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Summary of hydrogeological investigations using piezometers at Chimimbe and Chikobwe Dambos, Malawi, 1986-1988

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PREFACE

This is the final report in a series describing work undertaken in two dambos in Malawi between 1986 and 1988. Previous reports (Allen, 1987; Allen 1988a; Allen 1988b) described in detail the methodology and results of fieldwork carried out at the main (Chimimbe) site and the subsidiary (Chikobwe) site. The purpose of this report is both to summarise and to supersede the previous reports.

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1. INTRODUCTION

This hydrogeological study formed part of the Basement Aquifer Project undertaken by a BGS team led by Dr E P Wright and funded by ODA. Part of the project involved the investigation of the properties of the regolith and saprock covering the crystalline basement, and in the present study the hydrogeological natures of two dambo sites in Malawi were investigated using piezometers.

Most of the work was carried out in the Chimimbe Dambo in the Dedza District of Malawi. This is about 60 km south of Lilongwe and a few kilometres from the border with Mozambique (Figure 1). In addition some work was carried out in the Chikobwe Dambo in the Ntchisi District approximately 70 km north of Lilongwe.

The specific objectives of the study were:

(1) To investigate the variation of hydraulic conductivity with depth through the regolith using piezometers at the Chimimbe Dambo site.

(2) To use piezometers to investigate the distribution of hydraulic head at Chimimbe.

(3) To use the available permeability and head data to improve knowledge of the groundwater flow regime in the dambo.

(4) To undertake a limited (single borehole) piezometer study of groundwater conditions at the Chikobwe Dambo.

The study was linked with other work undertaken at the Chimimbe site, comprising analysis of borehole core, surface geophysics and downhole geophysical logging.

2. PIEZOMETER EMPLACEMENT

The constraints of time and the requirements of the other studies resulted in concentration of the piezometer investigation along a NW-SE section from the centre of Chimimbe Dambo to the interfluve forming its SE border (Figures 2 and 3). A Boyles truck-mounted rotary rig was used to drill boreholes at either 100 mm diameter (cored) or 125 mm diameter (rock-bitted). These boreholes are numbered A1 to A6 on Figure 2. Two boreholes were drilled at each of three sites; the A1/A2 site at the topographic centre of the dambo, the A3/A6 site bordering the dambo and the A4/A5 site on the interfluve (Figure 2). Multiple piezometer installations were emplaced in these boreholes at depths ranging from 1 to 26 m.

Figure 4 shows the type of installation employed. A 50 mm diameter slotted plastic pipe normally formed the piezometer (although this was sometimes replaced by a 25 mm diameter pipe) and was connected to the surface by a 25 mm galvanised iron pipe. Gravel surrounded the piezometer tube and formed the test section, the top and bottom being isolated by a bentonite/cement plug. Water levels in the test section were monitored via a 13 mm plastic pipe. By emplacing several piezometers in a borehole and by using two boreholes at each site, up to five piezometers were emplaced at a site.

Figure 5 shows the locations of the piezometer test zones and the lithology of the weathered basement at the three sites. Piezometer test zone depths are given in Table 1.

In addition to the multiple installations, piezometers were emplaced singly in some of the shallow boreholes (Pr1-Pr24) drilled by a small power-auger at locations shown in Figures 2 and 3.

Several trial pits were dug to a depth of around 1 m near the edge of the dambo to investigate near-surface hydrogeological conditions. The locations of these excavations are shown in Figure 3.

At Chikobwe Dambo one cored borehole was drilled in the centre of the dambo and three piezometers were emplaced. Depth data are given in Table 2.

3. PERMEABILITY MEASUREMENTS

Hydraulic tests on the piezometers were carried out by the rising head, falling head or static injection head methods and were analysed by the Hvorslev method (Hvorslev, 1951). Some piezometers were tested several times and the results of individual tests are given in Allen, 1987; 1988a and 1988b. The final results of the series of tests are given in Table 1.

A total of five piezometers (A2-3, Pr5, Pr7, Pr19 and Pr23) were emplaced in the dambo clay at Chimimbe. Hydraulic conductivity values obtained from the piezometers ranged from 5 x 10^{-5} to 1 x 10^{-2} m/d. The lowest value is considered suspect because the test zone may have been contaminated by drilling mud invasion. The geometric mean value of the other measurements is 3 x 10^{-3} m/d.

At the dambo centre site (A1/A2) low values, of 0.1 m/d, were obtained for both saprolite and saprock with a similar value, of 0.2 m.d, for the underlying bedrock.

The dambo clay at the edge of the dambo is covered by thin sands which extend to, and somewhat beyond, the dambo-periphery site (A3/A6). These sands are permeable, and piezometers 20 and 21 gave hydraulic conductivity values of 3.3 and 5.6 m/d. The hydraulic conductivity of the sandy clays underlying the sands is uncertain because the values obtained from a piezometer in this material (A3-3) increased from 5 x 10^{-3} m/d to 2 m/d during testing. (The lower value is probably correct; the higher value was probably caused by leakage).

The soft saprolite underlying the sandy clays at the dambo-periphery site gave hydraulic conductivities of 0.05 m/d and 0.2 m/d, which are similar to those measured at the dambo centre site. A piezometer emplaced in bedrock (A6-1) gave a value of hydraulic conductivity of 0.1 m/d, again similar to that measured at the dambo centre.

Four piezometers were emplaced in the colluvium overlying the saprolite in the interfluve (A5-3, Pr14-1, Pr15-1, Pr15-2). Values of hydraulic conductivity obtained from this material ranged from 5 x 10^{-3} m/d to 4 x 10^{-2} m/d, with a geometric mean value of 1 x 10^{-2} m/d. Piezometers in the underlying saprolite and saprock gave values of hydraulic conductivity which varied from 0.1 m/d to 0.7 m/d, with a general tendency for an increase in hydraulic conductivity with depth.

In summary the values of hydraulic conductivity obtained from piezometer tests at Chimimbe ranged from around 10^{-3} m/d for the central dambo clays, to about 5 m/d for the sands at the edge of the dambo. The measured hydraulic conductivities of saprolite, saprock and bedrock were similar, with values generally around 0.1 m/d, although these were indications of somewhat higher values from the saprock (4×10^{-1} m/d) and brecciated saprock (7×10^{-1} m/d).

The hydraulic conductivity values obtained from the three piezometers (AIL-1, AIL-2, AIL-3) emplaced at Chikobwe are similar (Table 1). The somewhat high value (5×10^{-2} m/d) obtained for piezometer AIL-3, emplaced in the dambo clay is considered suspect because of problems experienced during piezometer installation. The other two piezometers, installed in saprolite and saprock gave similar low values of hydraulic conductivity (3×10^{-2} and 4×10^{-2} m/d) - about one quarter of the typical values found at Chimimbe. Whether this is significant cannot be determined with such a limited number of measurements.

