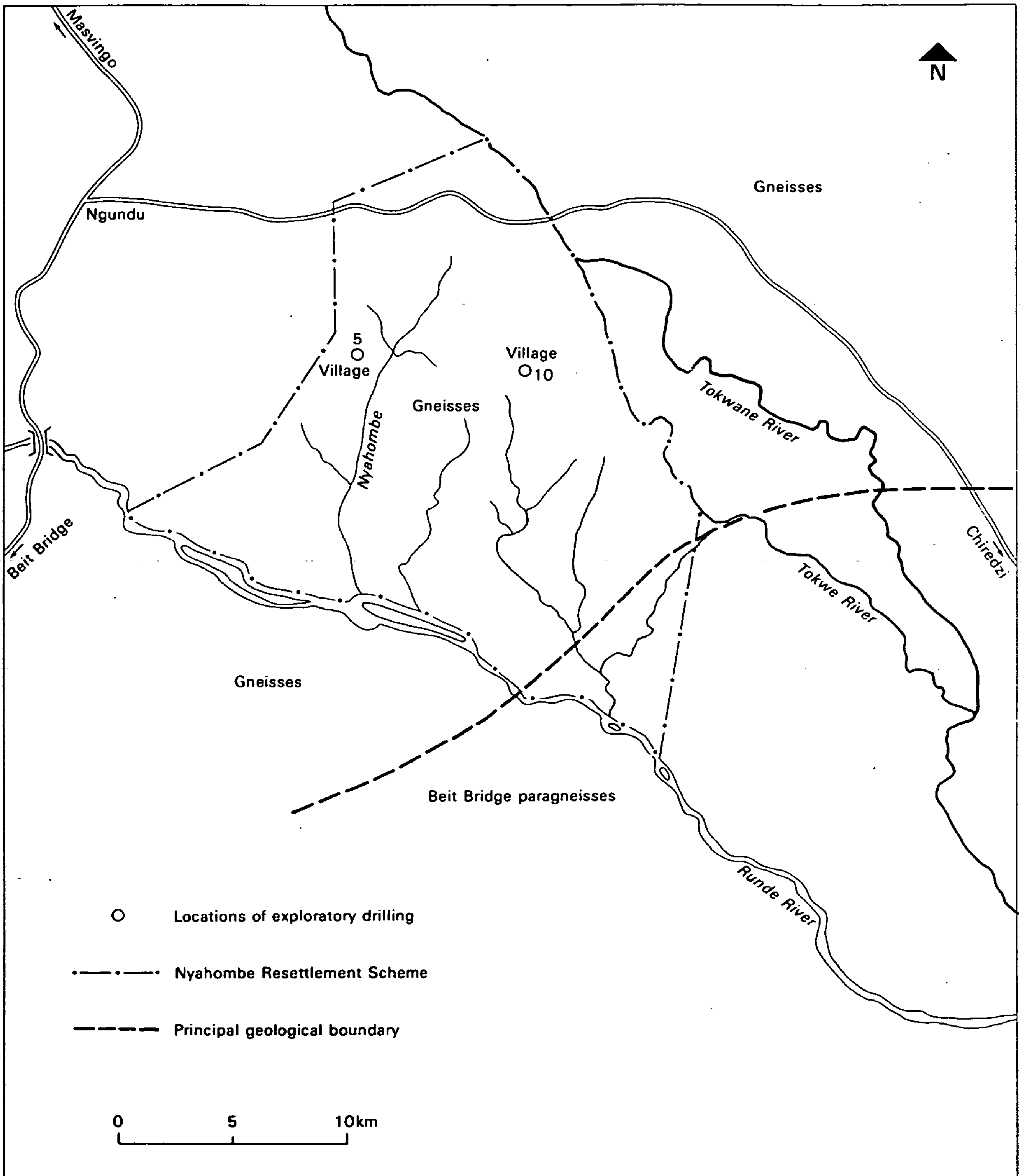


Figure 2. Location of target villages in the Nyahombe Resettlement Scheme.

Table 1. Potential for Collector Well Sites in Communal Areas

	Name	Location	Underlying Geology
(a)	Matibi No. 1 (Neshuru)	100-120 km W of LRS	Precambrian basement gneisses
(b)	Maranda	130-140 km W of LRS	Precambrian basement gneisses
(c)	Ndanga (Zaka)	80 km N of LRS	Basement gneisses and granites
(d)	Sangwe	60-80 km E of LRS	Mostly Karoo, some paragneisses
(e)	Ndowoyo	70-80 km E of LRS	Karoo basalts
(f)	Mutema	150 km NE of LRS (near Birchenough Bridge)	Granite and dolerite
(g)	Matibi No. 2	30-50 km S of LRS	Karoo basalts
(h)	Sengwe	100-120 km S of LRS	Karoo basalts, rhyolites and later granites
(i)	Chiswiriswi	30-40 km E of LRS	Paragneisses and Karoo
(j)	Nyahombe	80 km NW of LRS	Basement gneisses
(k)	Nyajena	80 km NNW of LRS	Basement gneisses
(l)	Chivi	110 km W of LRS	Basement gneisses

Villages 5 and 10 were selected as potentially suitable for collector wells and gardens following the criteria described above. It was agreed that exploratory drilling would be required to confirm the presence of groundwater at a suitable depth. Consequently, in November 1989, six test boreholes were drilled around Villages 5A and 5B (Table 2). Negligible water was encountered and the largely fresh, unweathered gneisses were quite unsuitable for well digging. This is confirmed by the slow rate of penetration of drilling at the site, 6-10 minutes for each 0.75 m rod (Figure 3). The rig was moved to Village 10A in December and two further boreholes were constructed (Table 2). The improved rate of penetration of 4-6 minutes per 0.75 m rod at this site (Figure 4) indicating more weathered and broken gneiss. Borehole 8 was pumped at 0.67 l/sec and drew the water level down to pump suction at 13.7 m in 12 minutes, with recovery to 4.73 m below ground level in 48 minutes (Table 3 and Figure 5) suggesting a transmissivity of about 1 m^2/d. Additional drilling was planned for early 1990, but heavy rain prevented access to the preferred sites. Two boreholes which were drilled encountered hard rock at very shallow depths.

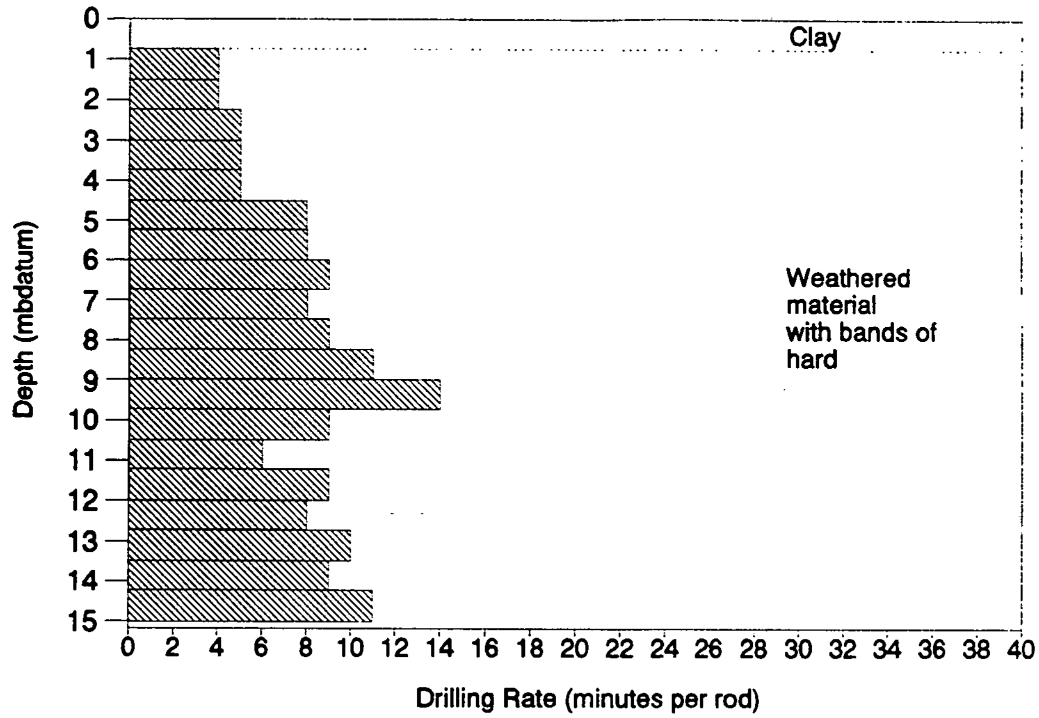


Figure 3. Rate of penetration log, borehole 1, Village 5A, Nyahombe Resettlement Scheme.

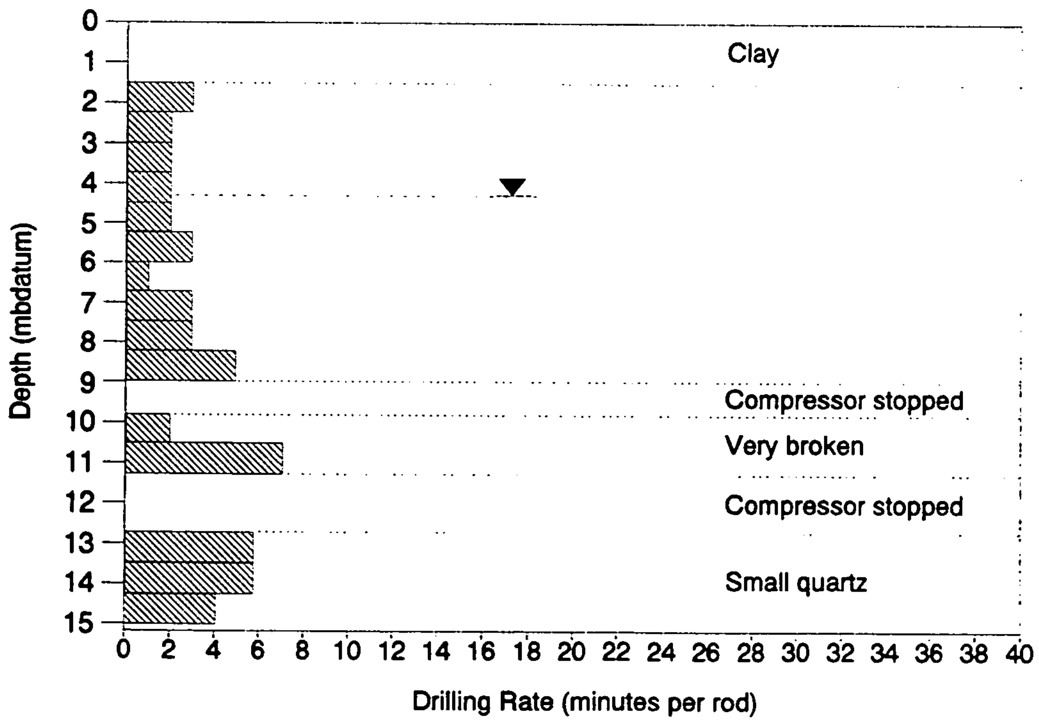


Figure 4. Rate of penetration log, borehole 8, Village 10A, Nyahombe Resettlement Scheme.

Table 3. Test Pumping Results at Borehole 8, Village 10A, Nyahombe Resettlement Scheme.

PUMPING TEST - DRAWDOWN DATA

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

FILE NO.: 0001
WELL NO.: VILLAGE 10A
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.39m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
13	7	30	0.00	4.600	0.000	0.6667
13	7	31	1.00	5.800	1.200	0.6667
13	7	32	2.00	7.240	2.640	0.6667
13	7	33	2.50	7.720	3.120	0.6667
13	7	33	3.00	8.250	3.650	0.6667
13	7	34	3.50	8.720	4.120	0.6667
13	7	34	4.00	9.300	4.700	0.6667
13	7	35	4.50	9.940	5.340	0.6667
13	7	35	5.00	10.320	5.720	0.6667
13	7	36	6.00	11.260	6.660	0.6667
13	7	37	7.00	12.090	7.490	0.6667
13	7	38	8.00	12.770	8.170	0.6667
13	7	39	9.00	13.440	8.840	0.6667
13	7	42	12.00	13.700	9.100	0.6667
						VALUE USED 0.6667

BRITISH GEOLOGICAL SURVEY

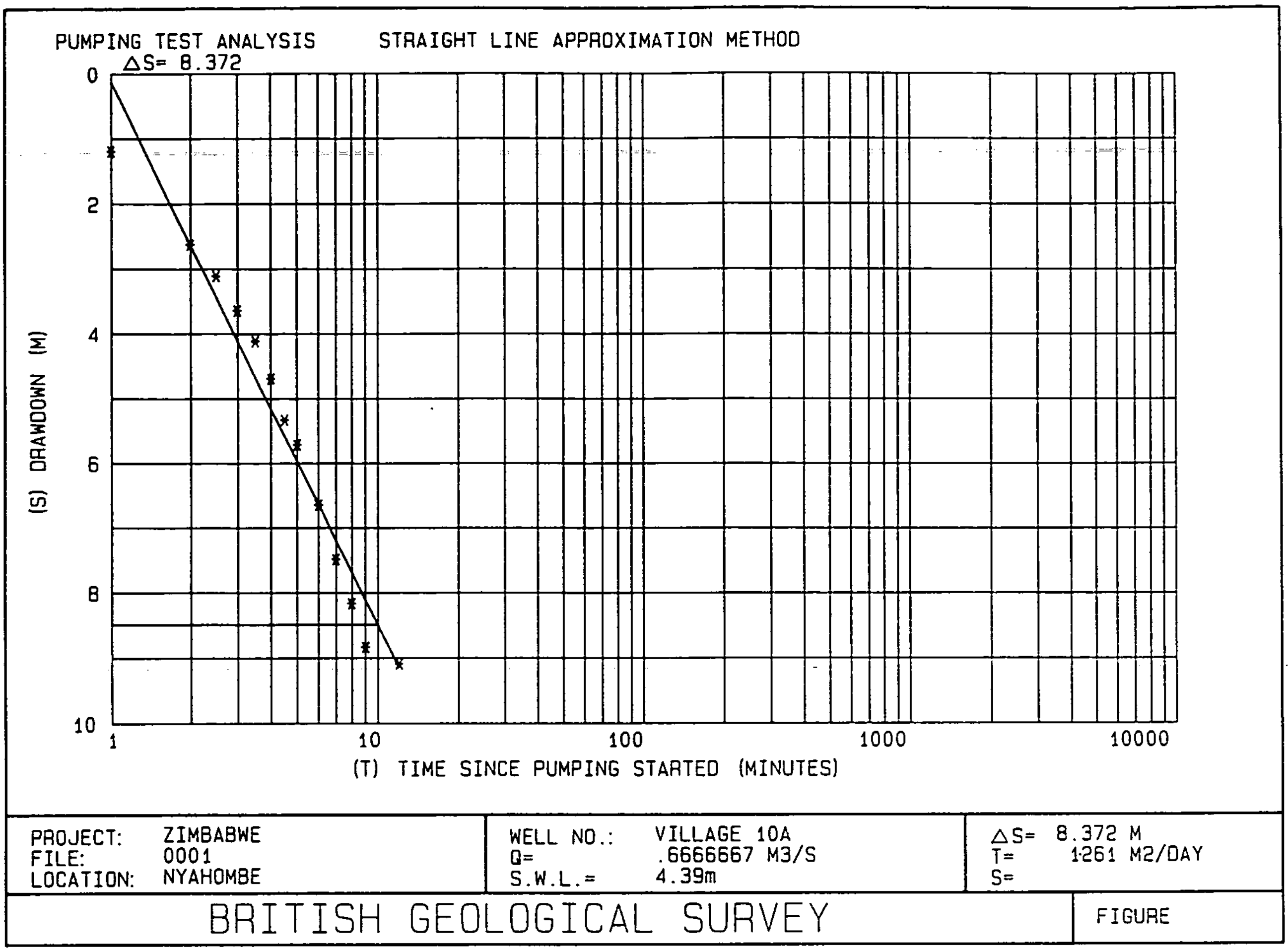
PUMPING TEST - RECOVERY DATA

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

FILE NO.: 0001
WELL NO.: VILLAGE 10A
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 4.39m
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)
13	7	43	12.50	0.50	25.00	14.000	9.400
13	7	43	13.00	1.00	13.00	13.600	9.000
13	7	44	14.00	2.00	7.00	12.850	8.250
13	7	45	14.50	2.50	5.80	12.500	7.900
13	7	45	15.00	3.00	5.00	12.160	7.560
13	7	46	15.50	3.50	4.43	11.750	7.150
13	7	46	16.00	4.00	4.00	11.330	6.730
13	7	47	17.00	5.00	3.40	10.700	6.100
13	7	48	18.00	6.00	3.00	10.070	5.470
13	7	49	19.00	7.00	2.71	9.400	4.800
13	7	50	20.00	8.00	2.50	8.770	4.170
13	7	51	21.00	9.00	2.33	8.250	3.650
13	7	52	22.00	10.00	2.20	7.720	3.120
13	7	54	24.00	12.00	2.00	6.900	2.300
13	7	56	26.00	14.00	1.86	6.250	1.650
13	7	58	28.00	16.00	1.75	5.750	1.150
13	8	0	30.00	18.00	1.67	5.400	0.800
13	8	2	32.00	20.00	1.60	5.160	0.560
13	8	4	34.00	22.00	1.55	5.000	0.400
13	8	6	36.00	24.00	1.50	4.910	0.310
13	8	8	38.00	26.00	1.46	4.850	0.250
13	8	10	40.00	28.00	1.43	4.800	0.200
13	8	12	42.00	30.00	1.40	4.750	0.150
13	8	14	44.00	32.00	1.38	4.760	0.160
13	8	17	47.00	35.00	1.34	4.780	0.180
13	8	27	57.00	45.00	1.27	4.750	0.150
13	8	32	62.00	50.00	1.24	4.740	0.140
13	8	42	72.00	60.00	1.20	4.730	0.130

BRITISH GEOLOGICAL SURVEY



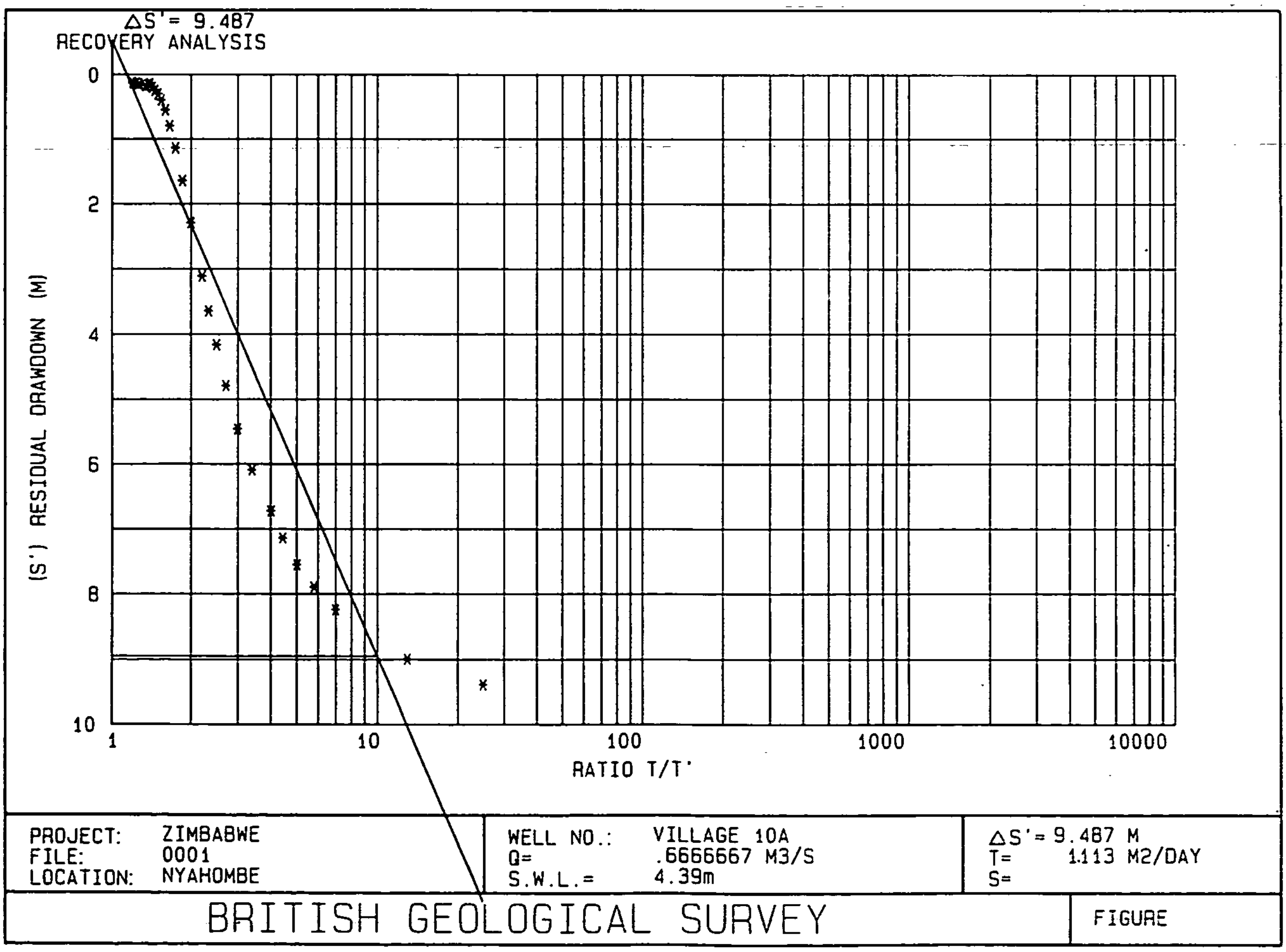


Figure 5. Test pumping, borehole 8, Village 10A, Nyahombe Resettlement Scheme.