4. WATER LEVEL VARIATIONS

Figure 5 shows the form of water levels along the dambo centre-interfluve section at Chimimbe during a dry season and a wet season, and Figure 6 shows the variation of these levels with time for various piezometers. Water level data are given in Table 2.

The general form of the water table is that which would be expected for a valley/interfluve system, with water levels following a subdued replica of surface topography and implying recharge under the interfluve and discharge at low elevations. No evidence of perched water tables was seen during drilling or during subsequent piezometer monitoring (although short-lived perched systems may exist) and variations in piezometric level with depth are small, therefore the water levels indicated on Figure 5 may be taken to represent the potentiometric surface of the full thickness of weathered material.

Piezometer water levels at the centre of the dambo vary between the ground surface (or a little above ground level) and 1.25 m below ground level. Water conditions in the saprolite are probably at least semi-confined by the low-permeability dambo clay.

Figure 6 shows the water-level variations with time for the piezometers at the dambo centre site (A1 and A2 boreholes) and detailed measurements are given in Table 2. Figure 6 implies that piezometers below the clay (A1-1, A2-1, A2-2) show an annual maximum water level probably in late December or early January (access to these piezometers was prevented during these months by waterlogged ground). Piezometer A2-3 which was emplaced in the near-surface dambo clay indicates a later maximum, but interpretation of water levels given by this piezometer is problematic because it is surrounded by material of very low permeability (possibly a result of formation damage caused by mud invasion). Therefore the response of this piezometer to external head changes may be substantially delayed and it is not regarded as a reliable indicator of current hydraulic head.

The two piezometers A1-1 and A2-2 span a depth range from 3 metres to 17.1 metres below ground level, and head variations between the piezometers can be used to identify the vertical component of water movement under the dambo centre. Table 2 indicates that the direction of flow between September 1986 and June 1987 was predominantly upwards, with approximate head gradients ranging from a barely detectable 2 x 10^{-4} m/m in September 1986 to 2 x 10^{-3} m/m in April 1987. The upward trend is only reversed in a set of readings taken in November 1986, where a downward gradient of 9 x 10^{-4} m/d was recorded. The reason for this is probably the onset of the rainy season with initial recharge through the cracks in the dambo clay giving a temporary increase in head at higher levels in the central dambo sequence.

Away from the dambo centre, along the line of the piezometer profile, water levels in the rainy season remain at, or close to, the surface for several hundreds of metres. In March 1988 the ground was waterlogged to a distance of 500-600 metres from the centre of the dambo. Further away water levels fell, reaching around 0.5 metres below ground level at the dambo-periphery site. The thin permeable sands which underlie the dambo-periphery area are therefore fully or partially saturated during the rainy season and play a significant part in the hydrology of the dambo. During the dry season water levels fall to below ground level across the whole of the profile, although levels in June 1987 still remained within 0.5 m of the surface at around 400 m from the dambo centre, and further along the dambo edge perennially swampy ground was present. Single piezometers emplaced along the profile at distances up to 550 m from the central dambo site (Pr2, Pr3, Pr4) show annual water level variations similar in type to those recorded by the dambo-centre piezometers (Figure 6), with the peak for the 1986/1987 rainy season occurring in December/January.

At the dambo-periphery site (A3/A6) the four piezometers show a rise in water levels at the onset of the rains in November/December 1986, but these peak later than the piezometers nearer the dambo, reaching a maximum level in February 1987. Head gradients deduced from the piezometer water levels shown in Table 2 are predominantly downwards*, starting at around 3 x 10^{-2} m/m in September to November 1986, increasing to about 6 x 10^{-2} m/m in December 1986 and January 1987 and falling to 3 x 10^{-2} m/m after this period (values derived from piezometers A6-1 and A3-2).

The shallowest piezometer, A3-3 shows an anomalously low head between mid February and early April 1987 indicating upward flow in the upper part of the saprolite (above about 5 metres). The explanation for this effect may lie in the fact that during this period potentiometric levels at the site lay at depths of around 0.4-0.8 metres below ground level, which is within the shallow permeable sands. When water levels rise to depths of less than 0.8 metres rapid interflow can occur, reducing the water level and therefore the head registered by the shallow piezometer A3-3. If however the sandy clay surrounding, and underlying, the piezometer acts as an aquitard, then the potentiometric levels registered by the deeper piezometers will continue to rise relatively unaffected by the inability of A3-3 to sustain an increased head. The implication therefore is that the near-surface sand is very permeable and is at least partially hydraulically separate from the underlying saprolite in this area.

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* The water level of piezometer A3-1 in May 1987 is part of no trend and a measurement error is suspected.

The piezometers on the interfluve, A4-1, A4-2, A5-1 to A5-3 and the well C3 show different responses to the rainy season than the piezometers in or near the dambo. Water levels measured at this site fall on a declining trend until January 1987 (Figure 6) by which time the piezometers close to the dambo have already peaked. A rapid rise in water levels follows, with a maximum at the end of March 1987.

The implication of this trend is that recharge to the saprolite on the interfluve is slow and is delayed by the low permeability of the colluvium and the greater distance to the water table (around 6.6 m as water levels start to rise).

Vertical head gradient interpretations from Table 2 are complicated by the fact that there is apparently a small error in the relative altitude determination made on boreholes A4 and A5. This can be avoided by only comparing water levels from piezometers in the same borehole. However the resulting head gradients are often contradictory. Careful water level measurements made in March 1988 failed to detect any vertical gradient but in view of the fact that the site is on an interfluve it may be assumed that recharge is occurring at the site but that the gradients are below the limit of detection by the methods used.

Water levels at Chikobwe are shown in Table 3. Borehole B1 is in the centre of the dambo, close to borehole A1L in which three piezometers were emplaced. Borehole DW67 was drilled on the interfluve.

During the period July 1986-May 1986 water levels in the dambo varied from a minimum in mid-October 1986 to a maximum in March/April 1987. During the same period water levels on the interfluve reached a minimum in late December 1986 or early January 1987 and thereafter rose to May 1987 and possibly afterwards. Thus there appears to be a time lag of about two months between the response of the dambo centre and that of the interfluve to the onset of the rainy season. By analogy with Chimimbe it is thought that this time lag occurs as a result of rapid interflow through dambo-peripheral sands, and delayed recharge through interfluve colluvium.

All three piezometers in the dambo centre indicate potentiometric levels above ground level between approximately late February and mid May 1987, and in one case (A1L-2, 21 March) a water level of nearly 0.4 m above ground level was recorded. These data show the dambo floor to be in an area of strong discharge potential during the above period. (However, this does not necessarily imply a significant flow of water because of the low permeability of the dambo clay).

If the piezometer levels are compared with each other no clear pattern of vertical flux is seen except in the period October-November 1986 when all the piezometers show an upward flux. The reason for the inconsistency at other times is unknown.

In general the limited data available from Chikobwe support a similar interpretation of water level responses as at Chimimbe - that the dambo floor is in a hydraulic discharge area and that water level responses on the interfluve are delayed compared with those in the dambo, by a combination of rapid interflow near the edge of the dambo and slow infiltration on the interfluve. The higher vertical hydraulic gradients in the centre of the dambo at Chikobwe as compared with Chimimbe are probably caused by the greater height of the interfluve above the dambo floor at Chikobwe.

5. CONCLUSIONS

The water level data given in Table 2 and illustrated in Figure 5 show that groundwater movement in the section of Chimimbe Dambo which was investigated conforms to that expected for a valley/interfluve system. The interfluve is a recharge area and the dambo centre is a discharge area, with the driving head between the two varying between about 10 m and 12 m. The vertical component of subsurface flow is predominantly downwards (recharge) over most of the profile, from the top of the interfluve (2 km from the dambo centre) to at least the dambo-periphery site (800 m from the dambo centre). The actual route of water flow towards the dambo in the plane of the section is however complex, because of variations in permeability of the materials composing the system. In addition the true flowpaths naturally require consideration of the third dimension along the axis of the dambo.

The range of hydraulic conductivities measured varies from the order of 10^{-3} m/d to 10^{1} m/d. Most of the material underlying the dambo - the bedrock, saprock and saprolite - gave values in the middle of this range when tested by piezometers. Table 1 shows that the range of values measured lies between 0.1 and 0.7 m/d with most values at the lower end of this range. These values must be regarded as preliminary, especially those for the saprock and unweathered rock, firstly because of the paucity of measurements and secondly because flow in these materials is essentially through fissures and therefore the relevance of individual piezometer measurements depends very much upon fissure spacing. In the saprolite intergranular flow is more likely to occur and the piezometer results are expected to be more reliable.

Water infiltrating into the saprolite and underlying material on the interfluve must first penetrate the colluvium. This has a hydraulic conductivity around an order of magnitude lower than that of the saprolite and therefore inhibits infiltration, delaying the response of interfluve water levels to rainfall by several weeks. This in turn suggests that interflow in the near-surface, loose, (and therefore probably permeable) layers of colluvium plays a significant role in the transport of infiltrated water towards the dambo. The perched water tables implied by this mechanism are apparently transient because no evidence of them was seen during drilling on the interfluve in the dry season.

The shallow sands bordering the dambo are partly to fully saturated during the wet season and possess permeabilities which are one to two orders of magnitude higher than the underlying saprolite. These sands therefore facilitate shallow interflow towards the dambo, the effect of which is seen in the rapid response of piezometer water levels to the onset of the rainy season.

The stiff clays in the dambo centre have a low permeability - around two orders of magnitude lower than the saprolite. Their effect is therefore to inhibit the discharge of upward-moving water under the dambo.

In general therefore the data suggest a dual system of subsurface flow (Figure 7a). Some infiltrating rainwater on the interfluve moves relatively rapidly at shallow levels towards the dambo, initially in the upper levels of the colluvium and eventually in the shallow sands bordering the dambo. This system responds rapidly to the onset of the rainy season but is transient and does not operate during the dry season, except to a minor extent near the edge of the dambo where water levels remain within the shallow sands throughout the year.

The remainder of the infiltrating rainwater penetrates the colluvium, or the clay underlying the shallow sands and enters the saprolite. Here it will move via long deep flowpaths (or possibly rapidly through interconnected fractures) to discharge areas bordering the dambo.

An analytical computer model has been used to examine the deep flow system. The model is simplistic in that it assumes a uniform value of hydraulic conductivity for the whole system, however it helps to illustrate several features of the flow regime. For example the model suggests that the zone of discharge extends to a distance of around 700 m from the dambo centre in the wet season, and this corresponds well with the observed area of discharge (Figure 5). Also the model can be used to predict the rate of discharge from the dambo. This rate is directly proportional to the value of hydraulic conductivity used in the model, and for the value of 0.1 m/d indicated by piezometry a seepage rate of 390 mm/yr is predicted in a zone between 200 m and 700 m from the dambo centre. This compares with a rate of 150 mm/yr, calculated from evapotranspiration data (E P Wright, pers. comm.). The discrepancy between the values may be ascribed to various causes (for example some of the upwardly moving water predicted by the model will in fact move along the dambo, deflected by the dambo clay) but the figures are close enough to suggest that the average permeability of the saprolite/saprock, bedrock system is of the order of 10^{-1} m/d.

The above discussion considers only flow in the plane of the section of Figures 5 and 7a. If the third dimension - along the axis of the dambo- is considered then a significant component of flow down the dambo is introduced because the average hydraulic gradient along the dambo is of the same order as that from the interfluves to the dambo centre (in the plane of Figure 5). If it is assumed that the saprolite, saprock and bedrock are regionally isotropic with respect to hydraulic conductivity and that porosities do not vary regionally then it follows that similar flow velocities may be expected down the dambo as across it. Therefore if a plan version of the dambo is considered (Figure 7b) flowlines from the interfluves towards the dambo will trend at 45^o to the dambo axis. As the dambo centre is approached the flowlines must curve along the direction of the dambo because a flowline lies along the dambo axis. The effect of the central dambo clay will be to inhibit vertical flow because of its low permeability and therefore to promote axial flows down the dambo and also discharge at the edge of the clay in the seepage zone. A rough quantitative estimate of the amount of axial subsurface flow out of the dambo from beneath the dambo clay is 1 l/s (Allen, 1988a).

The limited data from the Chikobwe Dambo support the above model, with the greater topographic variation at Chikobwe causing increased head gradients in the dambo centre.

While the piezometer investigations described above have identified the likely groundwater flow system in the Chimimbe Dambo there is significant scope for further work. The advantage of piezometers is that they enable the variation in certain hydraulic properties (hydraulic conductivity and head) through a geologic sequence to be assessed by measuring the properties at specific points. However the hydraulic properties of the sequence between the measured points can only be inferred. Piezometers will not detect a thin zone of anomalous permeability, such as might occur along a weathered quartz vein for example unless the piezometer test section is placed against such a zone. Since such zones of rapid recharge are now suspected to occur under dambos (E P Wright, pers. comm.) it would be advantageous to improve the conceptual model of the flow system at Chimimbe by attempting to detect them. This would involve drilling several boreholes into the fresh rock underlying the weathered material and performing logging and pump-testing operations.

6. ACKNOWLEDGEMENTS

I am pleased to acknowledge the following for their assistance during the periods of fieldwork; Mr K Murray of BGS, Mrs C Cruz of the British High Commission, Lilongwe and Mr Nthondo of the Ministry of Works and Supplies. Of the locally-recruited labour I would particularly like to acknowledge the efforts of Mr J Kanzule and Mr F N Kwiemda.