Table 2. Results of Exploratory Drilling, Nyahombe Resettlement Scheme.

Village	Borehole Number	Depth (m)	Water Struck (m)	Rest Water Level (m)	Lithology
5A	1	15.0	-	-	Weathered gneiss with hard bands
5A	2	3.75	-	-	Solid, hard granite or gneiss
5B	3	9.75	-	-	Weathered gneiss with hard bands, solid at 9.5 m
5B	4	5.25	-	-	Hard from 5 m
5B	5	12.0	-	-	Weathered material with hard and soft bands
5B	6	5.25	-	-	Hard, no weathered material
10A	7	13.5		5.35	Weathered gneiss, hard band at 6 m and hard at 13.5 m
10A	8	15.0		4.3	Weathered, very broken at 10.5 m and below

In the meantime, further discussion between BGS/IH and BHC, Harare and correspondence between ODA, BDDSA and BHC confirmed the latter's view that communal lands should be the location of collector wells which would test institutional aspects of small-scale irrigation. Farmers in resettlement areas have more land available to them than communal farmers and are thus potentially in a better position to generate a cash surplus. In the communal lands there are particular problems of availability of food, especially vegetables, in the dry season and farmers in communal areas can be expected to gain substantial benefits from small-scale irrigation. It was recommended, therefore, by ODA Engineering Division, the British High Commission and the Development Division in February 1990 not to proceed further with Nyahombe, and attention was turned to the communal lands. Visits were made to several locations (Lovell et al, 1990) in April 1990. Exploratory drilling was carried out without success in Sangwe in April and May 1990. As Sangwe remains a possible location of wells and gardens in future projects, the information obtained from this drilling will be incorporated into future reports on the area. Attention then turned to Sihambe Kraal, the successful results of which form the following chapter of this report.

3. COLLECTOR WELL AT TAMWA/SIHAMBE/DHOBANI KRAALS

3.1 Site Location and Description

Tamwa/Sihambe/Dhobani Kraals are located in south-east Zimbabwe at latitude 20°43'S and longitude 30°43'E, in Ward 22 in the southern part of Chivi Communal Area. The well serves three small villages which are situated approximately 5 km west of the main A1 road from Masvingo to Beit Bridge (Figure 1) at an altitude of approximately 800 m. The site is reached by turning off the A1 road at km 86, which is 7 km north of Ngundu and 110 km from Chiredzi. The site is located in Natural Region IV of Zimbabwe. Annual rainfall averages about 750 mm, but with a wide variation. Most rainfall results from high intensity storms during the period November to April, which is the rainy season, but severe dry spells can occur even during these months.

The three small villages of Tamwa, Sihambe and Dhobani Kraals are situated amongst kopjes, in an area largely used for cattle grazing and to cultivate rainfed maize and cotton. The geology of the area has been described by Robertson (1974). Regionally, the area covers part of the junction between the metamorphic rocks of the northern margin of the Limpopo Mobile Belt and the granite-greenstone terrain of the Zimbabwe Craton to the north. The area immediately around Tamwa/Sihambe/Dhobani Kraals is composed of granulite gneisses, with a dominant NE-SW structural trend, often picked out by thin bands of mafic granulite.

Prior to construction of the collector well, drinking water for all three villages was provided by a Lutheran hand-dug well in an adjacent vlei (to the north of the collector well site) and by private hand-dug well (Mr Mhlanga's well). There was insufficient water for gardens to be developed. Tamwa Kraal comprises 36 families, Sihambe Kraal 30 families and Dhobani Kraal 37 families.

3.2 Well Siting Investigations

The Kraals area was initially selected as a potential well site in April 1990. Great interest had been expressed in the idea of developing vegetable gardens, and by the time of a second visit a few days later the people in the area had requested help from their extension worker in identifying an area suitable for a communal garden. This was close to exposed rock which appeared to be a dyke. A well upgradient of the 'dyke' had water only a few metres below ground and was said to be reliable through the dry season. Provisional sites for exploratory drilling were selected.

Exploratory drilling was carried out in May 1990 (Figure 6). Four boreholes were constructed to depths of 13-17 m. Water was encountered at 8-16 m and rest water levels at the site were 2-3 m below ground level (Table 4).

Table 4. Results of Exploratory Drilling at Tamwa/Sihambe/Dhobani Kraals

Borehole Number	Drilled Depth (m)	Water Struck (m)	Rest Water Level (m)
1	13.0	8.0	2.0
2	17.0	10.0	3.0
3	15.0	10.0	3.0
4	17.0	16.0	2.0

Groundwater conditions are thus quite strongly confined at the site and this is confirmed by the clayey nature of the material encountered during drilling; samples were retained at 1 m intervals and subsequently described (Table 5). A short pumping test was performed on borehole 3 (Table 6). Pumping at 0.3 l/sec drew the water level down from 3.3 m to 9.35 m in 18 minutes, and after 88 minutes had recovered to 4.0 m. A transmissivity of about 1 m^2/d is estimated (Figure 7).

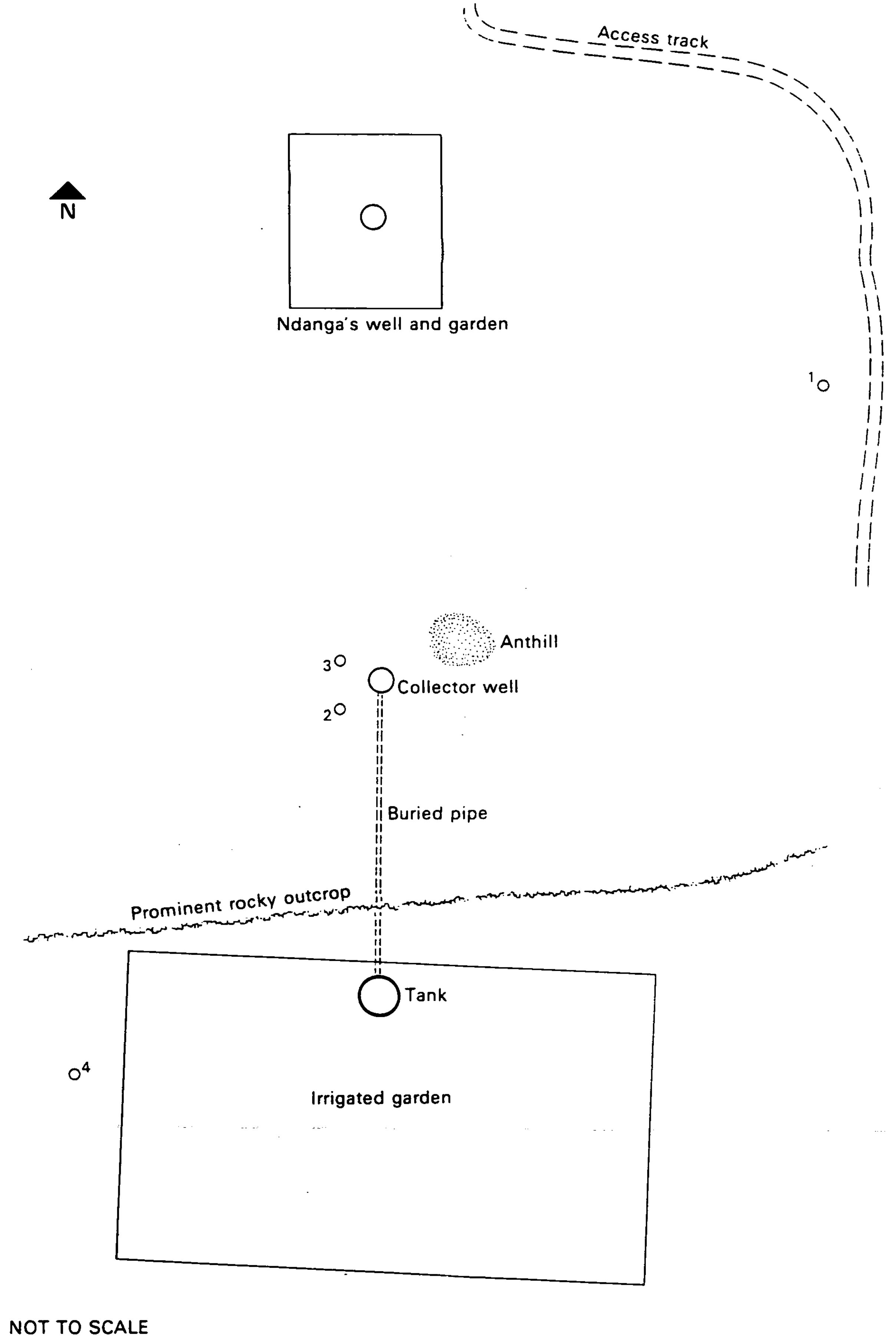


Figure 6. Sketch location of exploratory borehole sites, Tamwa/Sihambe/Dhobani kraals.

Table 5. Lithological Descriptions of Samples from Exploratory Boreholes, Tamwa/Sihambe/Dhobani Kraals.

Depth (m)	BOREHOLE 1 Description	Depth (m)	BOREHOLE 2 Description
1	Dark brown clay soil. Some small (3 mm) grey rock fragments.	1	Mixture of brown clay lumps and reddish lateritic nodules up to 5 mm across.
2	Dark buff-brown clay with few rock fragments.	2	As above. Dominantly lateritic material, and some brown clayey soil in lumps.
3	Paler, yellowish-buff brown clay. Few larger fragments.	3	Brown clay. Fewer lateritic nodules.
4	Missing.	4	Brown clay and fragments of weathered gneiss up to 3 mm in size.
5	Pale buff clay and silt with few rock fragments. Dry.	5	Paler buff clayey, silty lumps. Fragments of weathered gneiss up to 10 mm.
6	Pale buff clay and silt. No rock fragments bigger than 2 mm.	6	As above.
7	Pale buff clayey-silty matrix with few small rock fragments (as above).	7	Angular fragments of dark grey rock, some with fresh faces. Mostly thin covering of buff silty clay. Fragments up to 10 mm in size. Less clay.
8	Wet clay matrix, pale buff clay sand and silt, some (very few) weathered rock fragments.	8	As above.
9	As above.	9	Angular fragments of gneiss, some fresh. Also some with laminated crystals.
10	Greyer silty clay sand matrix, with more rock fragments embedded in it. Dark grey.	10	Angular fragments of weathered gneiss, some with iron staining, some fresher. Little clay.
11	Grey sandy clay (feels sandy). Very few rock fragments.	11	Lumps of grey-buff silty clay with rock fragments and some mica flakes and crystals.
12	Sandy grey clay as above. Some grey rock fragments.	12	Lumps of buff silty-sandy clay. Lots of mica crystals shining in the surface, and when lumps are broken.
13	As above. Still very weathered.	13	As above. Lots of mica, and quartz pieces in clay (silty and sandy) matrix.
		14	As above. More black fragments up to 5 mm, less mica.
		15	As above. Sandy buff-grey brown clay. Lots of angular black fragments and quartz grains and some micas.
		16	As above. Less clay in matrix, more angular fragments.
		17	As above. Greyer. Still weathered?

Table 5 (continued)

Depth (m)	BOREHOLE 3 Description	Depth (m)	BOREHOLE 4 Description
1	Red-brown clay soil, some small (5 mm) angular fragments of weathered gneiss, and small (5 mm) round, black nodular iron concretions. Dry.	1	Dark red-brown clay soil. Some iron-rich lumps up to 3 mm.
2	Small, round (2-5 mm) concretions of iron, black with buff-red coating, some small gneiss fragments. Dry.	2	Red-brown clay. No rock fragments.
3	Much smaller fragments (up to 2-3 mm), buff coloured. Not much clay? Dry.	3	Yellowish-brown clay, some very small weathered gneiss fragments. Some iron-stained lumps.
4	Very small fragments of buff-coloured weathered rock, ranging up to 10 mm. When broken, fragments show iron staining on faces. Dry.	4	Angular weathered rock fragments in buff clay. Much less clay.
5	Fine, dry, pale buff pieces from 1-3 mm mainly, some dark centres when broken, and iron staining coats, with buff clay cover, some clay balls.	5	Much greyer, less buff and reddish iron. Some rock fragments up to 10 mm across, have moderately fresh faces of dark gneiss.
6	Larger pieces of pale buff weathered rock, some clay lumps, some clay aggregating smaller pieces. Dry.	6	Grey fine dust of weathered gneiss, with angular hard fragments up to 5-10 mm, showing fresh faces. No soft unbroken lumps.
7	Buff lumps of clay and clay coated weathered pieces of gneiss. Clay balls. Dry.	7	Angular fragments of gneiss, some very fresh, dark grey. Little clay.
8	As above.	8	Angular fragments of gneiss, covered with buff silty clay matrix. Broken faces show fresh gneiss.
9	Similar to 7 above, becoming slightly greyer. Still plenty of clay.	9	As above. Hard angular fragments up to 10 mm across, mostly covered with buffish clay.
10	Lumps of pale, buff-grey clay and silt. Very few large fragments of weathered rock, up to 5 mm. High proportion of clay and silt.	10	As above.
11	As above. Very few large fragments, mostly clay and silt.	11	Similar to above. Smaller fragments, some fresh broken dark grey pieces.
12	Buff, silty sandy clay.	12	Small rock fragments in buff silty clay matrix.
13	As above.	13	Finer powder of grey rock fragments. Less clay. Some clayey lumps broken easily by hand.
14	Sand and gravel of weathered gneiss, some rounded fragments, reddish iron stained. In buff, silty clay matrix. Few larger pieces.	14	As above.
15	Fine dry dust of weathered gneiss. Some angular fragments up to 5 mm. No large lumps.	15	Missing.
		16	Buff-grey clay matrix in lumps, with few small pieces of rock.
		17	Silty clay matrix with sand and gravel of weathered rock. Few larger pieces.

Table 6. Test Pumping Results, Borehole 3, Tamwa/Sihambe/Dhobani Kraals.

PUMPING TEST - DRAWDOWN DATA

PROJECT: ZIMBABWE
LOCATION: TAMWA KRAAL
DATUM POINT: 30mm A.G.L.
PUMPING RATE: 0.338983 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0002
WELL NO.: DIBIE VILLAGE
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 3.30m
R = ----- FROM
SCREEN INTERVAL: TO

TIME			ELAPSED TIME	WATER LEVEL	DRAWDOWN	(Q)
DY	HR	MN	t (MIN)	(m)	s (m)	(L/S)
18	9	20	0.00	3.300	0.000	0.3390
18	9	22	2.00	3.770	0.470	0.3390
18	9	23	3.00	4.120	0.820	0.3390
18	9	24	4.00	4.600	1.300	0.3390
18	9	25	5.00	5.000	1.700	0.3390
18	9	27	7.00	5.880	2.580	0.3390
18	9	28	8.00	6.480	3.180	0.3390
18	9	29	9.00	7.080	3.780	0.3390
18	9	32	12.00	8.680	5.380	0.3390
18	9	36	16.00	9.350	6.050	0.3390
18	9	38	18.00	9.350	6.050	0.3390
						VALUE USED 0.3390

BRITISH GEOLOGICAL SURVEY

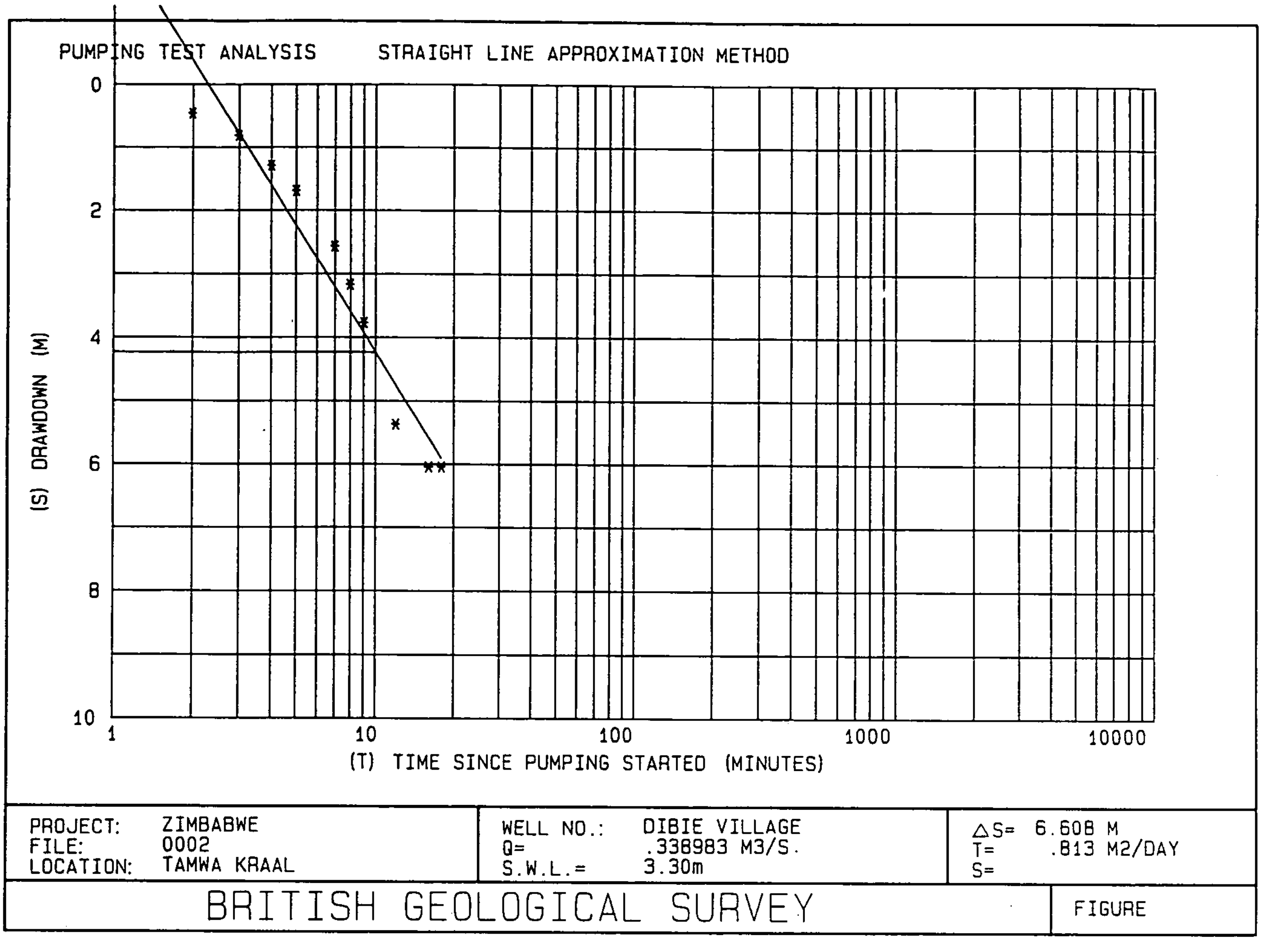
PUMPING TEST - RECOVERY DATA

PROJECT: ZIMBABWE
LOCATION: TAMWA KRAAL
DATUM POINT: 30mm A.G.L.
PUMPING RATE: 0.338983 L/S
AQUIFER THICKNESS:
CONDITIONS: UNCONFINED

FILE NO.: 0002
WELL NO.: DIBIE VILLAGE
ELEV. OF DATUM POINT:
STATIC WATER LEVEL: 3.30m
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)
18	9	38	18.00	0.00	0.00	9.350	6.050
18	9	39	19.00	1.00	19.00	9.120	5.820
18	9	40	20.00	2.00	10.00	8.900	5.600
18	9	41	21.00	3.00	7.00	8.730	5.430
18	9	42	22.00	4.00	5.50	8.570	5.270
18	9	43	23.00	5.00	4.60	8.350	5.050
18	9	45	25.00	7.00	3.57	7.920	4.620
18	9	47	27.00	9.00	3.00	7.550	4.250
18	9	48	28.00	10.00	2.80	7.300	4.000
18	9	50	30.00	12.00	2.50	6.970	3.670
18	9	52	32.00	14.00	2.29	6.600	3.300
18	9	54	34.00	16.00	2.13	6.400	3.100
18	9	56	36.00	18.00	2.00	6.190	2.890
18	9	58	38.00	20.00	1.90	5.920	2.620
18	10	0	40.00	22.00	1.82	5.710	2.410
18	10	4	44.00	26.00	1.69	5.460	2.160
18	10	6	46.00	28.00	1.64	5.370	2.070
18	10	8	48.00	30.00	1.60	5.270	1.970
18	10	10	50.00	32.00	1.56	5.170	1.870
18	10	13	53.00	35.00	1.51	4.050	0.750
18	10	28	68.00	50.00	1.36	4.200	0.900
18	10	38	78.00	60.00	1.30	4.100	0.800
18	10	48	88.00	70.00	1.26	4.000	0.700

BRITISH GEOLOGICAL SURVEY



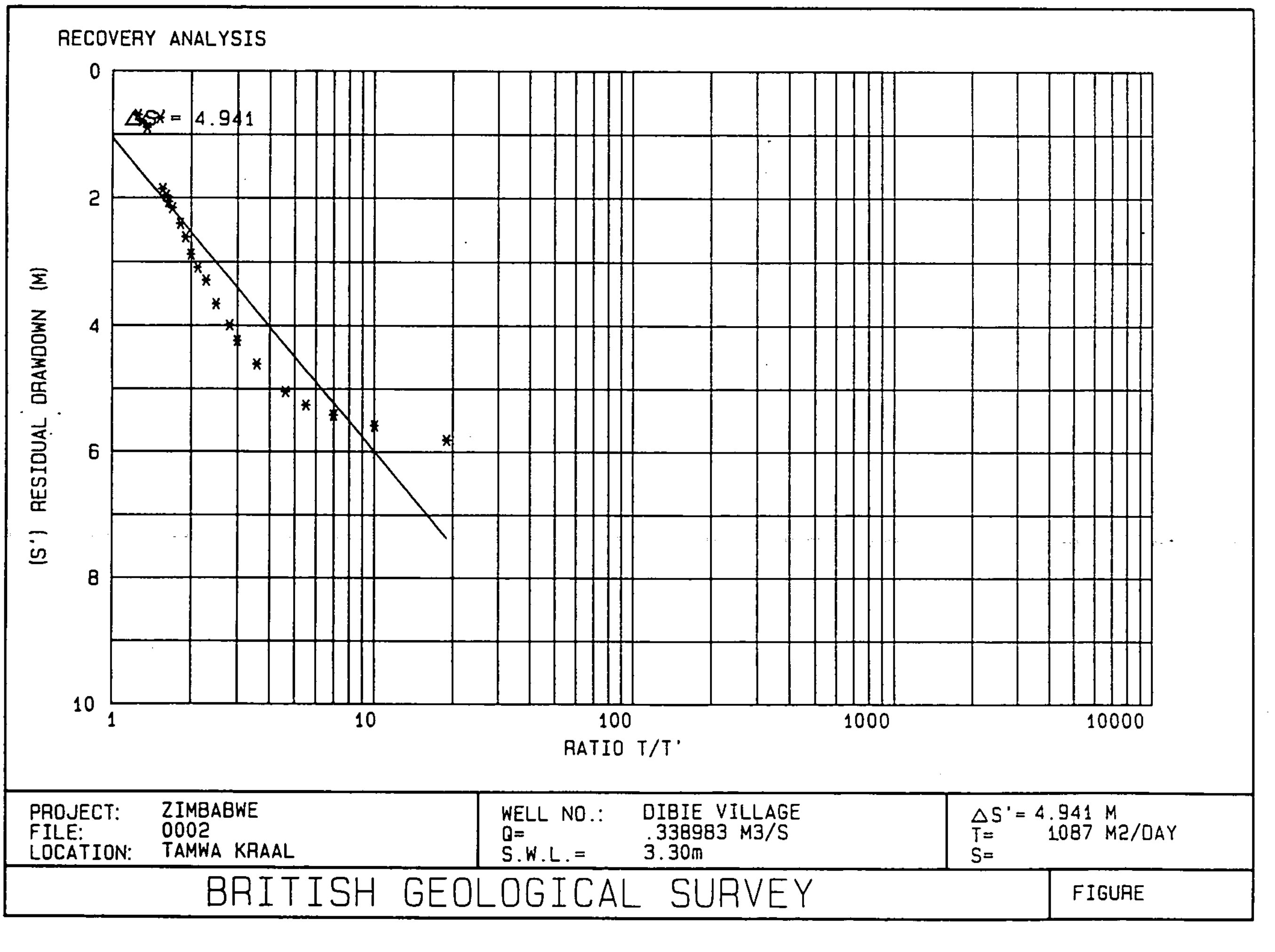


Figure 7. Test pumping, borehole 3, Tamwa/Sihambe/Dhobani kraals.

3.3 Well Construction

A site for the collector well was selected close to borehole 3. Digging began in May 1990, using four local labourers and a foreman, and supervised by the BGS contract driller. The formation consisted of weathered and broken gneiss, becoming harder towards the base of the well. Samples of the excavated material were described (Table 7) and some selected pieces taken to UK for full petrographic description.

Samples of rock from the base of the well can be described as pyroxenite, consisting almost entirely of anhedral plates of clinopyroxene up to 6 mm across, with accessory amounts (less than 5%) of green chrome-spinel as small, scattered grains within granoblastic pyroxene intergrowths. The spinel shows a reaction rim of colourless phlogophitic mica and pale brown amphibole and colourless mica also occur along grain boundaries as secondary alteration products. Weathering is not far advanced in these samples.

A sample from the prominent rocky outcrop close to the garden (Figure 6) is a pyroxene granulite consisting of a granoblastic intergrowth of anhedral quartz, andesine, microcline, hypersthene and augitic clinopyroxene, with minor amounts of opaque iron oxide. A similar sample from the spoil heap beside the well is an altered or sheared granulite, largely made up of granoblastic quartz intergrowths, enclosing highly altered plates of plagioclase and pseudomorphs of ferromagnesian minerals. The textural relationships between granoblastic quartz and larger grains of strained quartz suggest that cataclastic recrystallisation may have occurred, possibly within a shear zone. Evidence of secondary weathering is indicated by the highly altered state of the former ferromagnesian minerals. This is not, therefore, as appeared possible in the field, a dyke, but the well may be constructed in or close to a shear zone.

Table 7. Lithological Description of Collector Well Samples.

Depth (m)	Description
1	Rounded gravel and fragments of weathered material. Black centres, plenty of iron staining. Some appear nodular. Not much clay.
2	Soft, buff lumps of weathered material. Lot of iron staining. Some hard lumps, some balls of soft clay.
3	Soft grey clay lumps, pieces of pink and yellowish weathered feldspar-rich rock, clay skin on most of the hard lumps, lot of iron staining.
4	Hard fragments of weathered rock embedded in brown-buff clay matrix. Some fragments very iron-rich, some dark.
5	Much paler, buff material, clay and silt and soft lumps of weathered material. Some weathered lumps showing foliation when broken. Less iron staining.
6	Hard and soft lumps of weathered gneiss, less clay, clay coating of the hard lumps.
7	Missing.
8	Soft weathered lumps, buff coloured. Some clay. Some hard fragments.
9	As above.
10	Hard, angular fragments of pink feldspar-rich rock in buff clay matrix.
11	Hard angular lumps of dark grey rock, less clay, still some clay matrix.
12	Hard, angular fragments of slightly weathered gneiss, dark grey to black. Fresh faces show crystals.

Water was first encountered at 9.0 m. The first Armco lining was inserted when the well had reached 4 m. The well was completed to 12.0 m in mid-July 1990. Fifty-two working days had been required to complete the digging, and a further twelve were required to complete the headworks. No significant problems were encountered during the digging. Two pumping tests were carried out on the completed well, as described in section 3.4 below.

Because of other commitments and then serious illness, the BGS driller was unable to carry out the radial drilling immediately following completion of the well, and it was delayed until late March 1991. Four horizontal laterals were constructed in order, starting from the SW and then SE, NE and NW (Figure 8). The first encountered soft, weathered materials for 5 m and then hard rock to 24 m. Although there were fractures about every two metres, little inflow of water was observed, and the well screen could be inserted only to 5 m. The second passed through soft material to 4 m and then weathered rock to 26 m, with many fractures and a good inflow of water. The third was in hard rock to 2 m and then, after a prominent fault or fracture reached 20 m in moderately weathered rock. This lateral was stopped at 20 m because of the dry and dusty conditions with no apparent water inflow. After the hole had stood open for about an hour, however, a steady inflow of water had developed. The fourth lateral encountered hard rock to 8 m, with several large fractures and solid, hard rock from 8 to 16 m. The first 8 m provided a steady inflow to the well. All of the laterals except the first appear to have contributed flow to the well.

After the radials had been completed, further testing was carried out, as described in section 3.4. The well was completed with a brick parapet and cover with a frame and box to hold a float-operated autographic water level recorder. The well-head was completed with a 2 m deep sanitary seal and concrete apron around the well, and a galvanised metal cover, as shown in Figure 9, a cross-section showing the as-built final construction of the well. Finally, two modified Bush pumps, mounted side-by-side on a frame across the well (Figure 10) provide the water to a small header tank, from which domestic and irrigation water are separately metered by two Kent 40 mm PSM class C water meters. Irrigation water is taken by a buried 50 mm diameter pipe to an 11,000 litre capacity tank in the garden itself (Figure 11).

3.4 Well Testing

Two pumping tests were carried out on the well before radial drilling:

	20 March	21 March
Static water level (bd)	5.70 m	5.84 m
Duration of pumping	70 mins	100 mins
Pump discharge rate	0.6 l/sec	4.38 l/sec
Final water level	6.36 m	11.60 m
Final drawdown	0.66 m	5.76 m
25% recovery	160 mins	230 mins
50% recovery	350 mins	560 mins
75% recovery	1200 mins	1300 mins

The tests were analysed by the nomogram method devised by Barker and Herbert (1989) to give the following transmissivities (T, m^2/d) and storage coefficients (S):

	20 March		21 March	
	T	S	T	S
Recovery 25%	0.50	1.0	-	-
50%	0.63	0.06	-	-
75%	1.76	0.10	1.04	0.80

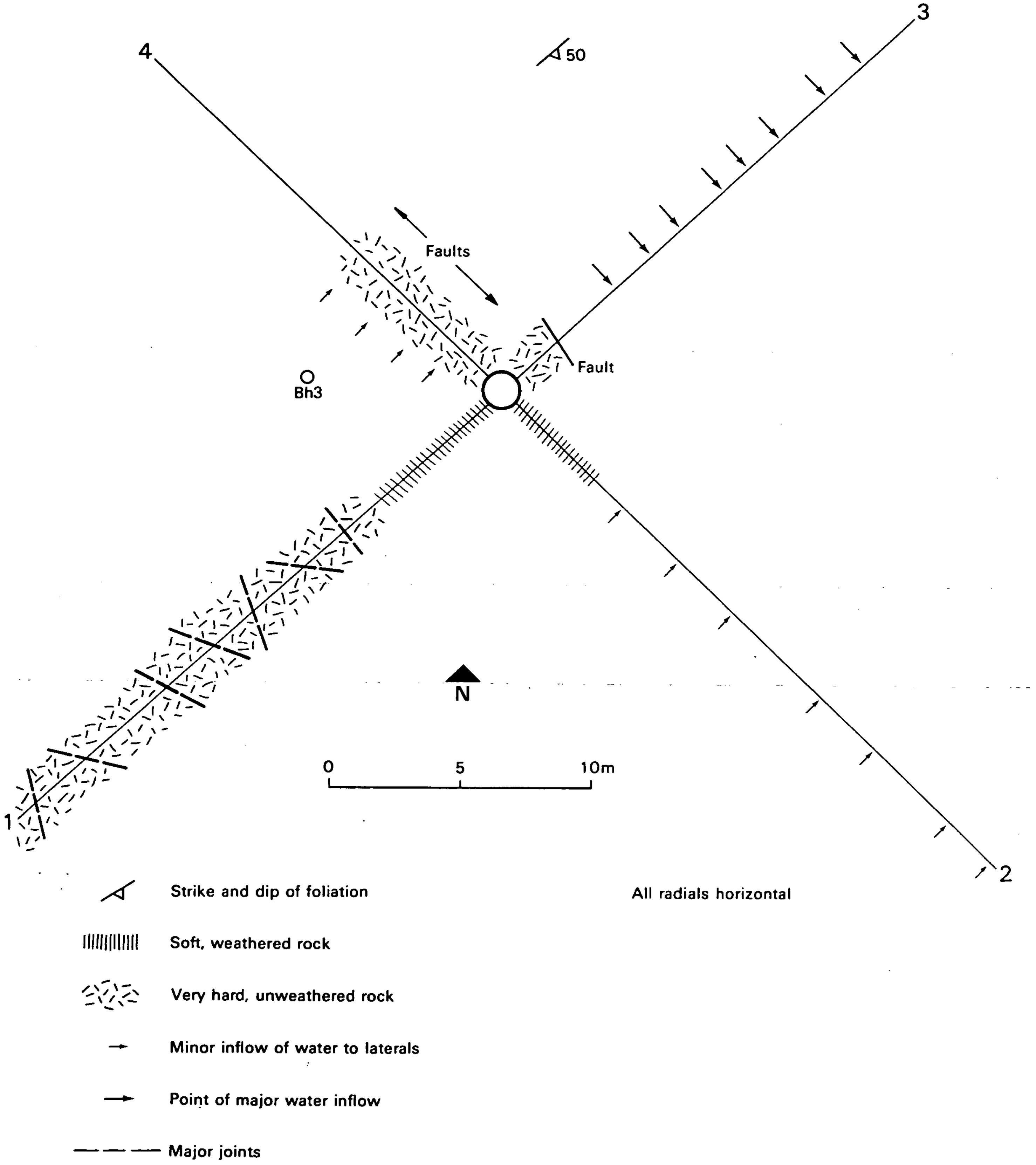


Figure 8. Layout of laterals at Tamwa/Sihambe/Dhobani kraals.

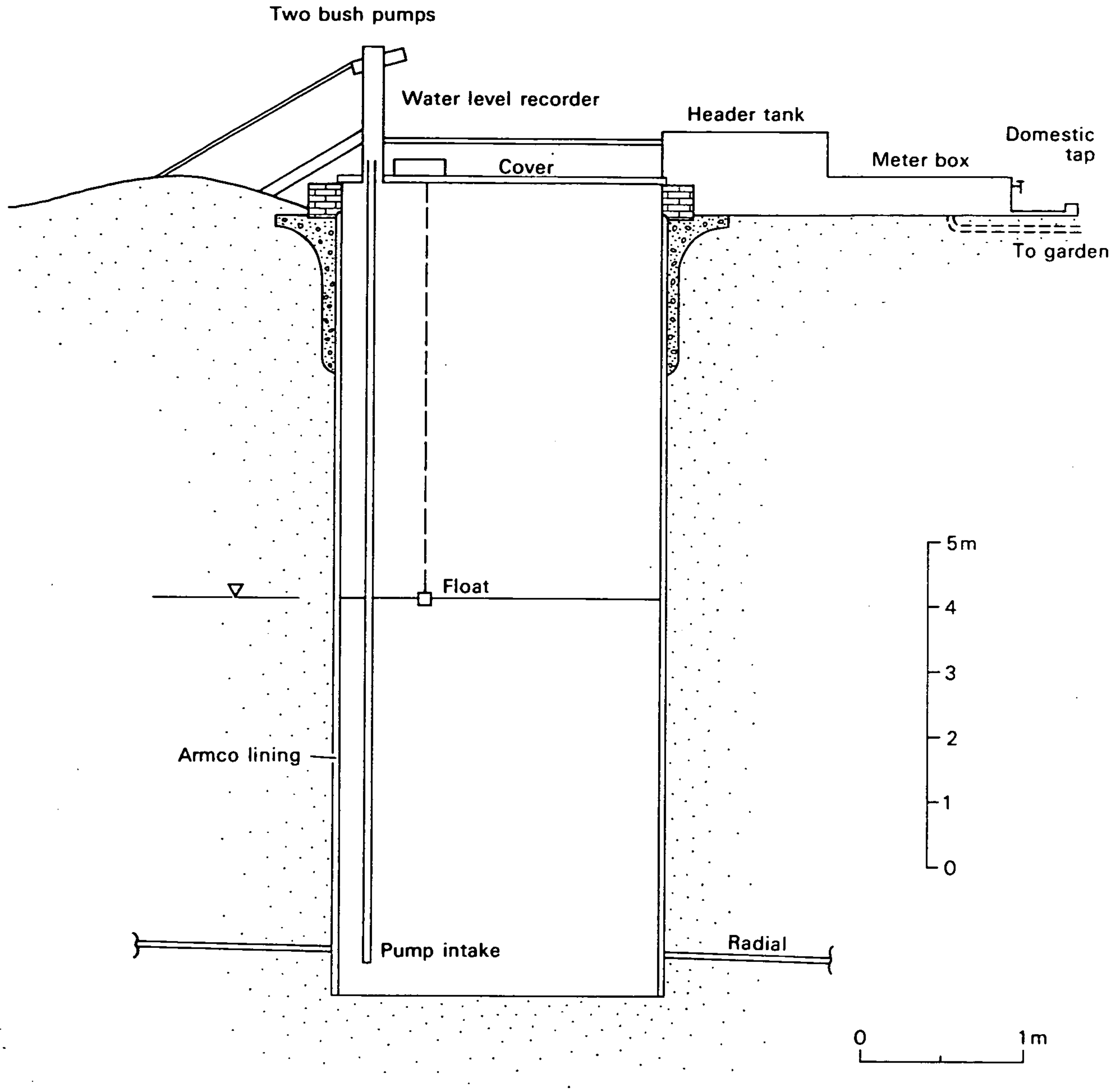


Figure 9. Section showing construction of Tamwa/Sihambe/Dhobani collector well.

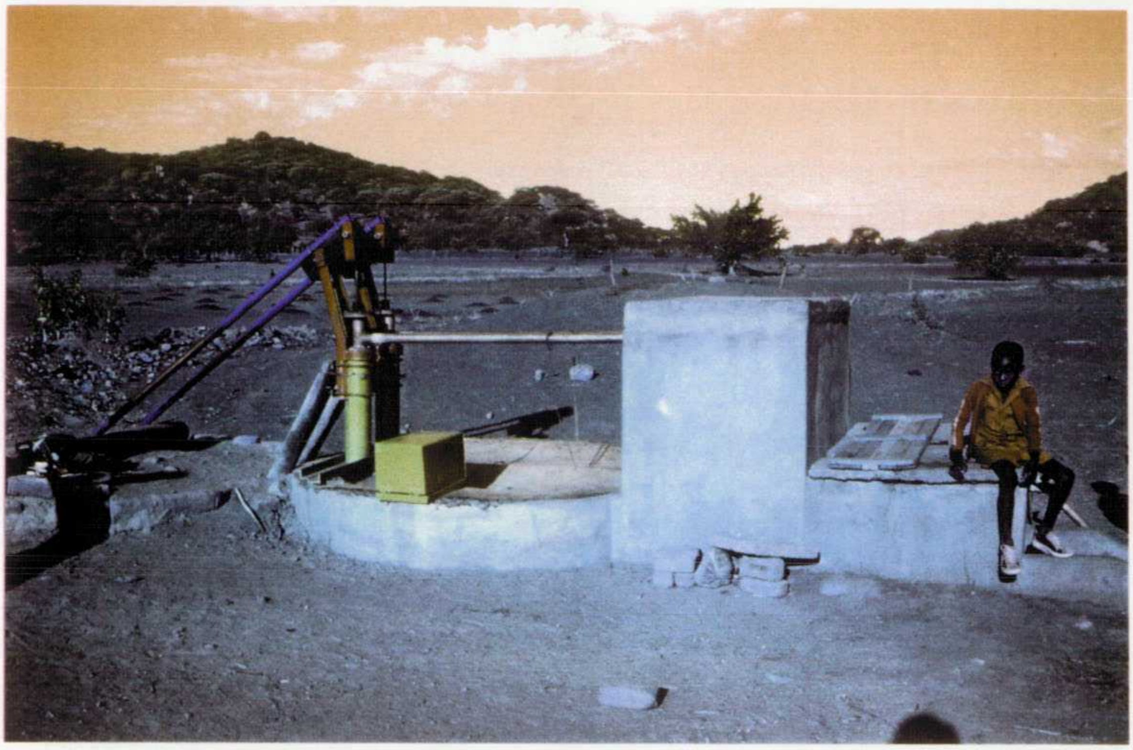


Figure 10. View of well completion showing two Bush pumps, well cover, water level recorder, header tank and meter box.