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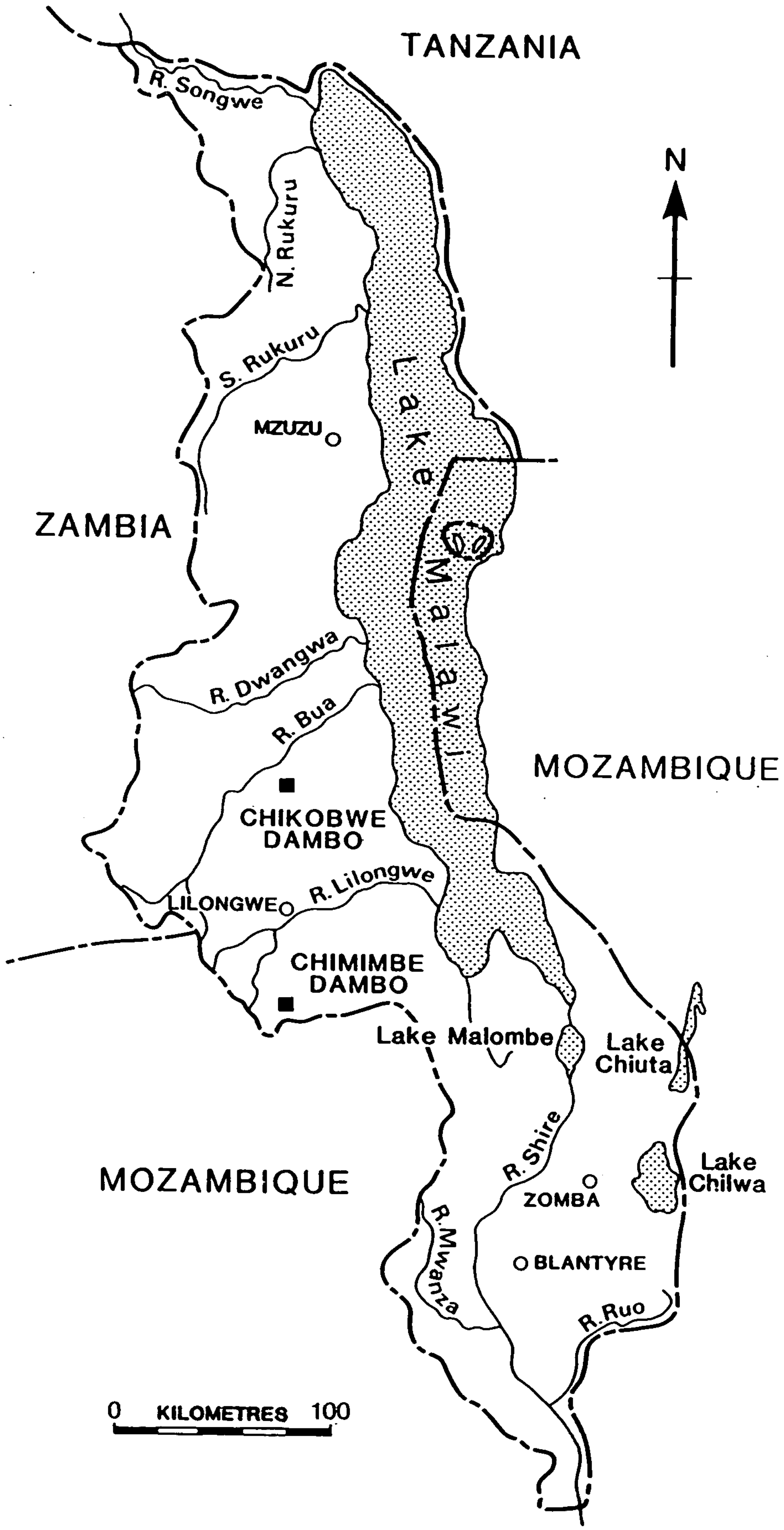


Figure 1. Site location plan.

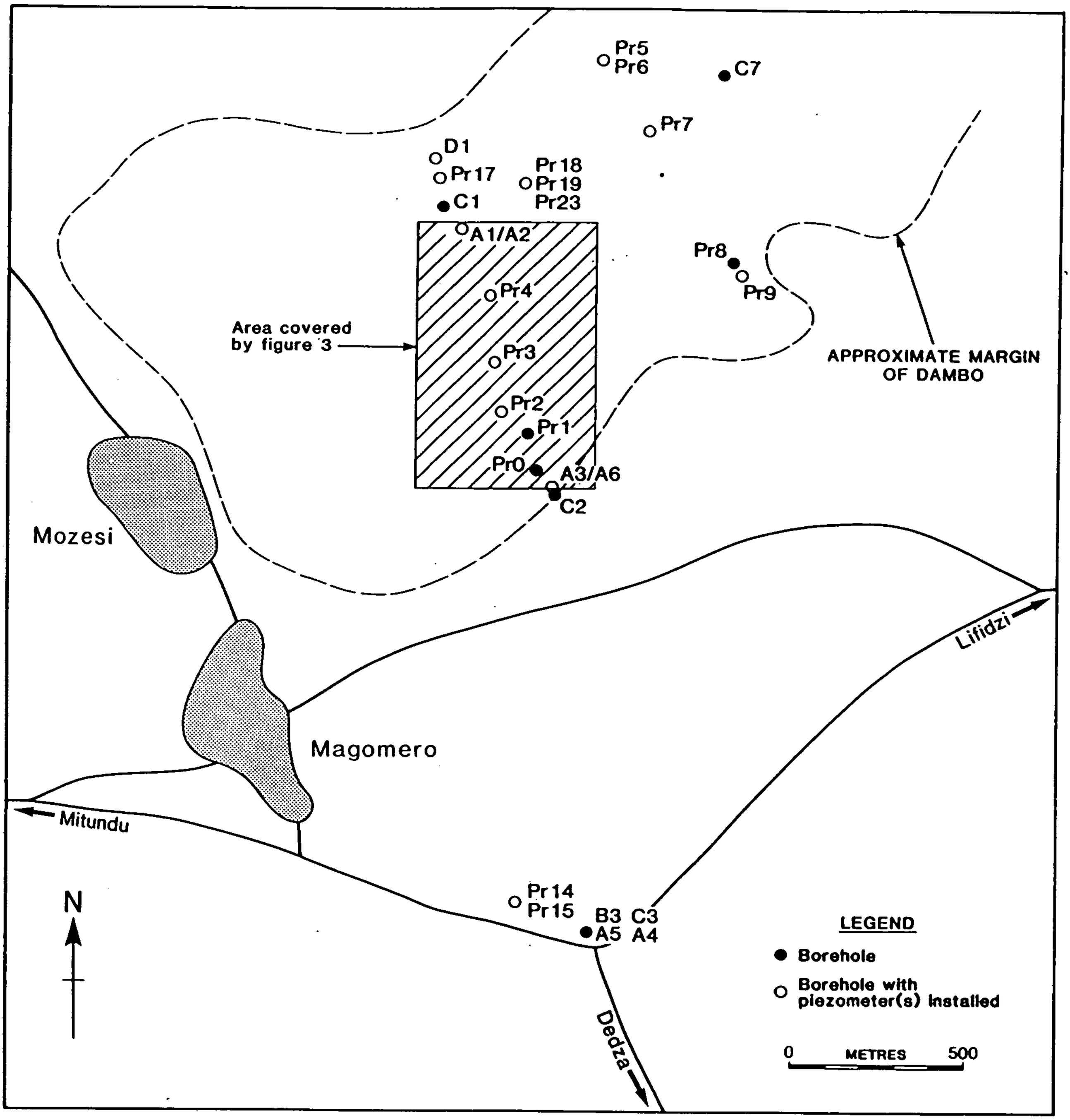


Figure 2. Plan of Chimimbe Dambo site.

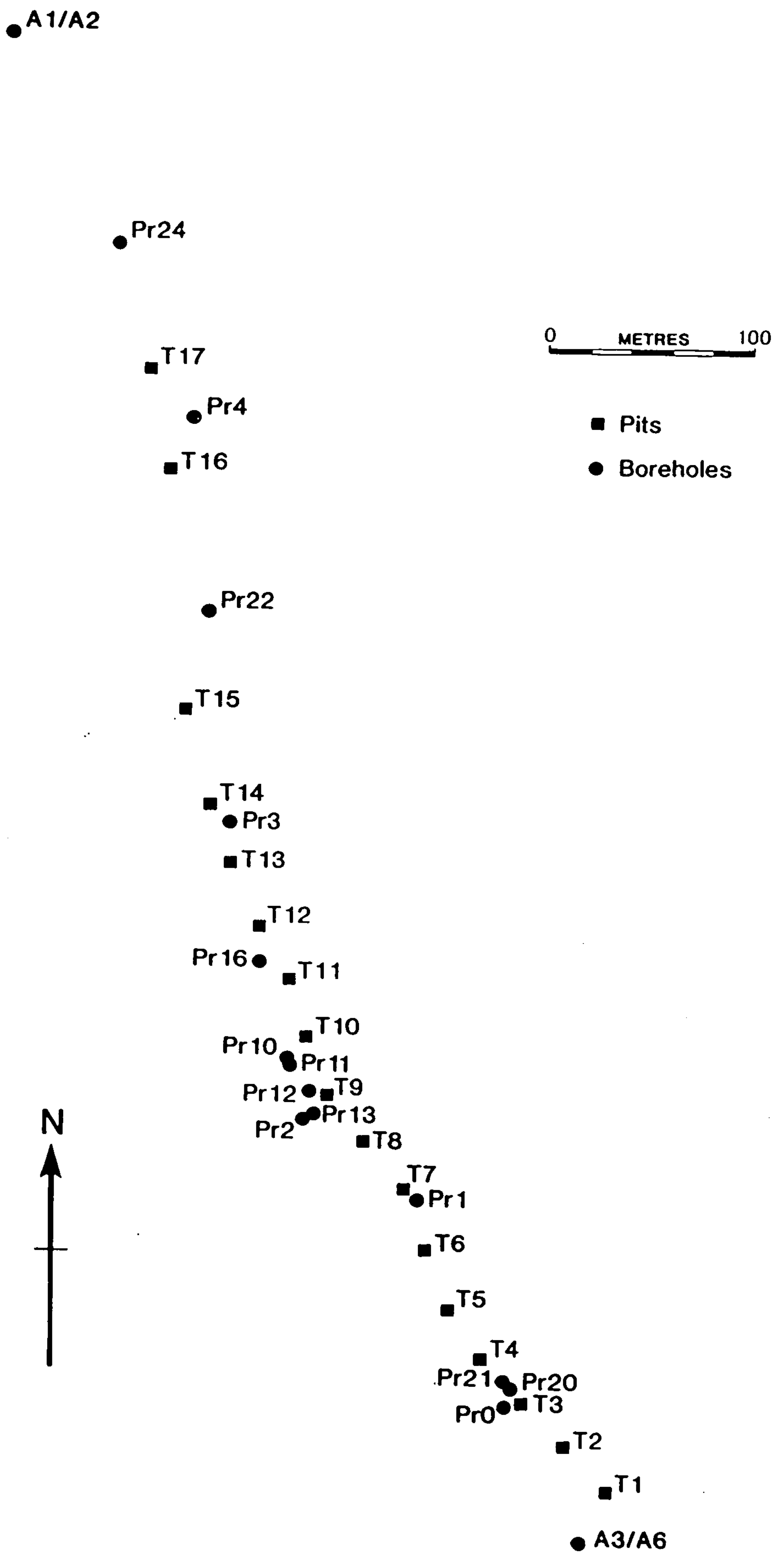


Figure 3. Detail of Chimimbe Dambo site between dambo centre boreholes (A1/A2) and dambo periphery boreholes (A3/A6).