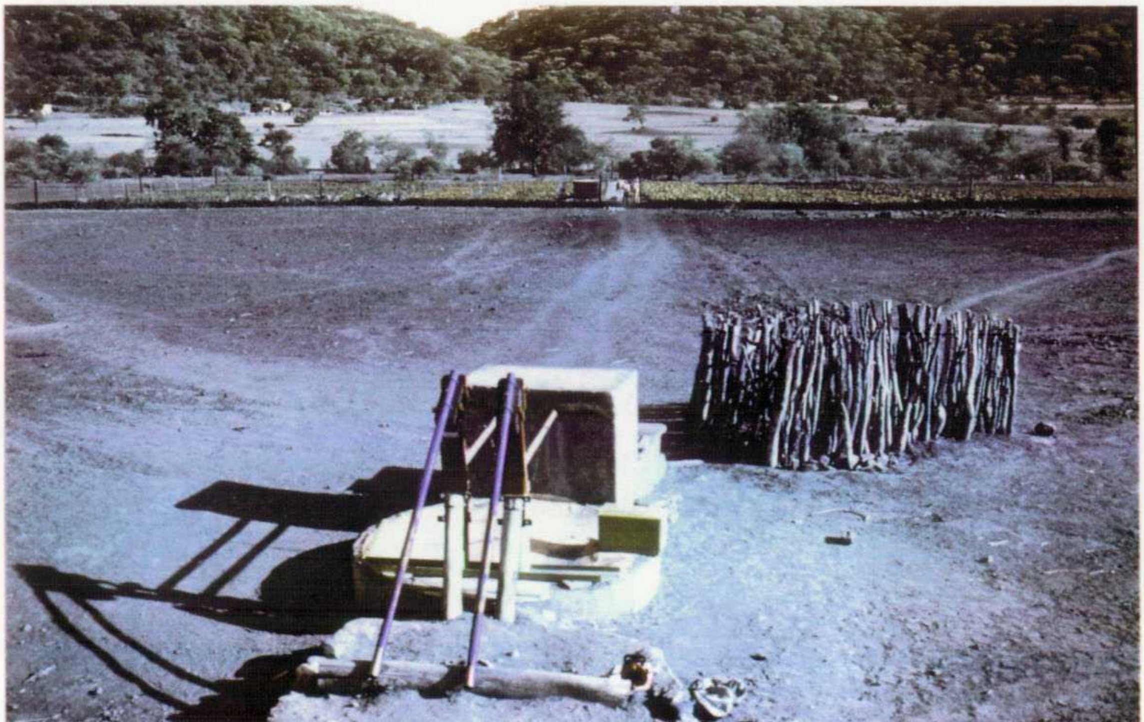


Figure 11. View showing collector well and pumps and fenced garden with tank. Note absence of rainfed cultivation (March 1992).

The 25% and 50% values for the test on 21 March fall outside the range for which the nomogram is applicable. The calculated transmissivity is in good agreement with that derived from the test pumping of exploratory borehole 3 (Figure 7).

After radials have been completed, the standard procedure is to carry out a test in which the water level is drawn down to pump suction (similar to the test on 21 March), followed by a longer test at a lower pumping rate to simulate a possible operating schedule for the well. The former is compared to the similar test performed before the radial drilling and the latter is used to assess the long-term sustainable yield of the well.

	<u>4 April</u>
Static water level (bd)	5.92 m
Duration of pumping	100 mins
Pump discharge rate	4.38 l/sec
Final water level	11.37 m
Final drawdown	5.45 m
25% recovery	210 mins
50% recovery	540 mins
75% recovery	1220 mins

Recovery from 11.35 m to 11.0 m took 40 minutes after the radial drilling, compared to 50 minutes before. Similarly, recovery from 11.25 m to 9.50 m took 310 minutes after the radial drilling compared to 340 minutes before. The improvement in yield achieved by the radial drilling is small; at 10% it is much less than at Chiredzi.

The test was analysed in the same way, to give the following transmissivity (T, m^2/d) and storage coefficient (S):

	4 April	
	T	S
Recovery 25%	-	-
50%	-	-
75%	0.98	1.30?

Again, the 25% and 50% values fall outside the range for which the nomogram is applicable. The increasing transmissivity in the test of 20 March implies a degree of partial penetration by the collector well, and the reducing storage coefficient suggests leaky aquifer conditions, although both the well itself and the exploratory boreholes encountered significant rises in water level once water was struck. In these circumstances, the 75% results are likely to be most representative of the aquifer characteristics (Wright et al, 1988), and agree with the results of the test on exploratory borehole 3 (Figure 7).

Modelling of the test pumping at the collector wells at Chiredzi and at Tamwa/Sihambe/Dhobani Kraals has been described by Kitching (1991, 1992). The model used is a two-dimensional, finite difference radial/depth model, solved by a successive over-relaxation technique. The typical network incorporated 16 vertical nodes and 26 radial nodes. The vertical node spacing could be varied to take account of any layering present in the aquifer, and horizontal and vertical permeabilities could be varied independently of each other at all nodes. The collector well itself was simulated by means of a thin disk of very high permeability, but with radius rather less than that of the actual collectors. With this construction, the model provided a reasonable confirmation of the theoretical analyses of large diameter well and collector well responses, and reproduced the observed drawdown and recovery curves for aquifer parameters typical of weathered basement aquifers (Kitching, 1992).

A long-term test was carried out from 12 to 18 April, following a strict daily regime of three two-hour pumping periods, separated by three-hour recovery periods. The pump discharge rate was 0.78 l/sec. The water level in exploratory borehole 3, at a distance of 6.9 m from the well centre, was measured at the beginning and end of each day. The water level information is summarised in Table 8 and Figure 12.

Table 8. Water Levels in Collector Well and Borehole 3.

Date		06.00	08.00	11.00	13.00	16.00	18.00
12 April	CW	5.95	7.20	6.87	7.88	7.43	8.34
	BH3	5.80	-	-	-	-	6.89
13 April	CW	6.90	7.91	7.50	8.37	7.85	8.59
	BH3	6.51	-	-	-	-	7.00
14 April	CW	7.10	7.97	7.58	8.41	7.92	8.71
	BH3	6.70	-	-	-	-	7.09
15 April	CW	7.18	8.15	7.75	8.54	8.03	8.82
	BH3	6.78	-	-	-	-	7.16
16 April	CW	7.25	8.17	7.82	8.60	8.08	8.95
	BH3	6.84	-	-	-	-	7.20
17 April	CW	7.34	8.35	7.89	8.81	8.27	9.12
	BH3	6.91	-	-	-	-	7.27
18 April	CW	7.45	8.46	7.98	8.88	8.34	9.19
	BH3	6.98	-	-	-	-	7.32
19 April	CW	7.61					

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 8) and averages 1.69 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 8). If these water levels are plotted against the log of time since pumping started (Figure 13), 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.

Thus, if the background drawdown at the pumping test rate 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:

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

In this case:

$$Q_s = 0.78 \times (11.5 - 5.95)/(2.8 + 1.69) = 0.96 \text{ l/sec}$$

This is an approximate figure and in this case is only just greater than the tested yield. On an operating schedule similar to the test pumping, therefore, the long-term sustainable yield of the well is estimated at about 21,000 litres per day. The straight line extrapolation is, however, subject

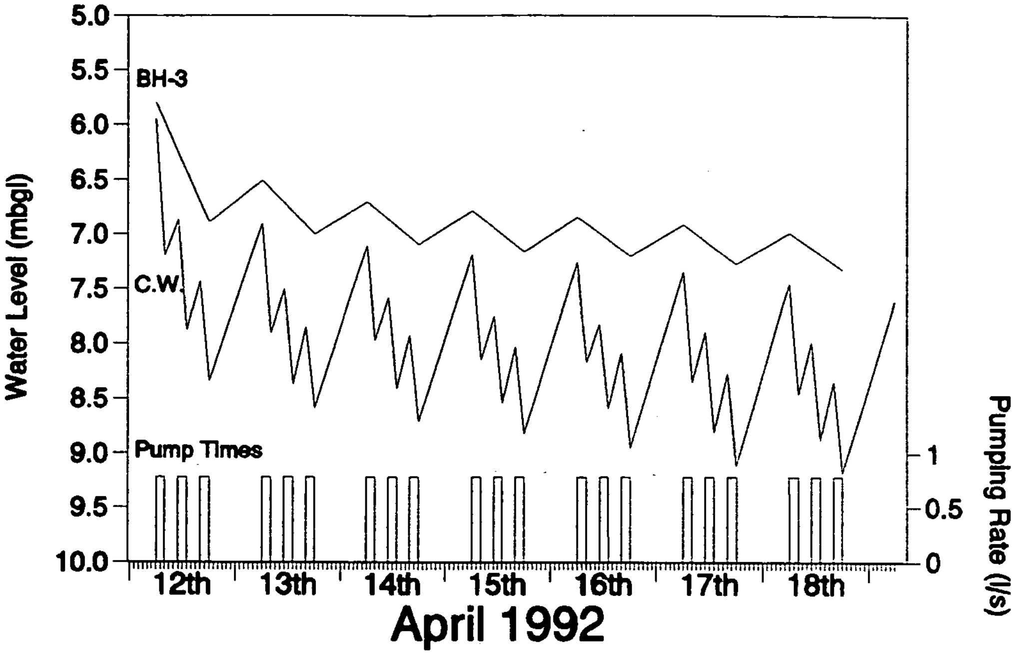


Figure 12. Pumping periods and water levels in long-term test.

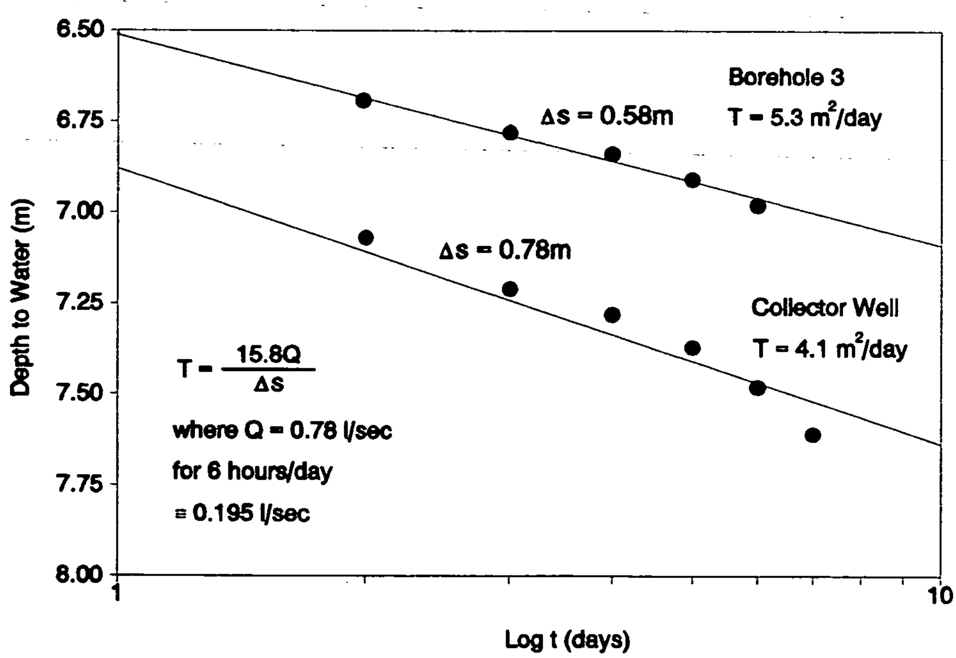


Figure 13. Water levels at beginning of first of daily pumping cycles.

to error as it 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 13) compares with about 1 m^2/d for the test pumping of the exploratory borehole and the short-term tests on the collector well. This difference has previously been attributed to the 'leaky' nature of the aquifer, although other explanations are possible, and has been widely reported from other collector well sites (Wright et al, 1988; Ball and Rodrigo, 1989). The transmissivity obtained from the analysis of the longer-term test may provide a better estimate of the 'regional' transmissivity than the exploratory borehole or the short-term testing of the collector well. Indeed, the modelling results of Kitching (1992) suggest a horizontal permeability of 0.8 m/d at this site which, for a saturated aquifer penetration of 5-6 m, implies an appropriate transmissivity in good agreement with that obtained from the long-term test (Figure 13).

3.5 Well Costs

Details of the direct costs of the well are given in Table 9. They are slightly higher than those given by Lovell et al (1992), as Table 9 includes the full cost of the exploratory drilling. The collector well site at Tamwa/Sihambe/Dhobani Kraals was selected on the basis of the criteria set out in Chapter 2 of this report. To test compliance with the hydrogeological criteria, exploratory drilling was carried out at the site, primarily to confirm depth to water and ease of digging. No geophysical surveying was carried out. The cost of siting given in Table 9 is thus the cost of drilling four exploratory boreholes and testing one of them. Drilling was carried out using a lightweight Holman air hammer rig and crew loaned by MEWRD.

Table 9. Construction Costs of Collector Well at Tamwa/Sihambe/Dhobani Kraals

Month	Salaries	Diesel	Compressor	Misc.	Total
Exploratory Drilling:					
May 1990	240	210	850	450	1,750
Digging:					
May 1990	388	63	-	-	451
June 1990	1461	630	2950	248	5,289
July 1990	723	210	-	180	913
					6,653
Plus 12 m of Armco lining					7,514
			Sub-total		14,167
Radial Drilling:					
March 1991	320	1540	3750	80	5,690
Test Pumping:					
March/April 1991	250	210	1200	-	1,660
Pump and Headworks:					
(Two Bush pumps, rods, rising main pipes, bricks, cement and materials for frame and cover)					3,345
Two water meters (from UK)					1,670
			Sub-total		5,015
	Total cost of well and pumps:				**28,282**

Costs in Zimbabwe Dollars: £1 = 4.2 Z$ (1991)

As at Chiredzi, 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, whose costs are not included. The costs of construction are estimated on the same basis as at Chiredzi (Chilton et al, 1990), and are broadly similar. Approximately half of the cost of the well is in the imported Armco lining, of which 60 m were shipped to Zimbabwe for the project. Digging experience suggests that the imported Armco was probably over-specified. Further savings might be made by using a 2 mm or 2.5 mm plate thickness or if a similar material could be manufactured locally. Because of the high cost of importing steel plate and the difficulty of obtaining foreign exchange facilities to do this, local supply appears unlikely at present.

4. PERFORMANCE OF COLLECTOR WELLS

4.1 Lowveld Research Station, Chiredzi

A programme of hydrogeological measurements, operated by LRS, IH and BGS, has been established (Table 10) and dates back to the completion of the first exploratory boreholes in October 1988. The results obtained in this programme of monitoring to June 1990 were presented and discussed by Chilton et al (1990) and are brought up to date (June 1992) in the present report. Monitoring of groundwater levels in the exploratory boreholes now provides data over four rainy seasons (Figure 14), including the drought season of 1991-92. Three of the additional exploratory boreholes, 1A, 13A and 20A were added to the network in March 1991.

Table 10. Hydrogeological Monitoring Programme at LRS, 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 pumping period
Water levels in exploratory boreholes	Weekly	10/88	Three boreholes from second phase of drilling added in March 1991
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

In the early part of 1989, water levels in boreholes 11 to 14 show a decline that is probably a response to the dewatering of the collector well during construction. This is followed by more extreme fluctuations in April and May

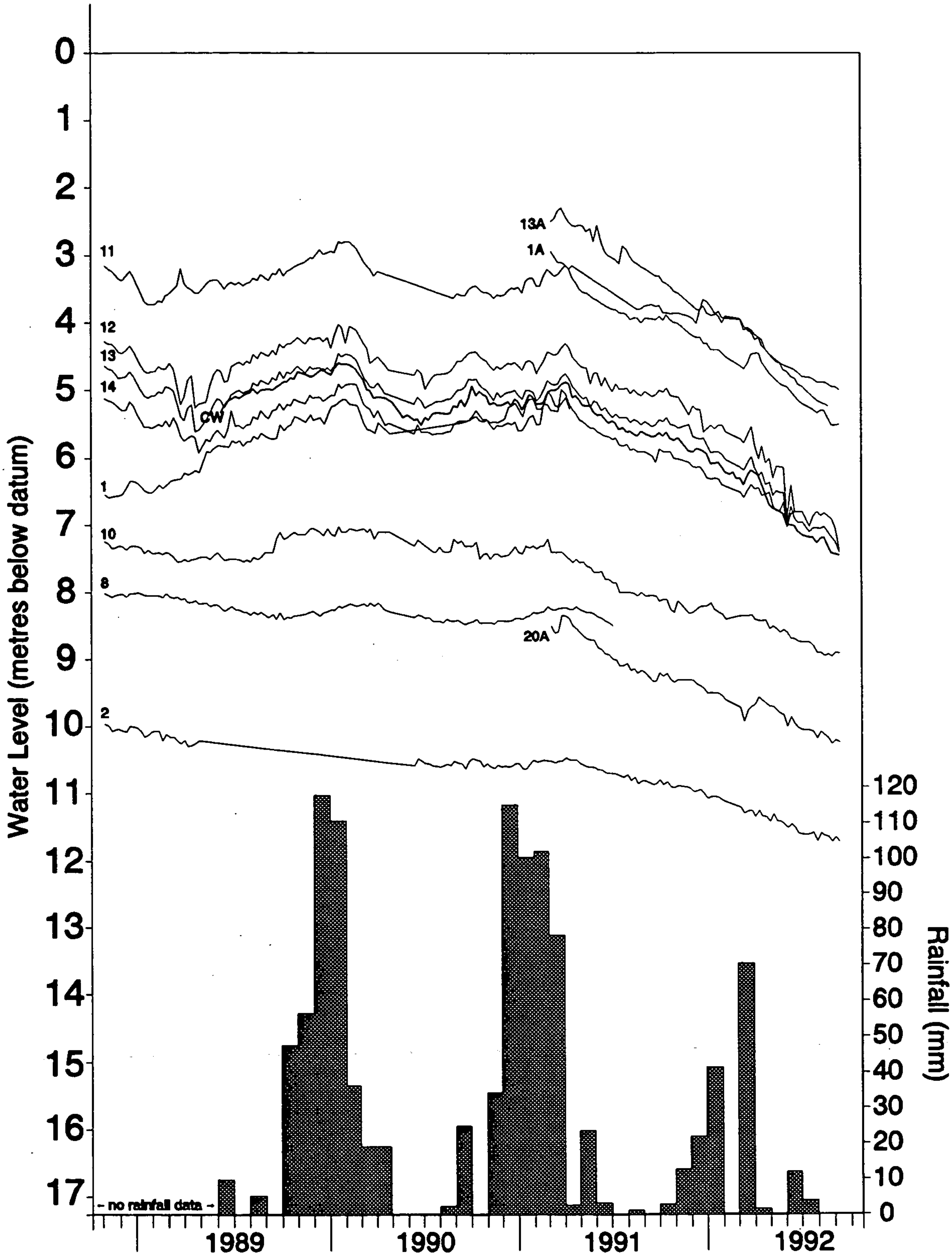


Figure 14. Water levels in exploratory boreholes and rainfall at LRS, Chiredzi.

(Figure 14), caused by the dewatering to construct the laterals and the subsequent 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 14). Although this is seen in borehole 1, it is less readily apparent in boreholes 8 and 10, which show more subdued seasonal responses. A gap in monitoring occurs in mid 1990, resulting from breakdown of the water level dipper. Most wells show a response to the 1990-91 rainfall, most pronounced in boreholes 11 to 14, less in 8 and 10 and least in borehole 2 (Figure 14). Only 80 mm of rain in the 1991-92 season had fallen by the time of the visit in March, and groundwater levels over the whole area of the station have fallen consistently from April 1991 through into 1992.

Operation of the well to provide water for irrigation trials commenced in June 1989. Table 11 shows the volume of groundwater abstracted in each week since operations began, and Figure 15 shows the water level in the collector well over this period, together with abstraction volumes taken from Table 11 and monthly rainfall at Chiredzi. The well response to rainfall in 1989-90 and 1990-91 is clearly seen, as is the steady decline through 1991 and into 1992.

Abstraction from the well has increased slightly during the period, averaging 905, 952 and 1694 l/d in 1989, 1990 and 1991 respectively, and is distinctly more (5800 l/d) in 1992. Abstraction increased dramatically from April 1992 (Figure 15) as additional water has been used for vegetable cultivation at LRS in response to the drought, which has practically eliminated irrigation with surface water at the station. Nevertheless, the overall average abstraction from the well for the irrigation experiments of 1920 l/d is only a fraction of the installed capacity (22,000 l/d) and the estimated safe yield (65,000 l/d), reflecting the efficient water use of the irrigated cultivation trials.

The results of chemical analyses of water drawn from the collector well are shown in Table 12. Water quality from the well shows very little variation with time. In terms of its use for irrigation, water from the well plots as high salinity hazard (750-2250 μS/cm, USDA, 1954) and low sodium hazard (sodium adsorption ratio, SAR 1.8-2.3). Although designated by this classification as of high salinity hazard for irrigation, water of this quality is acceptable for drinking and other household purposes. Further, in semi-arid basement areas groundwater of similar composition can be widely expected and successful trials to establish whether subsurface irrigation using clay pipes could be used effectively with water of this quality are reported in Lovell et al (1992).

4.2 Tamwa/Sihambe/Dhobani Kraals

A programme of hydrogeological monitoring was established for Tamwa/Sihambe/Dhobani Kraals (Table 13), similar to that for the well at LRS Chiredzi. Monitoring of the amount of water abstracted is complicated as water is used for domestic supply as well as irrigation. As described in section 3.3 and shown in Figures 10 and 11, the two Bush pumps discharge into a concrete header tank at the wellhead, from which domestic and garden water are separately metered.

Operation of the well for irrigation commenced in July 1991. Figure 16 shows the water level in the well, the volume of groundwater abstracted and rainfall during the period. The water level used is the weekly average of the highest daily levels to try to minimise the effects of pumping. It had been intended to monitor water levels in borehole 3 on a less frequent basis to provide a check on levels, but the borehole became blocked with stones. Problems with installation of the meters meant that they were not operational until early January 1992. Figure 16 thus shows metered weekly water use for the garden and for domestic purposes since 6 January and estimates for the previous period from July 1991.

Table 11. Groundwater Abstraction from Collector Well, LRS Chiredzi.

Trace No.	Dates	Times Pumped	Volume (litres)
	1989		
1	07/06 - 14/06	2	10450
2	14/06 - 22/06	5	33900
3	22/06 - 30/06	3	18750
4	30/06 - 05/07	1	5850
5	05/07 - 12/07	1	2350
6	12/07 - 20/07	2	5650
7	20/07 - 26/07	3	6850
8	26/07 - 03/08	4	9350
9	03/08 - 10/08	2	4150
10	10/08 - 21/08	3	7800
11	21/08 - 30/08	4	8600
12	30/08 - 04/09	2	9600
13	04/09 - 14/09	2	10800
14	14/09 - 22/09	2	8300
15	04/10 - 11/10	0	0
16	11/10 - 18/10	1	4900
17	18/10 - 24/10	0	0
18	24/10 - 01/11	0	0
19	01/11 - 08/11	1	3550
20	08/11 - 16/11	2	6050
21	16/11 - 22/11	1	4510
22	22/11 - 29/11	2	10250
23	29/11 - 06/12	1	3850
24	06/12 - 13/12	0	0
25	13/12 - 21/12	1	3950
26	21/12 - 27/12	1	3400
27	27/12 - 03/01	2	7150

Trace No.	Dates	Times Pumped	Volume (litres)
	1990		
28	03/01 - 10/01	1	5380
29	10/01 - 18/01	0	0
30	18/01 - 24/01	1	2870
31	24/01 - 31/01	1	2475
32	31/01 - 07/02	3	10735
33	07/02 - 16/02	1	4430
34	16/02 - 22/02	1	2040
35	22/02 - 28/02	1	2125
36	28/02 - 07/03	1	3850
37	07/03 - 14/03	1	2900
38	14/03 - 21/03	2	4840
39	21/03 - 28/03	1	4245
40	28/03 - 05/04	0	0
41	05/04 - 12/04	1	4795
42	12/04 - 18/04	0	0
43	18/04 - 25/04	0	0
44	25/04 - 02/05	0	0
45	02/05 - 10/05	1	2315
46	10/05 - 18/05	2	10410
47	18/05 - 23/05	3	19885
48	23/05 - 30/05	1	5605
49	30/05 - 06/06	2	6360
50	06/06 - 13/06	3	12680
51	13/06 - 20/06	2	8330
52	20/06 - 27/06	3	10010
53	27/06 - 04/07	1	3600
54	04/07 - 11/07	2	11315
55	11/07 - 18/07	3	11740
56	18/07 - 25/07	3	12160
57	25/07 - 01/08	3	12725
58	01/08 - 08/08	4	14610
59	08/08 - 15/08	3	13295
60	15/08 - 22/08	3	18930
61	22/08 - 28/08	1	4085
62	28/08 - 05/09	1	6225
63	05/09 - 12/09	0	0
64	12/09 - 20/09	2	10675
65	20/09 - 26/09	2	7545
66	26/09 - 03/10	0	0
67	03/10 - 10/10	2	7565
68	10/10 - 17/10	2	14665
69	17/10 - 24/10	1	6320
70	24/10 - 31/10	1	5365
71	31/10 - 07/11	3	11690
72	07/11 - 14/11	2	13780
73	14/11 - 21/11	2	11460
74	21/11 - 28/11	0	0
75	28/11 - 05/12	1	6840
76	05/12 - 12/12	1	1245
77	12/12 - 19/12	1	5895
78	19/12 - 25/12	0	0
79	25/12 - 02/01	2	8465

Trace No.	Dates	Times Pumped	Volume (litres)
	1991		
80	02/01 - 10/01	3	19355
81	10/01 - 17/01	1	1190
82	17/01 - 23/01	1	3245
83	23/01 - 30/01	2	13175
84	30/01 - 06/02	5	25390
85	06/02 - 13/02	3	18130
86	13/02 - 20/02	2	11260
87	20/02 - 28/02	0	0
88	28/02 - 06/03	0	0
89	06/03 - 13/03	1	625
90	13/03 - 20/03	2	7105
91	20/03 - 27/03	0	0
92	27/03 - 03/04	0	0
93	03/04 - 11/04	1	2945
94	11/04 - 17/04	1	5190
95	17/04 - 25/04	2	16005
96	25/04 - 02/05	4	23330
97	02/05 - 09/05	3	14845
98	09/05 - 16/05	1	1015
99	16/05 - 23/05	0	0
100	23/05 - 31/05	7	27765
101	31/05 - 06/06	3	10475
102	06/06 - 13/06	3	17005
103	13/06 - 20/06	5	21180
104	20/06 - 27/06	3	18380
105	27/06 - 04/07	4	19460
106	04/07 - 10/07	5	17165
107	10/07 - 17/07	4	13280
108	17/07 - 25/07	7	28000
109	25/07 - 01/08	6	19070
110	01/08 - 08/08	3	11850
111	08/08 - 15/08	3	19400
112	15/08 - 22/08	4	12495
113	22/08 - 29/08	1	5670
114	29/08 - 06/09	4	20405
115	06/09 - 13/09	5	24900
116	13/09 - 20/09	3	19940
117	20/09 - 27/09	2	16955
118	27/09 - 04/10	2	13140
119	04/10 - 11/10	2	11650
120	11/10 - 18/10	0	0
121	18/10 - 25/10	6	28710
122	25/10 - 01/11	2	10855
123	01/11 - 08/11	1	1945
124	08/11 - 14/11	0	0
125	14/11 - 21/11	2	10225
126	21/11 - 28/11	2	16945
127	28/11 - 05/12	3	22635
128	05/12 - 13/12	2	9590
129	13/12 - 19/12	0	0
130	19/12 - 27/12	1	6575
131	27/12 - 02/01	0	0

Trace No.	Dates	Times Pumped	Volume (litres)
	1992		
132	02/01 - 09/01	6	33670
133	09/01 - 16/01	5	35720
134	16/01 - 23/01	3	25802
135	23/01 - 30/01	5	27125
136	30/01 - 07/02	4	27673
137	07/02 - 14/02	3	24887
138	14/02 - 21/02	1	18932
139	21/02 - 28/02	2	31838
140	28/02 - 06/03	3	26960
141	06/03 - 13/03	3	30371
142	13/03 - 20/03	3	12976
143	20/03 - 27/03	0	0
144	27/03 - 04/04	2	13872
no chart	04/04 - 09/04	?	20827
145	09/04 - 16/04	7	73136
146	16/04 - 24/04	6	68674
147	24/04 - 30/04	5	40772
148	30/04 - 08/05	7	62701
149	08/05 - 15/05	6	67411
150	15/05 - 22/05	4	51111
151	22/05 - 30/05	4	52313
152	30/05 - 07/06	5	143965
153	07/06 - 15/06	5	72182
154	15/06 - 22/06	3	

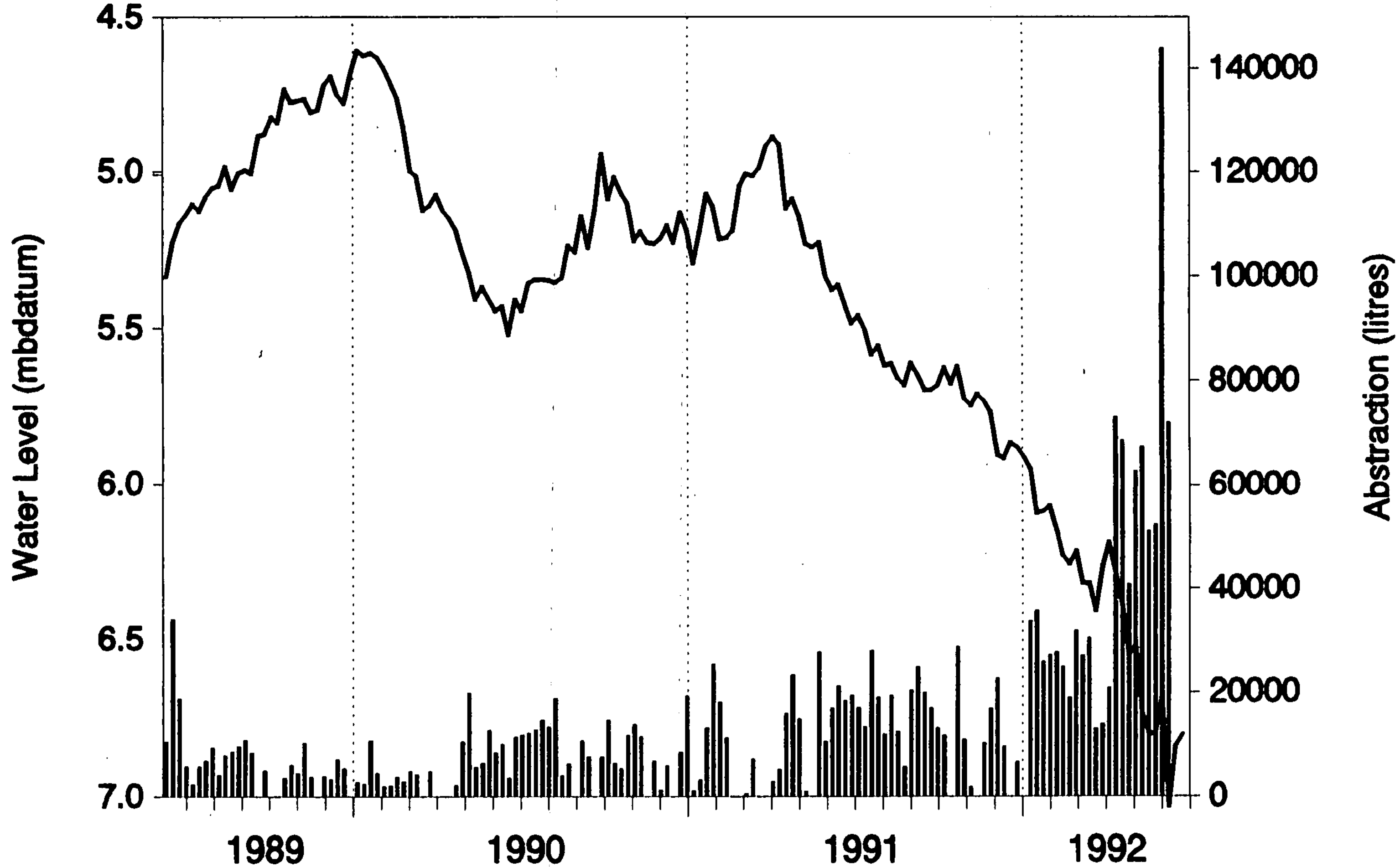


Figure 15. Collector well abstraction and water level at LRS, Chiredzi.

Table 12. Summary of Chemical Analyses at Chiredzi

Location	Date	EC ($\mu S/cm$)	pH*	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
Collector Well (long test)	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	998	-	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	69	67	604	41.3	60.5	0.5	-	-	-
Collector Well	22.04.91	-	8.36	81	<0.5	69	66	634	22.8	55.5	3.7	29.0	-	-
Collector Well	20.08.91	-	8.13	81	<0.5	60	63	607	24.2	45.0	4.6	30.5	-	-
Collector Well	11.03.92	-	-	78	<0.5	67	60	616	22.0	54.3	5.2	30.7	0.38	0.2
Canal	06.06.89	78	-	6.6	2.3	5.5	2.7	41	3.0	4.5	0.1	6.7	0.04	0.37
Canal	06.04.90	-	-	5.9	3.0	4.9	2.0	34	4.2	6.0	0.5	-	-	-
Canal	26.04.91	-	7.50	5.1	3.8	8.4	3.5	71	1.3	7.4	2.9	11.0	-	-
Canal	11.03.92	-	-	6.9	4.2	12.5	5.2	78	1.3	4.3	2.4	16.9	-	-

all figures in mg/l unless stated
* indicates laboratory measurement

Table 13. Hydrological Monitoring Programme at Tamwa/Sihambe/Dhobani Kraals

Measurement	Frequency	By Whom	From Date	Remarks
Water level in collector well	continuous	Chairman of garden committee	4/91	Munro recorder weekly chart, IH/LRS to check
Well discharge	continuous	IH/LRS	1/92	Water for domestic use and irrigation separately metered
EC, chloride of well discharge	monthly	IH/LRS	5/91	
Water level in exploratory borehole 3	when visited	IH/LRS	-	Proposed: not implemented as borehole blocked
Full chemical analysis of well water	infrequent	BGS	4/91	Analysis at BGS

During a 25-day period in January 1992 the separate metering was checked by direct counting by two local people of buckets used for domestic and garden use. Over this period extremely good agreement was observed between direct observation and metering:

	Metered Use (l)	Counted Use (l)	Average Daily Use (l)
Domestic	58,267	59,380	2,353
Garden	271,576	261,155	10,655

as described in detail by Lovell et al (1992). From January to June 1992, daily consumption for domestic use has increased a little, presumably because more people come to the collector well as other sources dry up. It remains, however, generally in the range 2,500 to 4,000 litres (about 20,000 litres per week, Figure 16). In March 1992 it was estimated that perhaps 1200 people were using the collector well for drinking water. If so, this implies a very low per capita consumption of 2 litres a day, and surveys of water use confirmed that many families supplement their domestic requirements from other wells (Lovell et al, 1992).

The water level in the well fell steadily from July to December and more rapidly since then (Figure 16). From July to November only half the garden was planted and the operating regime for the well was not properly established (Lovell et al, 1992). Since the middle of December, the whole garden has been planted and irrigated. The present regime is:

Monday, Tuesday	05.30-10.30)	garden
Thursday, Friday	12.00-17.00)	
	17.00-17.30	domestic use
Wednesdays, Saturdays and Sundays		domestic use only

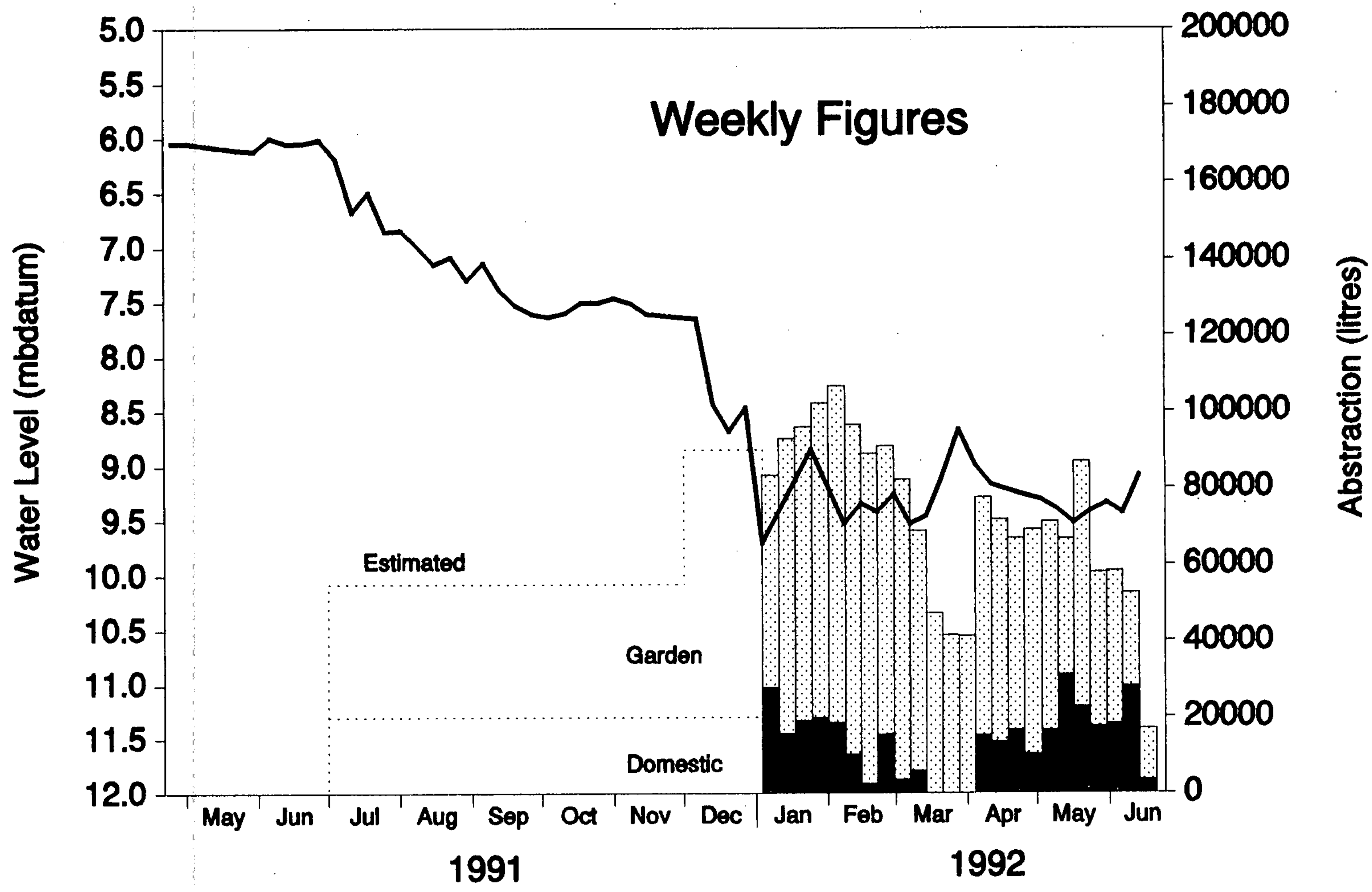


Figure 16. Collector well abstraction and water level at Tamwa/Sihambe/Dhobani kraals.