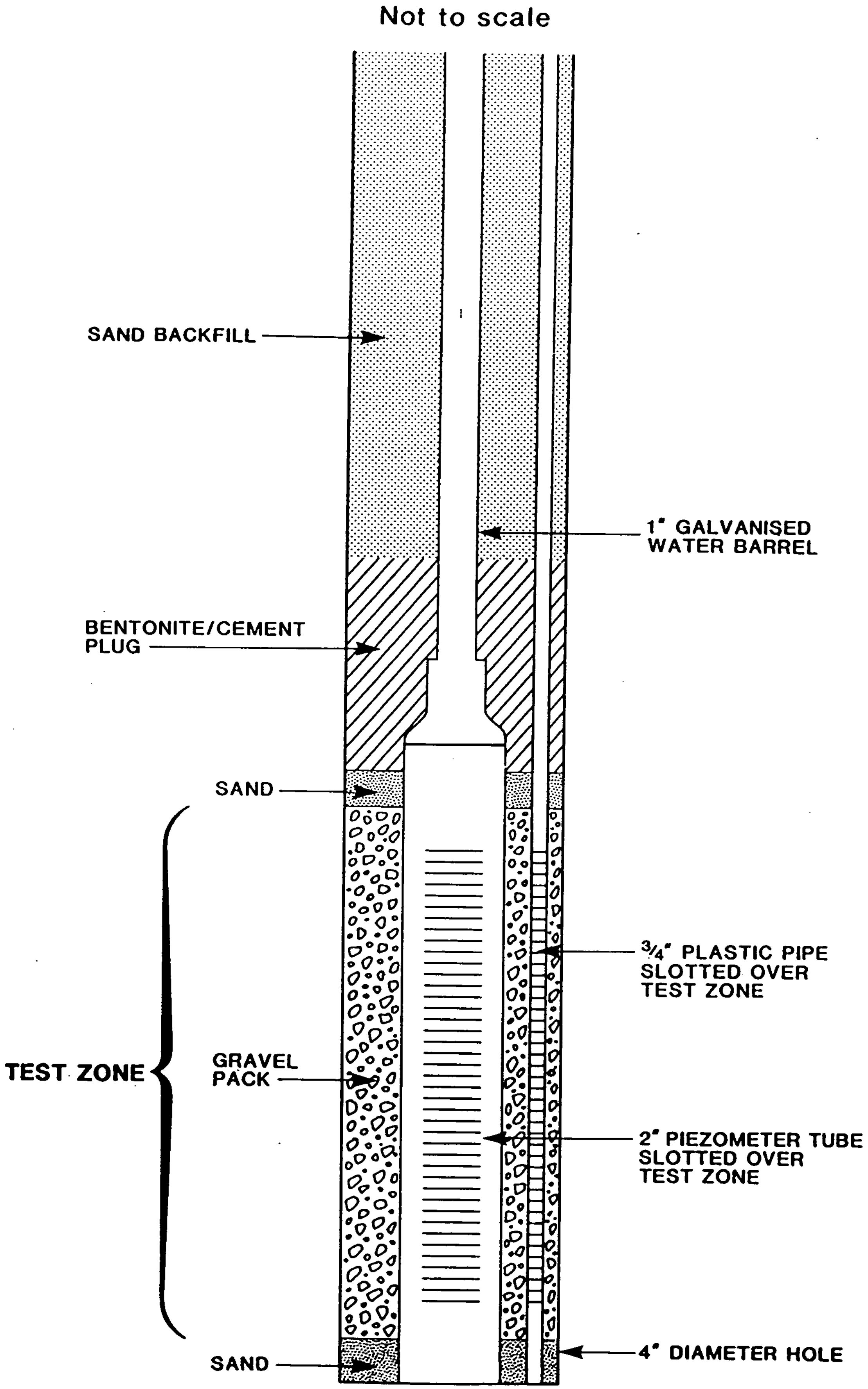
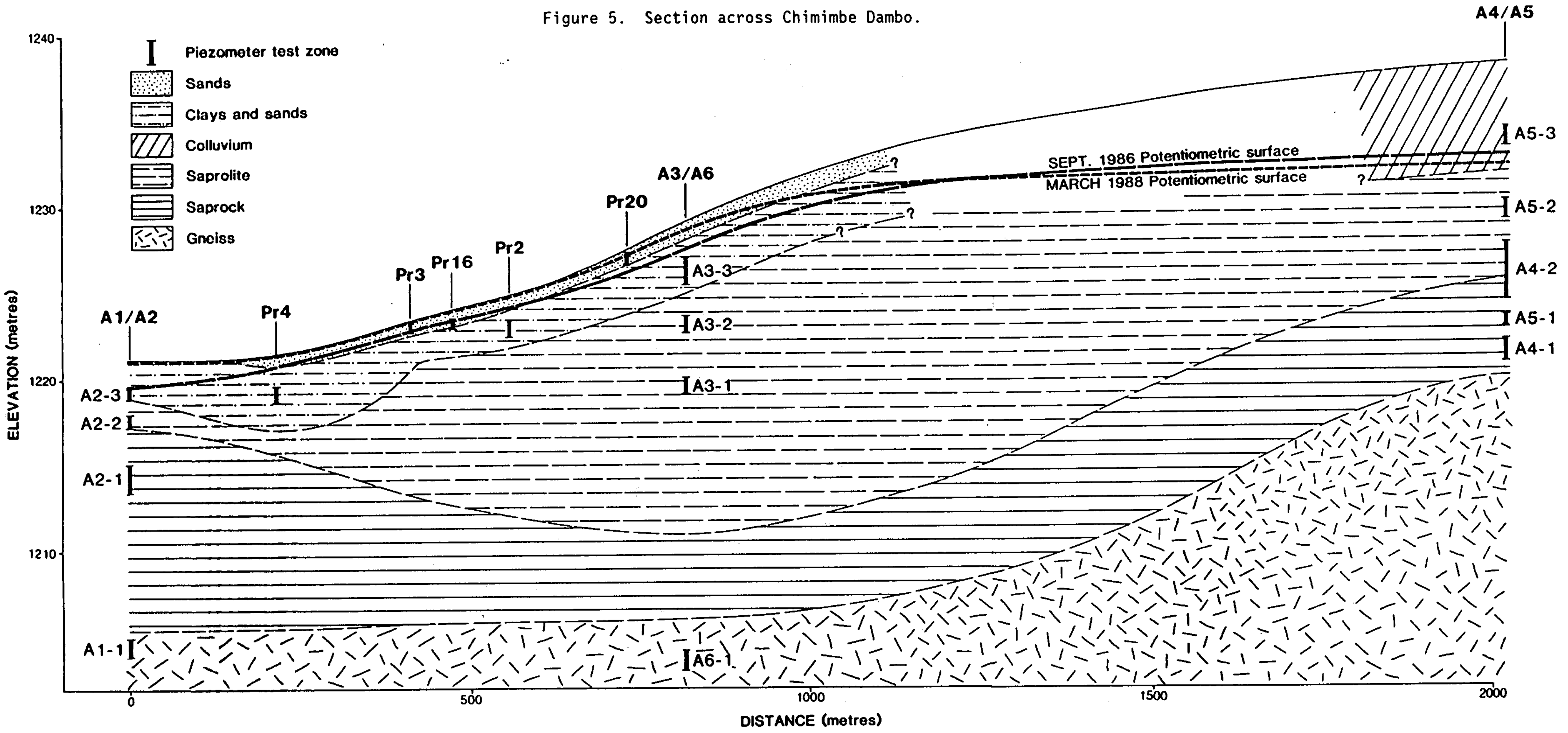


Figure 4. Piezometer installation.

Figure 5. Section across Chimimbe Dambo.