Though serious in many other ways, the 1991-92 drought in southern Africa provides an opportunity to test the projected long-term sustainable yield against actual abstraction and drawdown data. Figure 17 shows a semi-log plot of the same water level data used to construct Figure 16. There is a distinct breakaway point and change in slope which appears to coincide with the increase in abstraction required to cultivate the whole garden. As stated above, there has also been a slight increase in abstraction for domestic use, with more people coming to the well as other sources dry up. The increase in abstraction for irrigation may have been more gradual than shown in Figure 16.

Extrapolating the steeper part of the decline (Figure 17), it was estimated in March that, at 12,000 to 15,000 l/d abstraction, the water level could reach pump suction in June or July, assuming no recharge took place during the remainder of the "rainy" season. Reducing abstraction back to something like half that rate could extend the period of irrigation from the well to the end of the year. This interpretation assumed that the accelerated fall in water level in December and January was caused by the increased abstraction for the second cropping season. If, however, the breakaway was caused by a geological boundary condition, then the situation may be more serious.

The implications of the monitoring results were discussed at a project progress meeting in March, and presented to the garden committee and members at a meeting. It was agreed that steps were required to reduce abstraction, so as to conserve water for domestic use by garden members and non-members alike. The members of the scheme had already decided to cut their water demand by ceasing cultivation of some of the beds (growing tomatoes) and the consensus of the meeting was that members would work (when harvesting crops) to reduce the cultivated area from seven beds to four beds per family. This was accomplished, and overall abstraction from the collector well decreased, allowing some recovery of water levels in March, April and May (Figure 16). Overall abstraction has been reduced from 12,000-15,000 l/d to 10,000 l/d or less. This was assisted by the single heavy rainfall in March, which probably did not produce any recharge, but reduced abstraction dramatically for a period (Figure 16), allowing fuller recovery from pumping of the water level in the well. It now appears likely that the well will be able to meet a daily demand of 10,000 litres for the remainder of the current dry season until (hopefully) recharge and reduced demand can be anticipated in the coming 1992-93 rainy season.

Thus, although the continuous monitoring of abstraction and water level in the collector well has been used pro-actively as a management tool at this site, it does raise an important point. Extrapolation of the seven-day test on completion of the collector well (section 3.4) to 200 days (a normal dry season) provided an estimate of sustainable discharge of 21,000 l/d. Extrapolating further to 550 days to take account of drought conditions and a further year with no recharge, the estimated sustainable discharge is 19,000 l/d. In practice, as seen from Figure 17, a daily discharge of 15,000 litres appeared in March 1992 not to be sustainable through the current dry season. This illustrates the difficulty of fitting a line to data from a seven-day test and extrapolating to longer-term drawdowns. With the hindsight provided by the monitoring data, the position of the semi-log drawdown line in Figure 13 could be adjusted to extrapolate to a 200-day yield of anything down to 19,000 l/d. This is still in excess of the probable sustainable yield of perhaps 12,000 l/d, and as suggested above, may reflect the presence of hydrogeological boundaries. This would not be surprising, given the geology at the site.

The results of chemical analyses of water drawn from the collector well and neighbouring wells are shown in Table 14. The water is of good quality, of medium salinity hazard (USDA, 1954) and low sodium hazard (sodium adsorption ratio, SAR 1.2). In March 1992, water samples were taken from two neighbouring hand dug wells to see whether chemical differences occurred which might be indicative of poor hydraulic continuity in the weathered basement

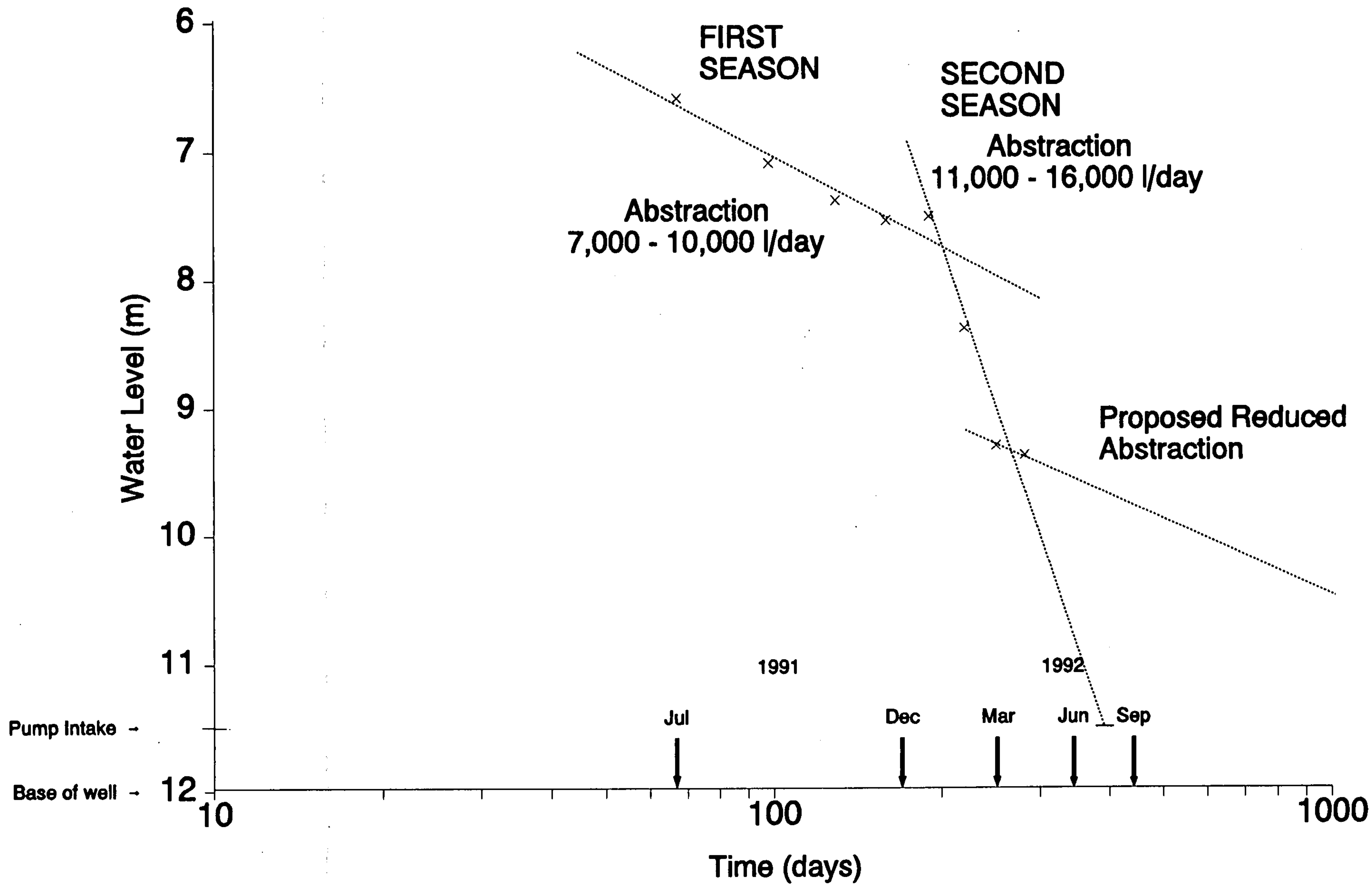


Figure 17. Semi-log plot of water level data, Tamwa/Sihambe/Dhobani kraals.

Table 14. Results of Chemical Analyses at Tamwa/Sihambe/Dhobani Kraals

Location	Date	EC ($\mu S/cm$)	pH*	Na	K	Ca	Mg	Alkalinity* as HCO_3	SO_4	Cl	NO_3-N	Si
T/S/D Collector Well	?	301	7.9	13.0	0.3	33.8	16.0	175.5	0.9	17.3	6.4	-
Collector Well	25.04.91	-	7.73	31.6	<0.5	26.3	19.4	253	8.9	41.6	1.1	37.7
Collector Well	10.03.92	-	-	32.6	<0.5	25.2	17.3	182	2.2	17.5	6.3	37.6
Mhlanga's Well	10.03.92	-	-	16.0	0.8	19.5	12.1	128	5.1	10.8	3.2	27.4
Majazi Well	10.03.92	-	-	33.6	0.8	39.8	66.7	332	0.9	132.0	<0.5	34.1

aquifer. Mhlanga's well (Table 14), very close to and up hydraulic gradient from the collector has a generally similar groundwater chemistry. In contrast, the Majazi well, several hundred metres to the west and in a different drainage sub-catchment, has a distinctly different chemistry, higher in overall mineralisation and particularly higher in magnesium and chloride.

4.3 Collector Wells from 1983-87 Programme

As part of the overall appraisal of the sustainability of collector wells as sources of water, a survey was undertaken of collector wells constructed in Zimbabwe since the commencement of the collector well research in 1983. This should have been carried out earlier in the project, but the current drought in Zimbabwe made it a particularly opportune time to revisit some of the earlier wells to see if they were operating.

The results of the survey are shown in Table 15. Of ten collector wells, four are in regular use and six are not used. All of these four are located at schools; indeed four out of five of the school wells were in use at the time of the survey. None of the wells which were not closely associated with schools were in use. The two earliest wells at Murape and Marikopo have Bush pumps which were provided by the British High Commission's small projects fund and both were being extensively used for domestic supply for the school and local people, and at Murape to water a small school garden.

It is of interest to note that, at the time of construction the well at Marikopo was considered to be a failure and the site unsuitable for a collector well because of the limited weathered zone (Wright et al, 1985). Water inflow to the well was insufficient for test pumping and the yield was estimated at less than 1000 l/d. It would be of interest, therefore, to estimate current abstraction. At both these sites, water was being drawn by the school and by local residents. From the original notes at the time of construction (Wright et al, 1985), the water demand at Murape was stated as being for 600 pupils (day only) and 75 residents (staff and families), with a new secondary school under construction. At Marikopo, demand was stated to be for several hundred pupils and some staff.

At St Nicholas School in Chiota Communal Area, in contrast, the school boundary fence had been extended to enclose the collector well. A Bush pump and top slab had been provided by the District Council. The pump is used only by the school for domestic water and for a garden, and locked at night to prevent local people from using it. At the time of construction the water demand for 1000 pupils and 25 residential (staff and families) was acknowledged to be dominant, but the collector well was sited outside the school grounds so that it could act as a source of supply to the local community. The water demand at Mukumba School was equally great, although the school did have existing shallow wells.

The two collector wells at the Institute of Agricultual Engineering at Borrowdale, Harare are amongst the most successful in the programme and it is a great pity that neither have to date been used effectively. At one time the Willowtree site had a solar-powered electric pump installed, which had fallen into complete disuse when visited in February 1988. More recently an ox-driven pump, designed by Mr Rastall, the BGS contract driller and built in the MEWRD workshop, had been given to an FAO/Agritex project to irrigate fruit trees but that project appeared to be abandoned when the well was visited in April 1992. The windpump collector well was briefly used for trials of an earlier ox-driven pump made by Mr Rastall but has never been properly utilised.

The collector well at Chininka Clinic was constructed in 1988 at the request of the Masvingo Provincial Office of MEWRD because of poor supplies from boreholes in the area. No pump has, however, been fitted to the completed well.

Table 15. Review of Collector Wells from 1983-87 Programme.

Location	Date of Completion	Depth (m)	Rest Water Level at Construction (m)	Tested Yield (l/sec)	Geology	Weathering Depth (m)	Type of Pump	Date Installed	Water Use	Abstraction	Water Level (m) [April 1992]	Notes
Murape School, Seki	June 1984	14.3	2.6	1.5	Older Gneisses	20.4	Bush	?	Domestic, garden	?	4.15	School and local people. Pump supplied by BHC small projects fund.
Marikopo School, Seki	August 1984	11.7	4.2	-	Older Gneisses	10.7	Bush	?	Domestic	?	3.60	As above.
Hatcliff Willowtree	November 1984	10.8	5.9	3.6	Basement Epidiorite	14.8	Ox-driven	Sept 1991	None	Nil	5.50	Pump fitted by P Rastall. Not in use.
Hatcliff Windpump	December 1984	10.0	3.3	2.6	Granite	>26.0	None	-	None	Nil	3.0	Not used.
Mukumba School, Chiota	October 1986	11.0	2.9	1.5	Granite	>11.0	None	-	None	Nil	4.20	Sealed. Not used, but school short of water.
St Nicholas School, Chiota	October 1986	12.0	4.3	1.5	Older Gneisses	12.0	Bush	?	Domestic, garden	?	6.80	School fence extended to enclose well. Slab and pump supplied by District Council. School and school garden only.
St Lioba's School, Wedza	November 1986	11.3	3.8	1.0	Adamellite Granite	17.0	Bush	?	Domestic	?	4.0	School and local people. Slab and pump from DDF.
Chininka Clinic, Gutu	1988											Not visited. Not used.
Wenimbi Village 13	March 1988	17.5	2.9		Younger Granites	>25	None	-	None	Nil	2.0	Sealed. Not used.
Wenimbi Village 12	March 1988	17.5	7.7		Younger Granites	>25	None	-	None	Nil	8.0	Sealed. Not used.

Comparison of April 1992 water levels with those at the time of completion of the various wells show no excessive drawdowns, even at those in regular use. All still had a significant depth of water in the well, although these can be expected to have lowered by the time of writing. This suggests that perhaps the operating collector wells are not heavily used, or reflects the fact that the drought has not be so severe in northern and central Zimbabwe as in the south.

The poor record of uptake and use of the completed collector wells illustrates the need for arrangements to be made and sources of funds to be identified from the beginning, if their eventual use is to be assured. A formal mechanism for funding pump installation needs to be made; the recipient communities are not in a position to mobilise funds themselves. While pump installation and operation of the wells was understandably not a prime objective of the earlier phase of collector well work in Zimbabwe, it is disappointing that so many successful collector wells are not being used. It is, however, encouraging that those which are in regular use are apparently sustaining their supplies even in the current drought.

5. ADDITIONAL WORK ON RECHARGE SOURCES AT CHIREDZI

With an average rainfall of about 450 mm, the Chiredzi area is considerably drier than any of the other successful collector well locations in Zimbabwe. Water levels are less than 10 m below ground at all of the initial exploratory borehole sites located at the station. Immediately around the well itself, they are within 5 m of the ground surface; highly favourable for a collector well which was why the site was chosen.

Records of rural water supply boreholes in this part of the Lowveld and some limited exploratory drilling early in this project away from LRS show that water levels are often much deeper. Discussion of the results obtained from the collector well at LRS (Chilton et al, 1990) suggested that the apparent shallow groundwater at LRS Chiredzi might result from enhanced local recharge from the irrigated sugar estates to the south. Certainly the irrigated land and the canal is close (Figure 18) and has received Lake Kyle water for many years. It is also possible that the storage reservoirs on the station itself (Figure 18) might act as local sources of recharge, although this perhaps seems less likely as they are small and probably heavily silted. The canal itself is lined.

Further work to investigate this question was suggested (Chilton et al, 1990), and in March 1991 a further 20 shallow exploratory boreholes were drilled at selected points within the station (Figure 18) to provide additional data on depth to groundwater (Table 16). Three of these were lined and have been incorporated into the weekly water level network.

From Figure 18 and Table 16, it can be seen that water levels over much of the southern part of the station are particularly close to ground level, being within 1.5 to 2 m under the area where the main irrigated trials are carried out. This must pose questions about the usefulness of the results obtained from these trials, especially for deep-rooting tree crops. The clayey nature of the subsoil and upper part of the weathered basement is indicated by the often substantial rises between the depth at which water was struck and the final rest water level, so the situation may not be as bad as it first appears. Nevertheless, it seems likely that regular irrigation over a long period of time has produced additional infiltration and a rise in water levels in this part of the station.

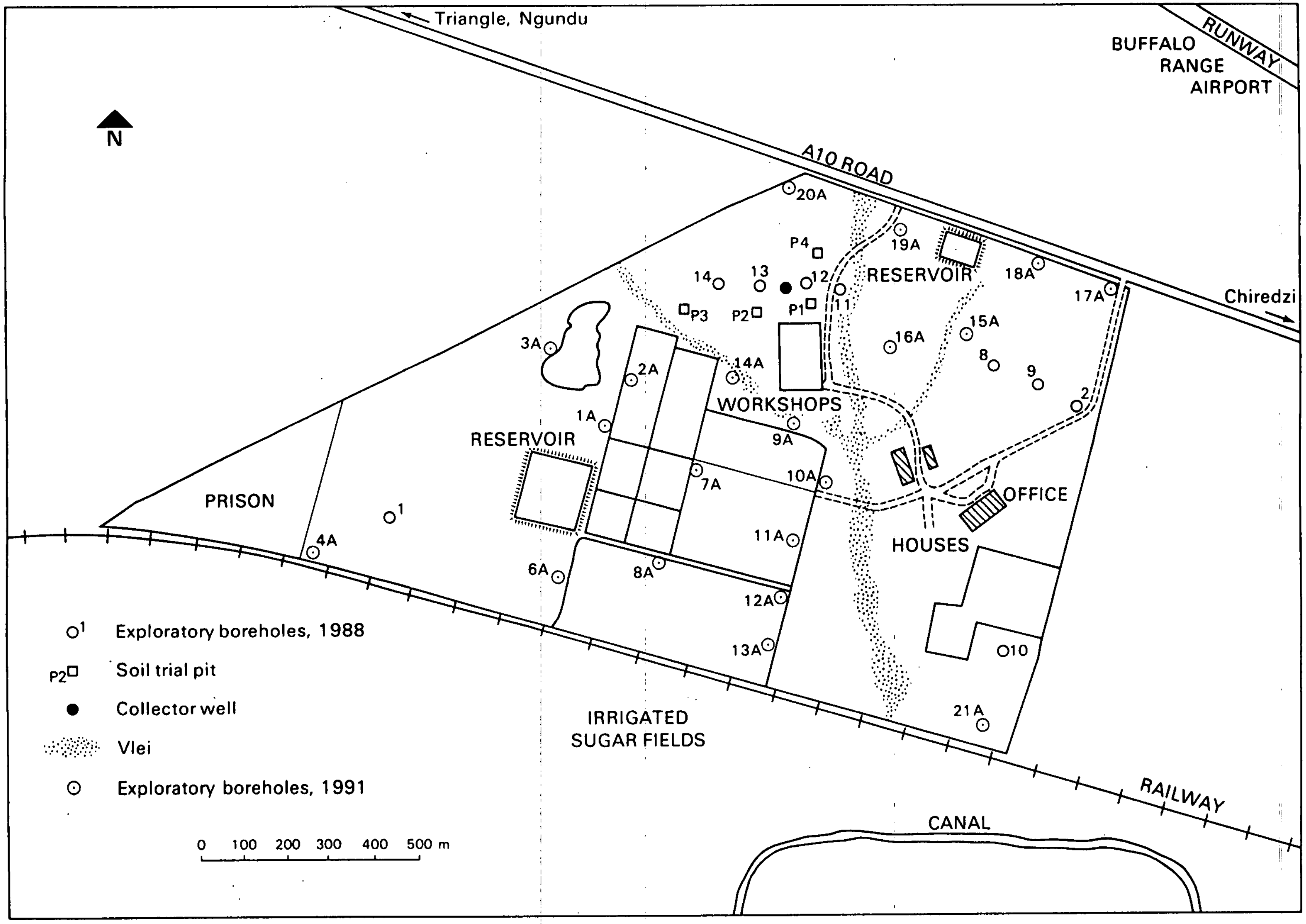


Figure 18. Location of additional exploratory boreholes, LRS Chiredzi.

Table 16. Additional Exploratory Drilling at LRS, Chiredzi.

Borehole Number	Drilled Depth (m)	Water Struck (m)	Rest Water Level, 3/91 (m)	Rest Water Level 26/4/91 (m)
1	7.5	5.0	2.75*	2.95*
2	11.0	11.0	3.25	3.52
3	7.5	7.5	4.60	4.80
4	16.5	16.5	4.00	4.35
6	3.75	3.75	1.53	1.71
7	4.50	4.50	1.97	2.22
8	4.50	4.50	1.40	1.60
9	11.25	11.25	1.30	1.22
10	3.75	3.75	1.67	1.90
11	10.50	10.50	2.22	2.47
12	3.75	3.75	1.95	2.25
13	6.75	4.75	2.24*	2.31*
14	4.25	4.25	2.00	2.20
15	10.50	10.50	5.72	5.65
16	8.25	8.25	4.19	blocked
17	9.75	9.75	7.65	7.75
18	12.00	12.00	6.65	6.60
19	12.00	12.00	5.57	5.67
20	28.50	28.50	8.25*	8.23*
21	15.00	15.00	6.27	-

Boreholes 1A, 13A and 20A have been incorporated in the monitoring network.

* corrected to ground level

Using a contour map of LRS with 5 ft vertical intervals, a plot of piezometric contours at the station was prepared (Figure 19). This indicates a hydraulic gradient from SW to NE in the southern part of the site. Groundwater flow appears to be generally towards the vlei. However, the lowest groundwater levels appear to be offset to the east of the vlei, rather than coinciding with its present line. This local water table configuration appears to confirm the presence of recharge sources in or to the south of the station, either the irrigated sugarcane fields, the irrigated land on the station or the storage reservoirs (Figure 19).

In April 1991 water samples were taken for chemical and stable isotope analysis from the collector well, from the canal and from the reservoirs on the station, from some of the new exploratory boreholes and from pumping boreholes away from the station, to be representative of the regional groundwater chemistry. The results are shown in Table 17 and Figures 20 to 24.

Looking first at the stable isotope data, there is a wide spread of δ^2H (deuterium) and $\delta^{18}O$ measurements (Figure 20). The three surface water sources do not group closely together, neither do the three remote pumping boreholes, and there is a wide spread of results from the exploratory boreholes on the site. This is perhaps surprising, and at first sight, therefore, stable isotopes do not appear to provide assistance in identifying the influence of local recharge sources. Closer inspection, however, shows that of the new exploratory boreholes, those at the extremities of the station (4, 17, 20, 21, Figure 19) group at the lower left of Figure 20, and are most depleted in δ^2H and $\delta^{18}O$. These samples may be most representative of local

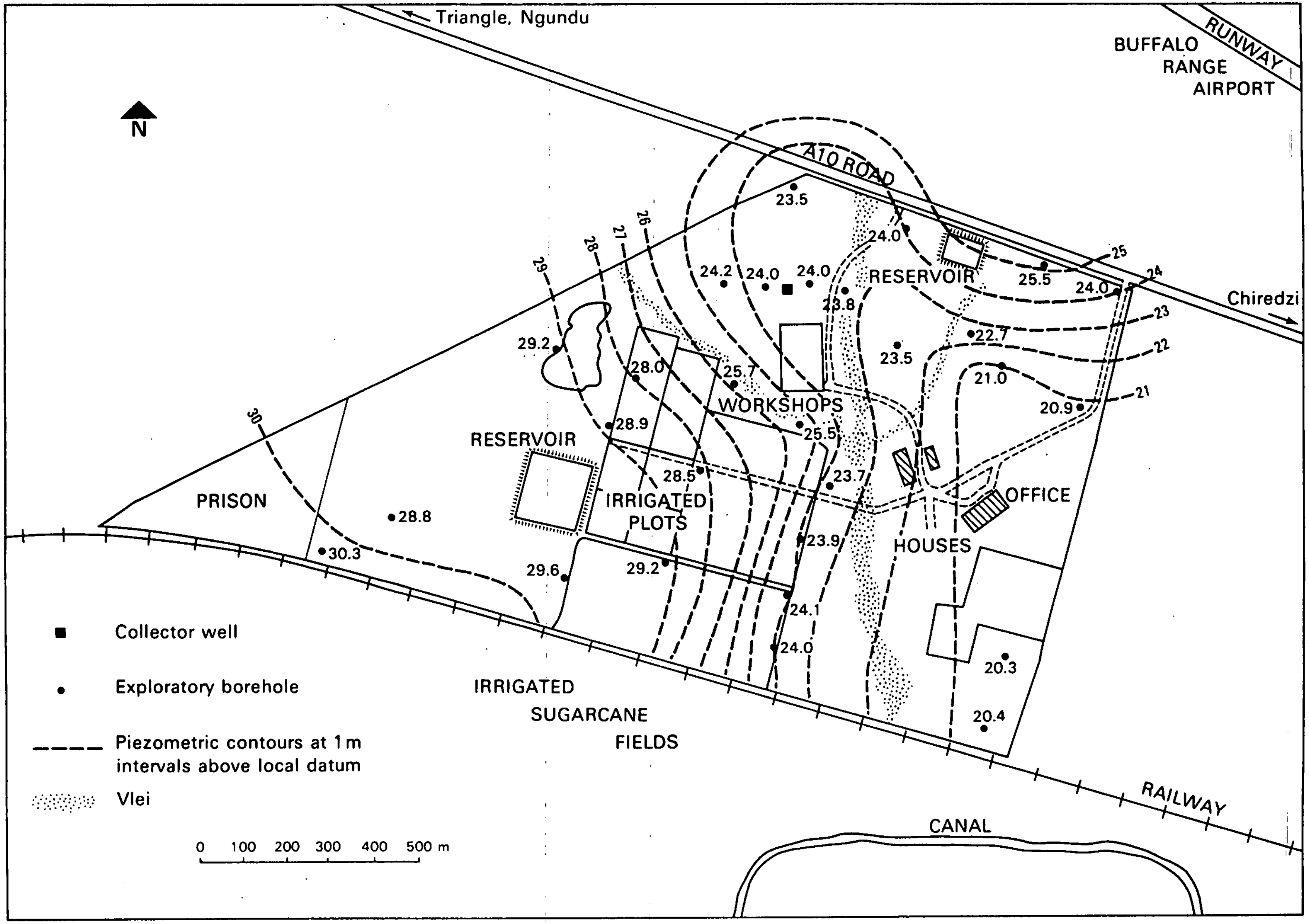


Figure 19. Piezometric contours in March 1992, LRS Chiredzi.

Table 17. Results of Chemical and Stable Isotope Analyses, LRS Chiredzi.

Locality	Date	SEC*	δ^2H	$\delta^{18}O$	pH*	Na	K	Ca	Mg	HCO_3*	SO_4	Cl	NO_3-N	Si	Sr	Ba	Li	B	Fe	Mn	Cu	Zn	Al
		µS/cm	‰	‰		<----				mg/l				---->	<----				µg/l				---->
Chiredzi BH 1A	Mar 91	345	-14	-0.5																			
Chiredzi BH 2A	Mar 91	675	-18	-1.3																			
Chiredzi BH 3A	Mar 91	1114	-17	-1.6																			
Chiredzi BH 4A	Mar 91	4320	-27	-3.3																			
Chiredzi BH 6A	Mar 91	774	-20	-2.1																			
Chiredzi BH 7A	Mar 91	535	-11	-1.4																			
Chiredzi BH 8A	Mar 91	326	-1	-0.9																			
Chiredzi BH 9A	Mar 91	1373	-9	-2.3																			
Chiredzi BH 10A	Mar 91	307	-2	+0.3																			
Chiredzi BH 11A	Mar 91	723	-19	-3.0																			
Chiredzi BH 12A	Mar 91	1067	-21	-3.4																			
Chiredzi BH 13A	Mar 91	597	-16	-2.6																			
Chiredzi BH 14A	Mar 91	747	-21	-1.0																			
Chiredzi BH 15A	Mar 91	1219	-31	-3.9																			
Chiredzi BH 16A	Mar 91	1048	-19	-1.7																			
Chiredzi BH 17A	Mar 91	1218	-33	-5.7																			
Chiredzi BH 18A	Mar 91	1823	-26	-3.7																			
Chiredzi BH 19A	Mar 91	1820	-15	-1.6																			
Chiredzi BH 20A	Mar 91	1803	-33	-4.7																			
Chiredzi BH 21A	Mar 91	1688	-39	-5.1																			
Crown Ranch	27 Apr 91	670	-20	-3.0																			
Dabwa Buisness Centre	27 Apr 91	557	-36	-6.0	7.89	52.0	<0.5	26.8	23.6	283	0.9	32.6	<0.5	34.2			<7.0	<30					
Buffalo Range Ranch	22 Apr 91	888	-24	-3.9	8.19	35.5	<0.5	61.7	70.1	546	17.3	9.8	9.3	35.5			13.0	80					
Tamwa Kraal Collector	25 Apr 91				7.73	31.6	<0.5	26.3	19.4	253	8.9	41.6	1.1	37.7			<7.0	<30					
Chiredzi BH 4A	24 Apr 91	3560	-29	-4.7	7.89	661.0	1.6	77.9	69.5	1063	0.8	810.0	<0.5	28.0			<7.0	360					
Chiredzi BH 1A	26 Apr 91	363	-10	-0.4	8.06	26.2	<0.5	22.5	14.3	197	3.1	13.5	2.7	53.3			<7.0	40					
Chiredzi BH 17A	26 Apr 91	712	-34	-5.6	7.96	33.0	1.4	126.0	70.7	659	8.0	83.5	4.8	47.0			<7.0	140					
Chiredzi BH 20A	26 Apr 91	1770	-32	-4.7	8.19	227.0	1.4	76.6	56.5	837	30.7	170.0	<0.5	20.2			10.0	220					
Chiredzi BH 13A	25 Apr 91	599	-19	-1.7	8.28	24.9	<0.5	66.0	26.3	313	6.1	10.0	0.9	53.2			<7.0	120					
Chiredzi LRS Collector	22 Apr 91	1129	-25	-2.6	8.36	81.1	<0.5	69.3	65.6	634	22.8	55.5	3.7	29.0			<7.0	150					
Chiredzi N. Block Tank	22 Apr 91	136	-18	-1.6	7.61	4.9	3.7	7.2	2.9	44	2.4	3.6	<0.5	5.3			<7.0	<30					
Canal	26 Apr 91	147	-26	-3.5	7.50	5.1	3.8	8.4	3.5	71	1.3	7.4	2.9	11.0			<7.0	<30					
Chiredzi South Dam	26 Apr 91	198	-21	-3.0	7.75	4.1	3.5	6.7	2.9	54	1.6	7.5	<0.5	13.2			<7.0	<30					
Chiredzi LRS Collector	20 Apr 91				8.13	81.3	<0.5	69.4	63.3	607	24.2	45.0	4.6	30.5			9.0	150					
Tamwa Kraal Collector	21 Apr 91				7.83	30.6	<0.5	29.8	18.0	205	3.7	16.8	3.7	37.8			<7.0	<30					
Chiredzi BH 10	09 Mar 92	2150	-31	-4.3		488.0	11.7	65.0	52.6	1590	<0.5	91.5	29.3	22.8	296	137	<7.0	250	54	1670	<10.0	20	<100
Chiredzi BH 2	09 Mar 92	1442	-28	-3.1		232.0	2.5	71.1	55.9	989	6.7	96.8	1.2	23.7	281	99	<7.0	410	164	393	<10.0	<20	<100
Chiredzi BH 21A	09 Mar 92	2010	-33	-4.2		433.0	2.6	35.2	21.6	1250	1.2	110.0	<0.5	29.6	253	184	<7.0	350	111	723	<10.0	<20	<100
Tamwa Kraal Collector	10 Mar 92					32.6	<0.5	25.2	17.3	182	2.2	17.5	6.3	37.6	80	14	<7.0	<30	30	28	<10.0	471	<100
Tamwa Majazi Well	10 Mar 92					33.6	0.8	39.8	66.7	332	0.9	132.0	<0.5	34.1	223	185	<7.0	<30	23	341	<10.0	87	<100
Mhlangas Well	10 Mar 92					16.0	0.8	19.5	12.1	128	5.1	10.8	3.2	27.4	39	29	<7.0	<30	42	42	<10.0	<20	<100
Chiredzi LRS Collector	11 Mar 92	1039	-23	-2.3		78.4	<0.5	67.0	60.2	616	22.0	54.3	5.2	30.7	383	11	<7.0	140	200	32	<10.0	1280	<100
Chiredzi BH 2A	11 Mar 92	1107	-12	-1.3		48.6	11.4	132.0	47.3	769	<0.5	26.8	2.5	37.3	420	343	<7.0	110	51	4150	<10.0	22	<100
Canal	11 Mar 92					6.9	4.2	12.5	5.2	78	1.3	4.3	2.4	16.9	77	74	<7.0	<30	3910	77	<10.0	23	7650

* - indicates laboratory measurement

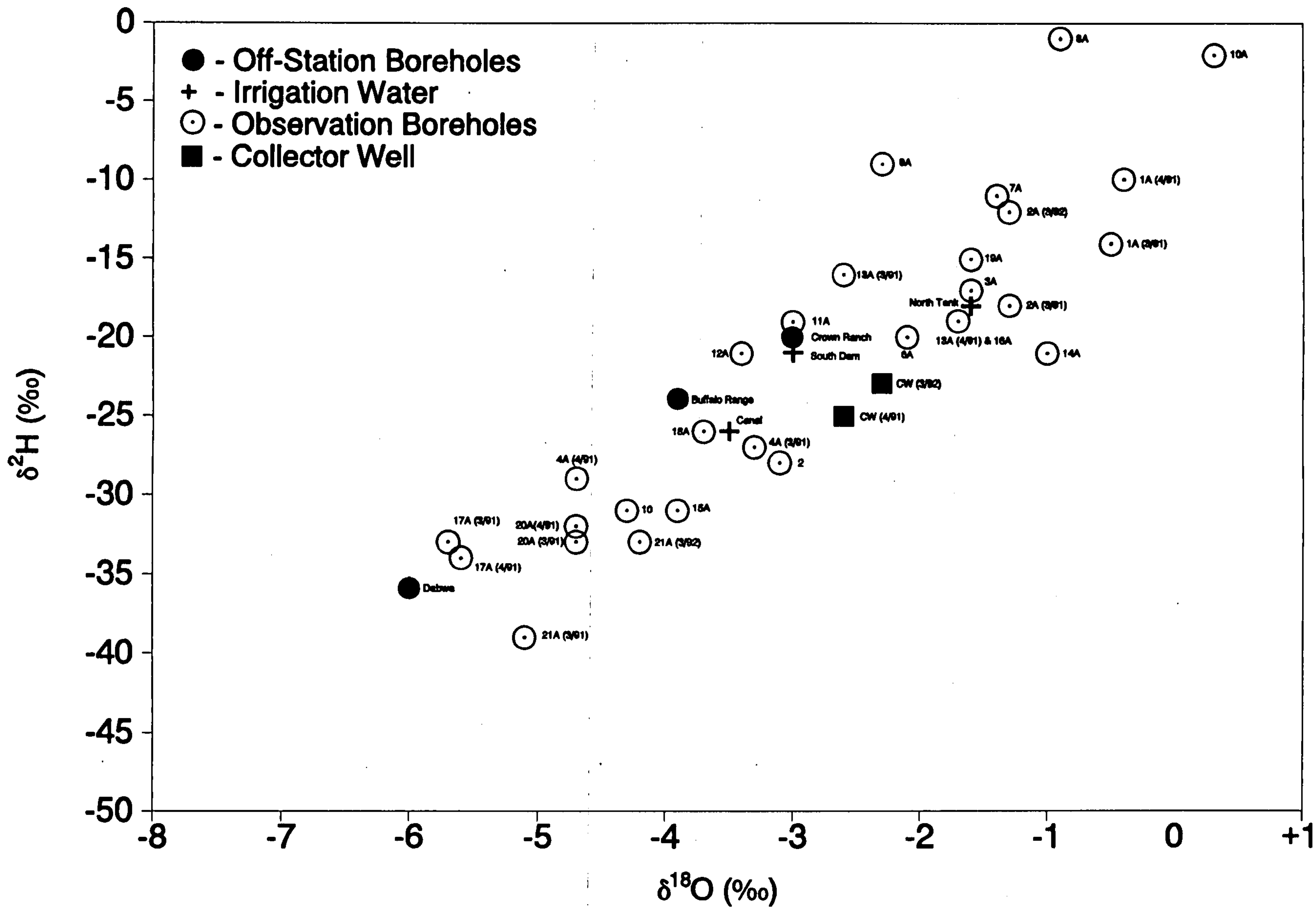


Figure 20. δ^2H against $\delta^{18}O$, LRS Chiredzi.

groundwater, less likely to be influenced by recharge from irrigation. The more distant pumped boreholes may be too far away to represent local groundwater conditions. Samples were collected in March 1992 from old boreholes 2 and 10 and new borehole 21A (Figure 19), also at the extremities of the station to try to confirm this, and they plot in the same region of Figure 20.

Turning to the samples from other exploratory boreholes, they cover a wide spread, spanning the three principal surface water samples (Figure 20). There is no obvious correlation, for example, between borehole samples and proximity to the north and south storage reservoirs (Figures 19 and 20). If, however, samples from boreholes 4, 17, 20 and 21 are representative of the underlying groundwater, then the whole of the central part of the station may be affected by recharge from surface sources. Further, as boreholes 4 and 21 appear not to be affected, any such recharge is more likely to originate from within the station than from the sugarcane fields to the south. This is confirmed by contouring the δ^2H results (Figure 21) which shows a plume of water least depleted in δ^2H originating under the irrigated fields on the station and extending down hydraulic gradient to the north east. The most-depleted groundwater, unaffected by infiltration of surface water, is largely restricted to the corners of the station. The water used for irrigated trials on this section of the station is pumped from the south reservoir (δ^2H -21‰) and has clearly been modified to less than -10‰ during the irrigation and infiltration process.

This interpretation is borne out by the chemical analyses (Table 17). Boreholes 1 (Chilton et al, 1990) and 4A in the south-west corner of the station (Figure 21) have a very distinct groundwater chemistry, high in sodium and chloride. Thus, although they are close to the sugarcane fields, they appear to be uninfluenced by an infiltration from them. Plotting δ^2H against chloride (Figure 22) shows samples from boreholes in the centre of the station 1A, 2A, 13A, close to the surface water sources and those at the extremities of the station, 2, 10, 4A, 17A and 20A plotting far from the surface water sources, with the collector well itself in between. It does appear likely that groundwater in the central and southern part of the station is affected by local infiltration, as suggested by the groundwater level contours. This is further demonstrated by plotting δ^2H against specific electrical conductivity and contours of specific electrical conductivity. In the former (Figure 23), samples from the irrigated part of the station and those to the south form two distinctive groups. In the latter (Figure 24) the presence of a plume of low-conductivity groundwater originating from the irrigated lands is confirmed.

6. CONCLUSIONS

In the hydrogeological component of the study of the feasibility of using collector wells for small-scale irrigation, two collector wells have been successfully completed in the weathered basement of southern Zimbabwe. The first, at the Lowveld Research Station, Chiredzi is constructed to 12.0 m in weathered dolerite, the second, at Tamwa/Sihambe/Dhobani Kraals in Chivi Communal Lands is constructed to the same depth in weathered pyroxene granulite at the northern edge of the Limpopo Mobile Belt.