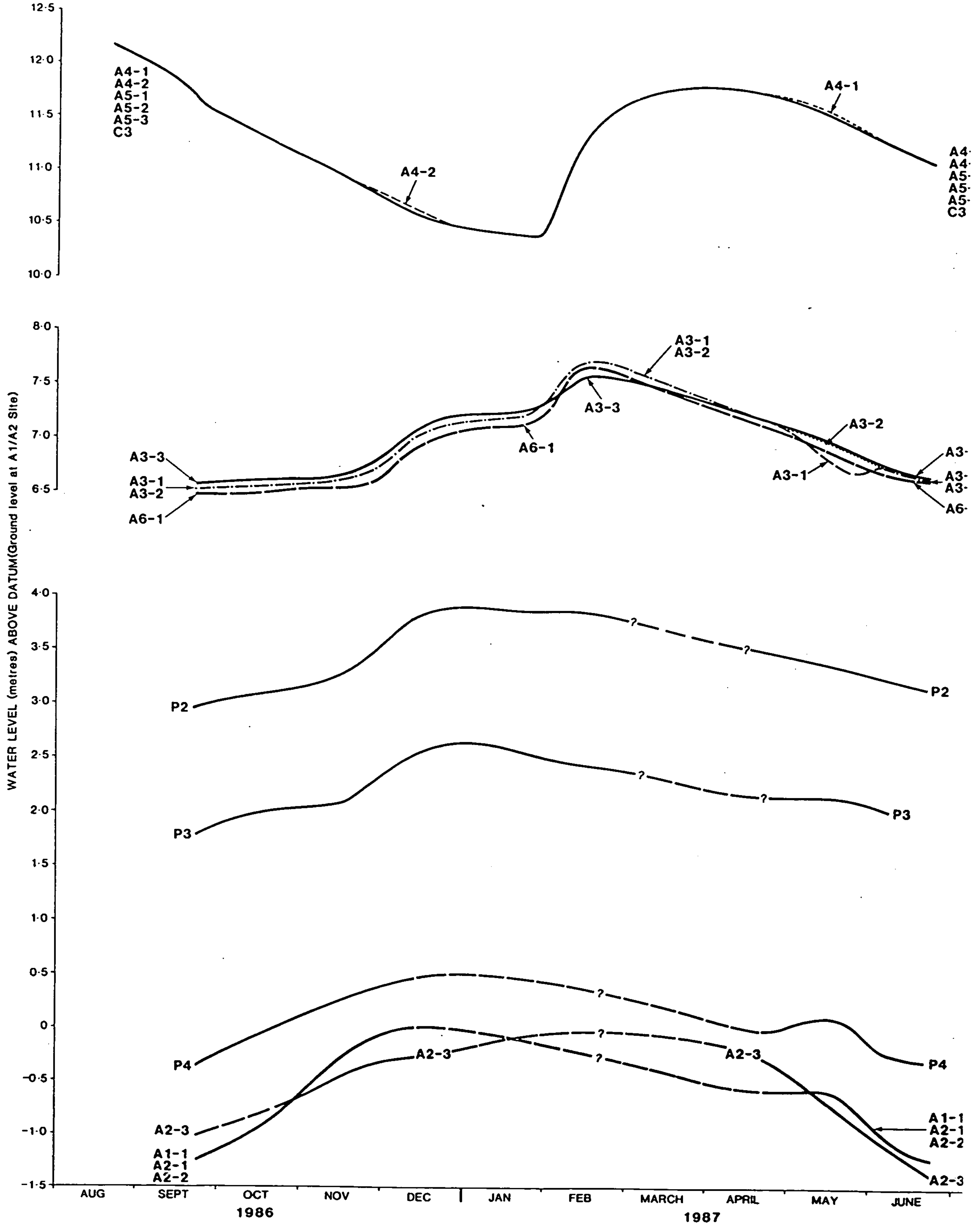
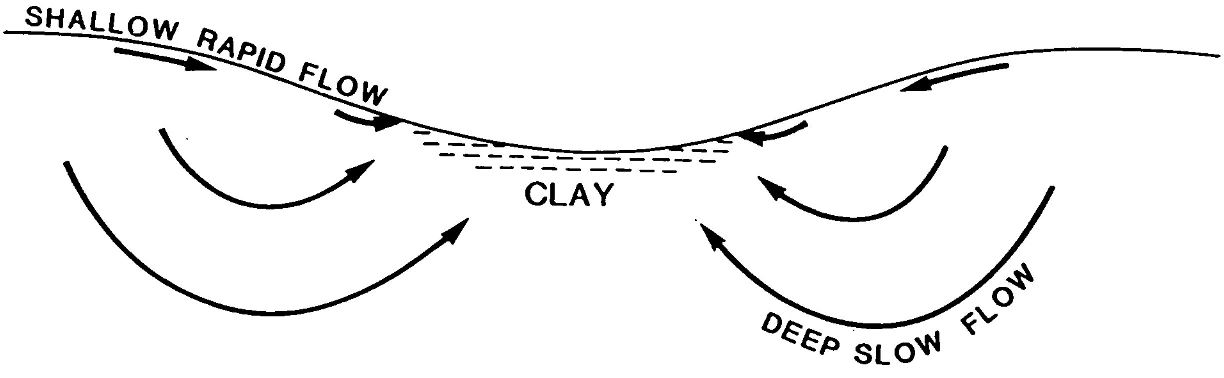
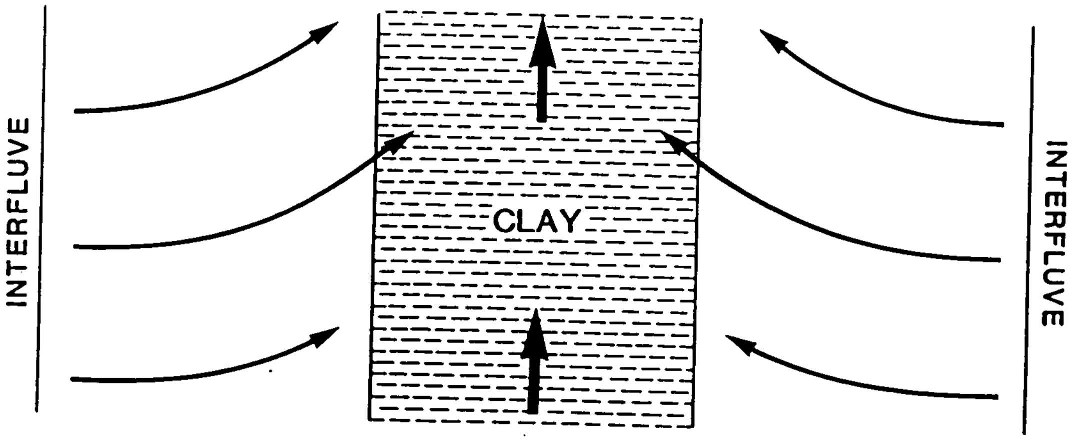


Figure 6. Water level variations in Chimimbe piezometers.



a) Cross-section



b) Plan

Figure 7. Conceptual model of groundwater flows at Chimimbe Dambo.