The first well, completed in May 1989, has been operated at low discharges of about 1000 l/d in 1989 and 1990, 1700 l/d in 1991 and 6000 l/d in 1992. Initially the water was used for irrigation experiments at LRS; more recently greatly increased abstraction has been used for vegetable cultivation at the station in the current drought. The performance of the well has been monitored throughout this period. The second well was completed in May 1991 and was initially operated to provide up to 5000 l/d for domestic and garden use. This increased to 12,000 to 15,000 l/d by March 1992 but has subsequently been controlled by the users at about 10,000 l/d. Although

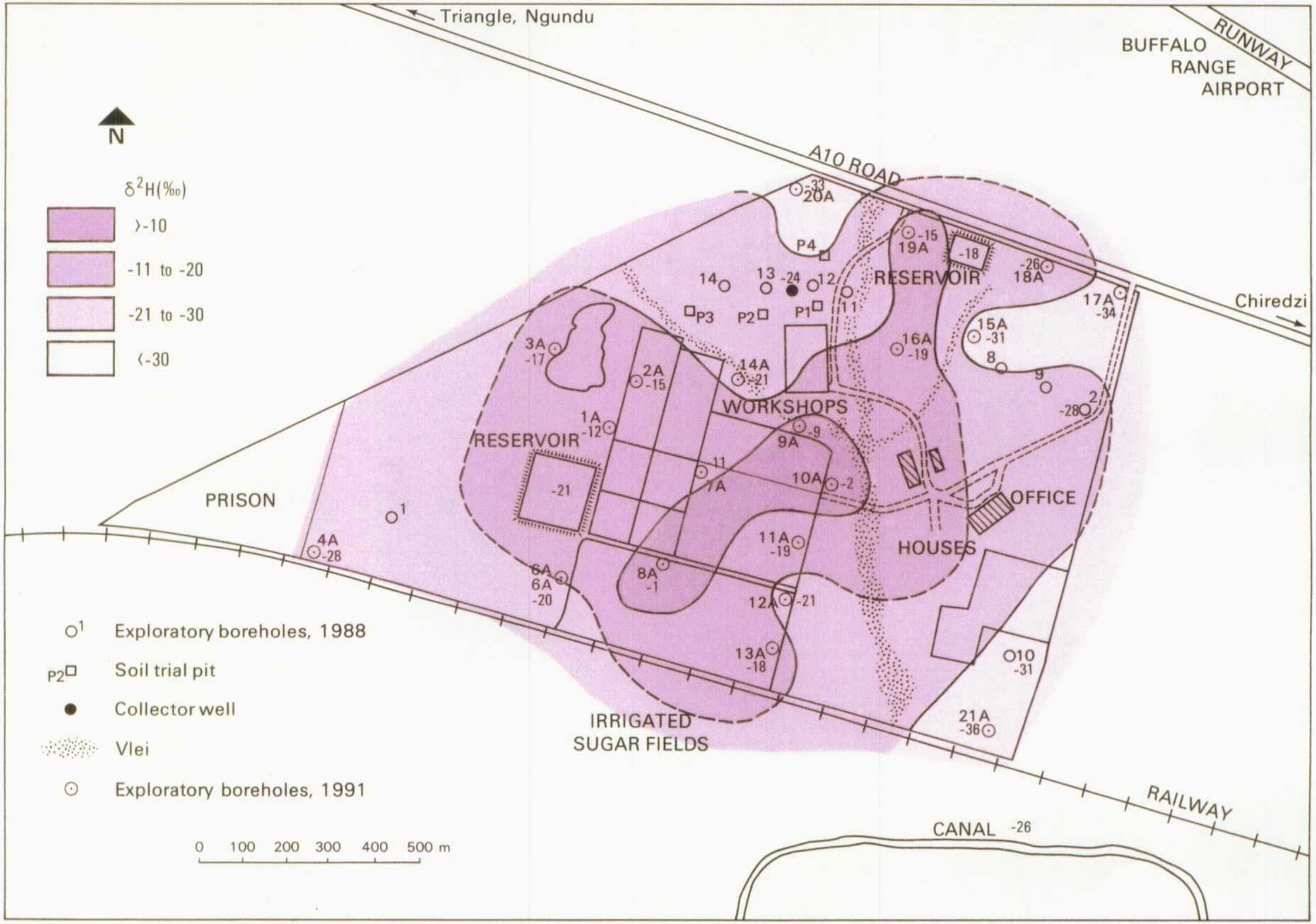


Figure 21. Contours of δ^2H concentrations, LRS Chiredzi.

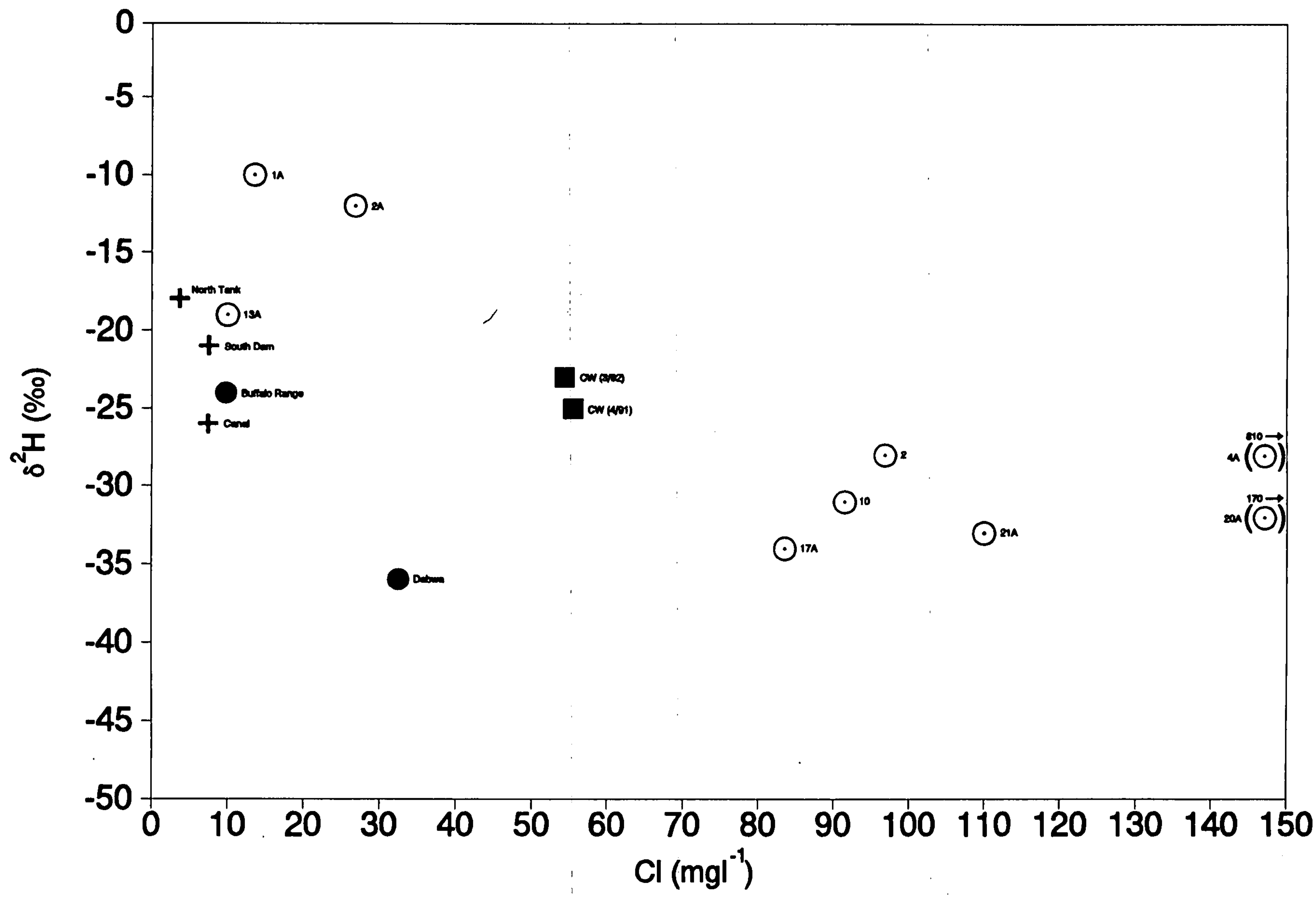


Figure 22. δ^2H against chloride concentrations, LRS Chiredzi.

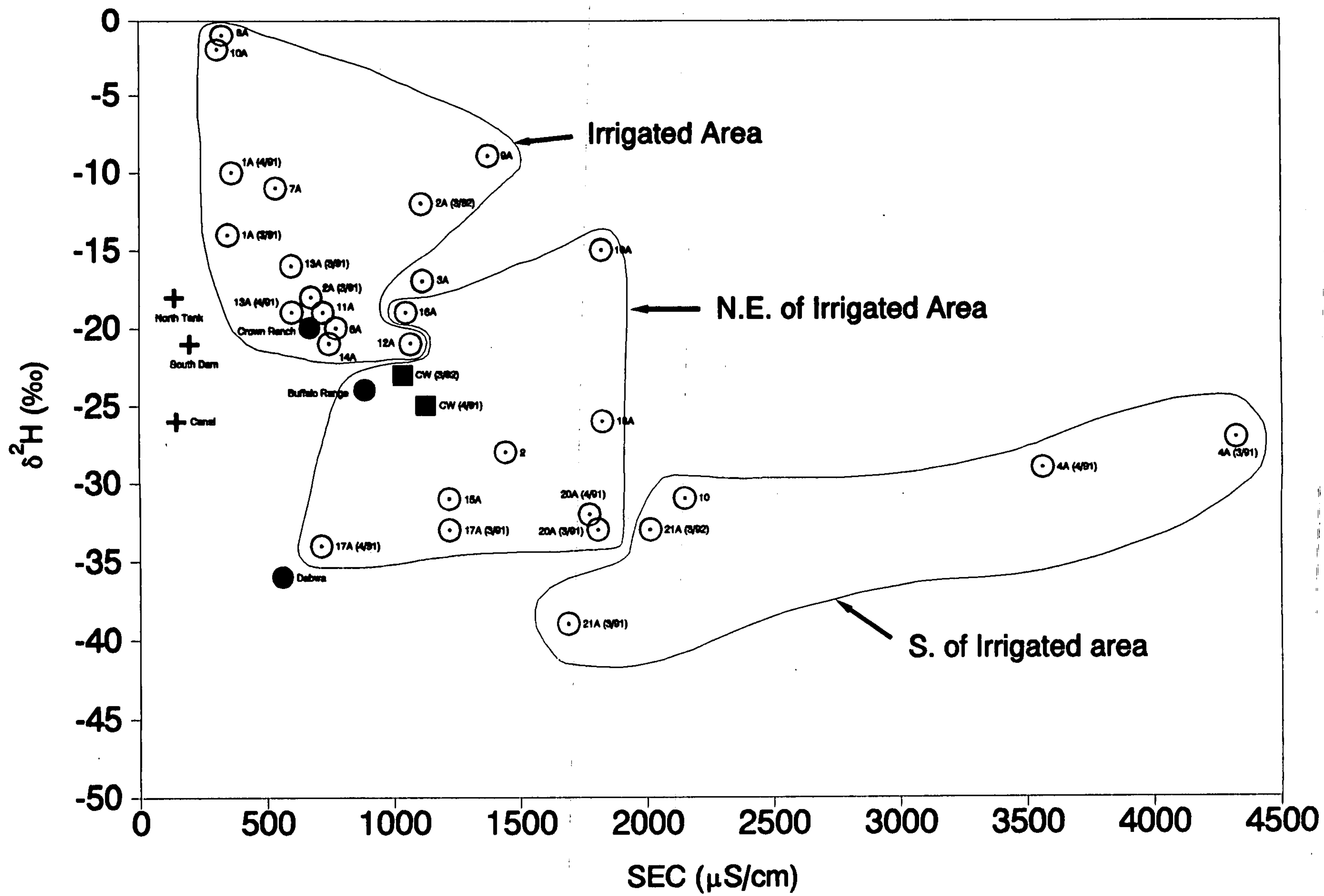


Figure 23. δ^2H against specific electrical conductivity, LRS Chiredzi.

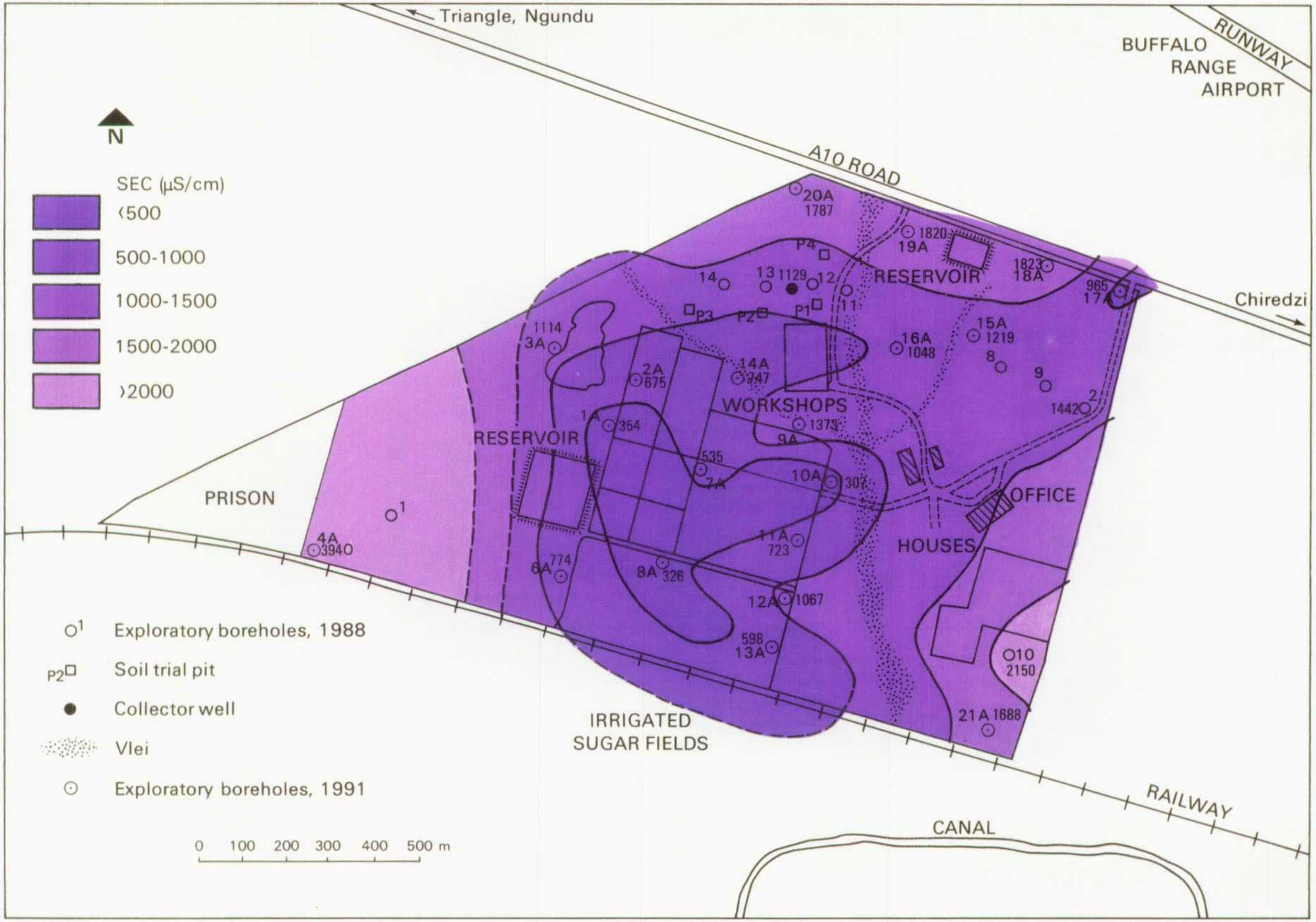


Figure 24. Contours of specific electrical conductivity, LRS Chiredzi.

significant declines in water level (1.5 and 3.5 m respectively) have been observed, both wells have provided sustained yields through the 1992 drought. It is, however, unlikely that they could sustain this through a second rainy season with negligible recharge.

With an annual average rainfall of about 450 mm, the Chiredzi area is considerably drier than any of the other successful collector well locations in Zimbabwe. The possibility that the shallow water levels which help to make the site so suitable were partly a result of enhanced local recharge with Lake Kyle water has been confirmed by additional hydrogeological studies at LRS. Water level information, groundwater chemistry and stable isotopes all point to a local source of recharge from surface water infiltration, and the isotopic and hydrochemical data point to infiltration from the irrigated fields on the station, rather than the canal itself or the irrigated sugarcane cultivation to the south.

The opportunity has been taken to review the performance of the wells constructed in previous phases of the collector well programme. While some continue to operate to provide vital domestic water supplies to local schools and communities, the general poor record of uptake illustrates the need for arrangements to be made and sources of funds to be identified from the beginning. This means working through existing institutional framework and local organisations right from the initial discussions about possible collector wells sites.

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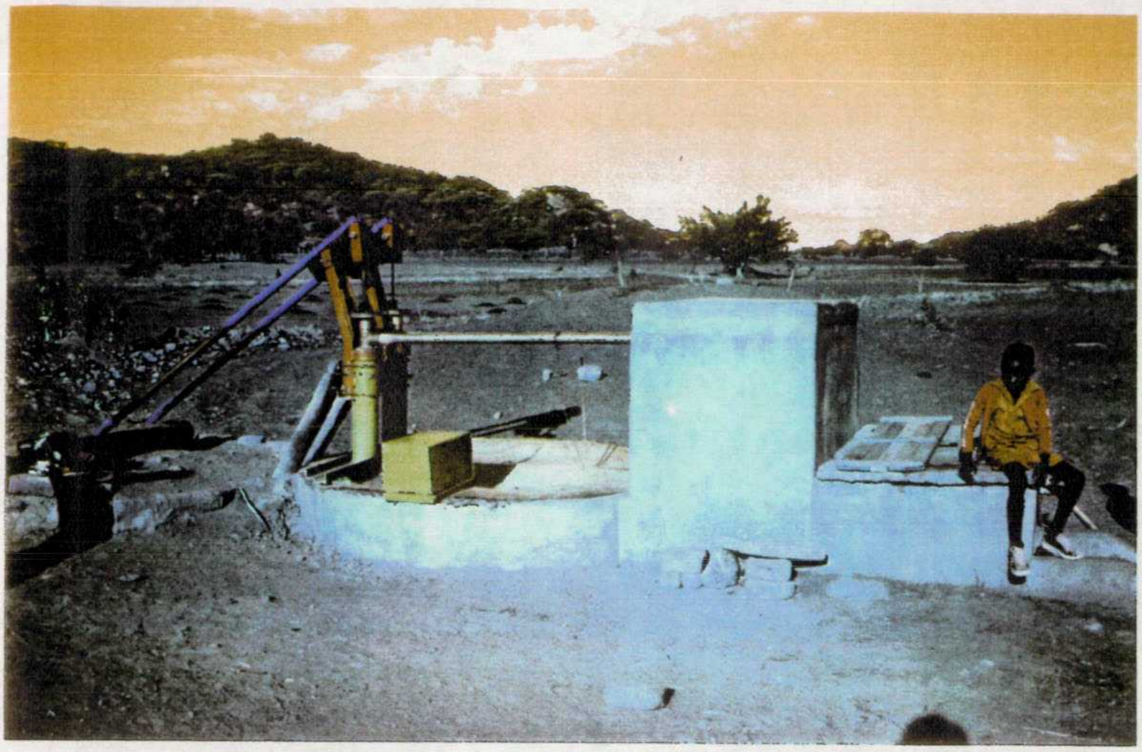

Figure 10. View of well completion showing two Bush pumps, well cover, water level recorder, header tank and meter box.

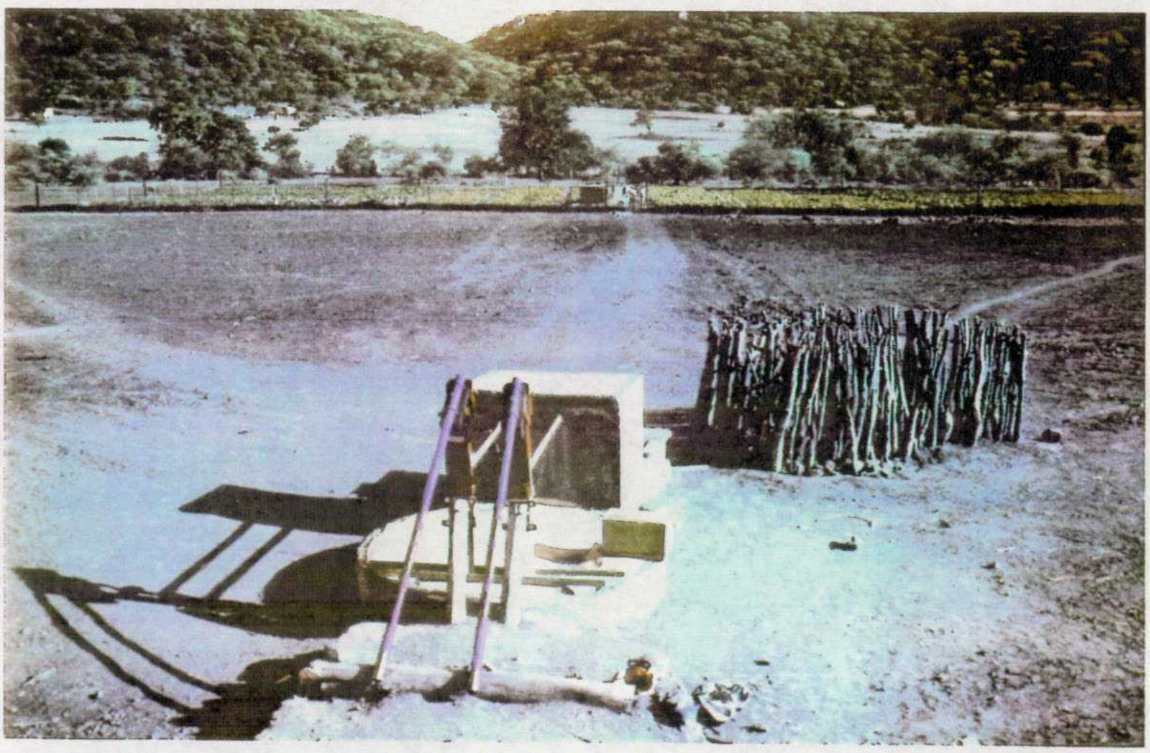

Figure 11. View showing collector well and pumps and fenced garden with tank. Note absence of rainfed cultivation (March 1992).