TABLE 1. PIEZOMETER TEST DATA

i) Chimimbe piezometers

Piezometer	Test Zone Depth (m)	Hydraulic conductivity (m/day)	Lithology
A1-1	16.00-17.07	0.2	Hard gneiss
A2-1	5.86-7.50	0.1	Saprock
A2-2	3.00-3.74	0.1	Saprolite
A2-3	1.35-2.00	$2x10^{-5}$	Clay
A3-1	9.00-9.90	0.2	Saprolite
A3-2	5.45-6.65	$5x10^{-2}$	Saprolite
A3-3	2.10-3.60	2.0	Sandy clay
A4-1	15.80-17.10	0.7	Saprock(brecciated)
A4-2	10.48-13.70	0.3	Saprolite/saprock
A5-1	14.50-15.10	0.4	Saprock
A5-2	7.95-9.00	0.1	Saprolite
A5-3	3.80-4.70	$5x10^{-3}$	Colluvium
A6-1	24.80-26.00	0.1	Hard gneiss
Pr2	1.20-2.25	6.1	Sand/sandy clay
Pr4	1.80-2.60	0.2	Sandy clay
Pr5	1.03-1.24	$1x10^{-2}$	Clay
Pr7	1.18-1.98	$6x10^{-3}$	Clay
pr14-1	7.18-8.20	$c4x10^{-2}$	Colluvium
Pr14-2	4.02-5.06	$9x10^{-3}$	Colluvium
Pr15-1	5.30-6.94	$3x10^{-2}$	Colluvium
Pr15-2	3.00-3.75	$8x10^{-3}$	Colluvium
Pr16	0.76-1.05	1.5	Sand
Pr19	2.00-3.11	$2x10^{-2}$	Clay
Pr20	0.40-1.00	3.3	Sand
Pr21	0.38-0.94	5.6	Sand
Pr23	1.17-2.20	$1x10^{-4}$	Clay

ii) Chikobwe piezometers

Piezometer	Test Zone Depth (m)	Hydraulic conductivity (m/day)	Lithology
A11-1	3.05-5.00	$4x10^{-2}$	Saprock
A11-2	8.85-10.50	$3x10^{-2}$	Saprolite
A11-3	14.13-15.22	$5x10^{-2}$	Clay

TABLE 2. WATER LEVEL DATA - CHIMIMBE PIEZOMETERS

Levels are given above ground level at the A1/A2 site (Chimimbe Dambo centre), i.e. a negative sign indicates a level below the A1/A2 datum.

PIEZOMETER	TEST ZONE DEPTH (m BGL)**	PIEZO DATUM LEVEL (m)	Water levels (metres above datum)													
			22/09/86	24/09/86	22/10/86	19/11/86	11/12/86	23/01/87	13/02/87	22/04/87	20/05/87	03/06/87	21/06/87	23/03/88	29/03/88	
A2-3	1.35-2.00	0.00	-1.035	-1.650	-0.760	-0.422	-0.288	*	*	-0.281	-0.742	-1.010	-1.343	*	*	Dambo centre
A2-2	3.00-3.74	0.00	-1.253	-1.288	-0.825	-0.213	-0.002	*	*	-0.595	-0.650	-0.987	-1.230	*	*	
A2-1	5.86-7.50	0.00	-1.252	-1.290	-0.824	-0.210	-0.022	*	*	-0.580	-0.645	-0.985	-1.225	*	*	
A1-1	16.00-17.07	0.00	-1.250	-1.277	-0.822	-0.225	-0.020	*	*	-0.565	-0.632	-0.974	-1.215	*	*	
A3-3	2.10-3.60	8.17	6.576	7.084	6.625	6.690	7.101	7.278	7.575	7.210	6.940	6.819	6.690	7.643	7.605	Dambo periphery
A3-2	5.45-6.65	8.17	6.530	6.505	6.542	6.640	7.033	7.243	7.728	7.195	6.940	6.791	6.653	7.705	7.665	
A3-1	9.00-9.90	8.17	6.525	6.504	6.595	6.642	7.022	7.228	7.723	7.195	6.750	6.787	6.648	7.703	7.663	
A6-1	24.80-26.00	8.14	6.465	6.455	6.524	6.557	6.919	7.135	7.672	7.140	6.875	6.723	6.588	7.630	7.601	
A5-3	3.80-4.70	16.90	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	Interfluve
A5-2	7.95-9.00	16.90	11.590	11.487	11.193	10.852	10.562	10.387	11.307	11.730	11.477	11.272	11.085	*	10.967	
A4-2	10.48-13.70	16.81	11.608	11.274	11.203	10.878	10.647	10.385	11.348	11.715	11.455	11.288	11.108	*	*	
A5-1	14.50-15.10	16.90	11.584	10.952	11.226	10.854	10.641	10.390	11.306	11.719	11.482	11.274	11.087	*	10.968	
A4-1	15.80-17.10	16.81	11.592	11.440	11.228	10.888	10.622	10.399	11.340	11.720	11.492	11.282	11.093	*	*	
Pr2	1.20-2.25	3.79	2.960	2.932	3.124	3.323	3.782	3.852	3.855	3.500	3.358	3.270	3.158	*	3.815	
Pr3	0.10-0.60	2.52	1.780	DRY	2.003	2.125	2.510	2.535	2.460	2.165	2.150	DRY	DRY	*	2.383	
Pr4	1.80-2.60	0.37	-0.360	1.985	0.004	0.280	0.458	*	*	-0.037	0.070	-0.202	-0.305	*	0.425	

** Metres below local ground level.

TABLE 3. WATER LEVEL DATA FOR PIEZOMETERS AND WELLS AT CHIKOBWE

i) PIEZOMETER WATER LEVELS

WATER LEVELS BELOW GROUND LEVEL (metres)

PIEZOMETER	TEST ZONE DEPTH (m BGL)	30/09/86	23/10/86	18/11/86	10/12/86	11/01/87	12/02/87	21/04/87	21/05/87
A11-3	3.05-5.00	0.520	0.630	0.537	0.503	0.257	0.046	-0.280	0.115
A11-2	8.85-10.50	0.525	0.580	0.518	0.515	0.176	0.030	-0.396	0.110
A11-1	14.13-15.22	0.490	0.570	0.505	0.500	0.210	0.066	-0.260	0.075

ii) BOREHOLES

DAMBO CENTRE
BOREHOLE

WATER LEVELS BELOW CASING TOP (metres)

30/09/86	23/10/86	18/11/86	10/12/86	11/01/87	12/02/87	21/04/87
0.965	0.980	0.936	0.880	0.573	0.276	0.150

BOREHOLE DW67
(INTERFLUVE)

WATER LEVELS BELOW CHART RECORDER DATUM (c1 metre above ground level)

14/07/86	14/08/86	12/09/86	29/09/86	23/10/86	18/11/86	10/12/86	22/01/87	12/02/87	19/03/87	21/04/87	19/05/87
10.880	10.910	10.963	11.100	11.118	11.188	11.230	11.208	11.187	c11.12	c11.03	c11.00