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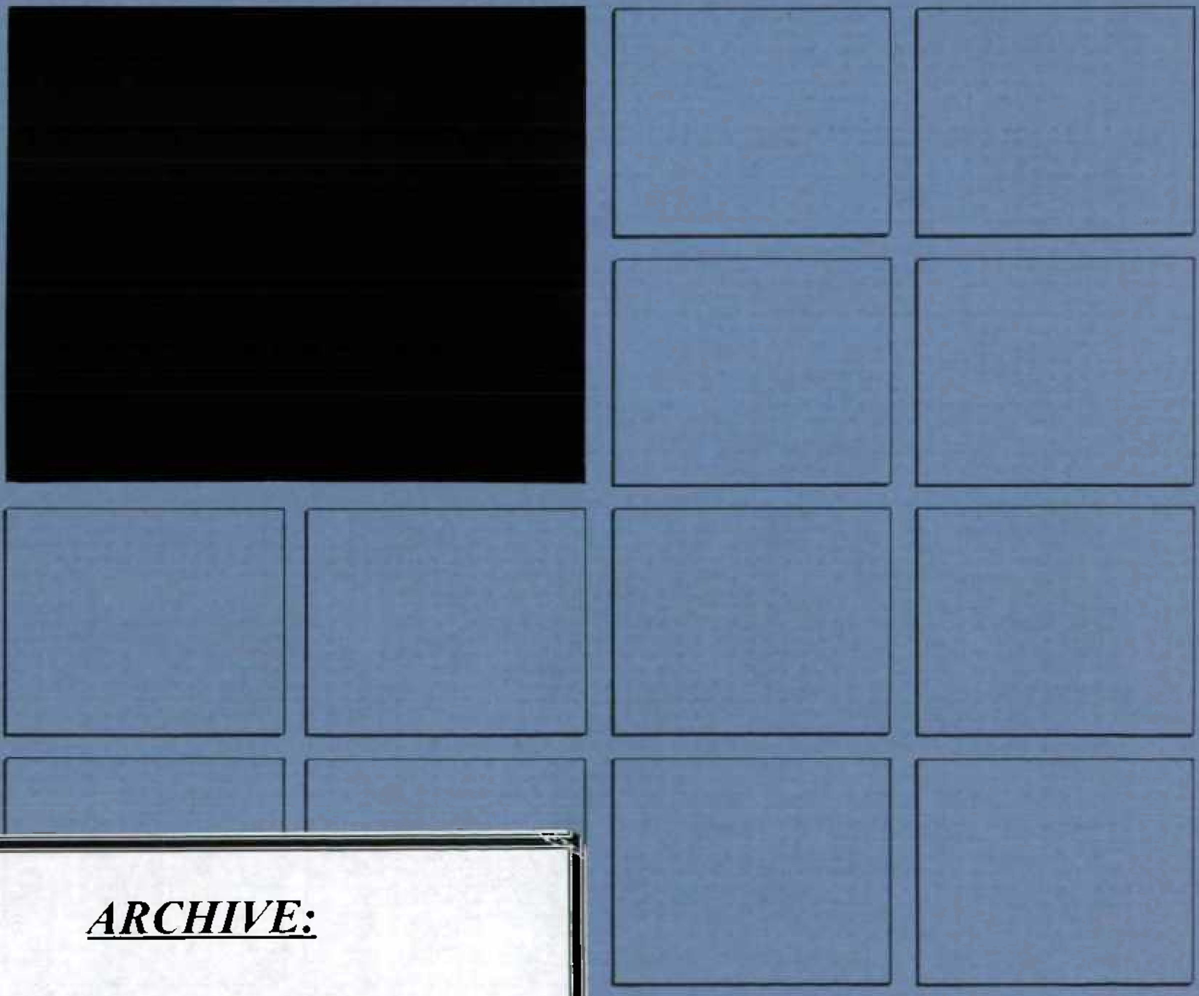

DRAFT

Deep Dean Soil
Water Study

Contents

DRAFT : IN CONFIDENCE

FINAL REPORT: CONTRACT NO. R255RX

SOIL MOISTURE STUDIES CONDUCTED BY THE INSTITUTE OF HYDROLOGY FOR WRC AT DEEP DEAN, EASTBOURNE, 1980-81.

Objectives

The objectives of the study were:

(i) To study the seasonal variation of soil water content and potential in the upper 3 m of the soil beneath a grassed control plot.

(ii) To derive the unsaturated drainage rates throughout the annual cycle and gain an understanding of the mechanisms controlling the drainage.

The contract was for a 12 month period, commencing on 1 September, 1980.

Approach

Soil moisture content was monitored (by neutron probe) at regular intervals to a depth of 3.7 m and soil moisture potential (using tensiometers) to a depth of 3.0 m for the period from September 1980 to September 1981. Daily mean drainage fluxes for weekly periods at different depths in the soil profile were calculated by the water balance method and, when a zero flux plane (ZFP) was present for a long enough period, by the ZFP method.

Approximate soil hydraulic conductivity characteristics were derived by means of Darcy's Law from the measured soil moisture potential and calculated drainage flux data; moisture release characteristics were also derived from the moisture content and potential data.

Pressure transducer tensiometers connected to a solid state logger were installed to monitor moisture potential hourly, to investigate the transient responses of the profile to individual rainfall events.

Instrumentation

Two sets of mercury manometer tensiometers (sets 1 and 2) and two neutron probe access tubes were installed adjacent to the WRC unfertilised grass control plot (Fig 1) in mid August 1980. Each tensiometer set consisted of

12 tensiometers, installed at 20 cm intervals from 20 cm to 120 cm below the soil surface and then at 30 cm intervals to a maximum depth of 3.0 metres. The access tubes were also installed to a depth of 3 m.

Examination of the soil moisture potential data collected in the latter part of August 1980 showed matric potentials very close to saturation at a depth of 3 m, and downward extrapolation of the potential profiles implied the possible existence of a saturated zone below a depth of about 3.5 m. In view of this, the two access tubes were replaced by 3.7 m tubes in September, and four additional tensiometers were installed at depths of 3.5, 4.0, 4.5 and 5.0 m as part of Set 2. In order to assess the possible lateral extent of the hypothetical saturated zone, two further sets of tensiometers were installed in late September, one (Set 3) about 20 m east of Sets 1 and 2 and the other (Set 4) about 20 m north (Fig 1). Tensiometer depths were the same as in Set 1. A 3.7 m access tube was installed adjacent to each of these additional tensiometer sets in mid November. Analysis of subsequent data and examination of the profile to 4.4 m in a specially dug pit revealed that a saturated zone could not normally exist at that depth, the near saturated conditions resulting from the rather unusual physical characteristics of the material below 2 m. The data from the additonal tensiometer sets and neutron probe access tubes are therefore not discussed further in this report.

Observations of soil moisture content and potential were made weekly until 26 June 1981 and subsequently at fortnightly intervals until 4 September 1981.

A tipping bucket raingauge (0.5 mm per tip) with a solid state memory was installed at the site at the end of January 1981 when it became clear that the WRC automatic weather station raingauge was not functioning correctly.

During April 1981 the mercury manometer tensiometers at 40, 80, 100, 120, 150, 180, 240 and 300 cm of Set 2 were replaced with pressure transducer tensiometers ("PTTs") connected to a solid state logger. Potentials were logged hourly at first and later two hourly.

An IH automatic weather station was installed adjacent to Plot 1 in mid-June 1981.

Methods of calculating drainage fluxes

1 The water balance method

This method was used calculating drainage during periods when there was no stable zero flux plane, ie autumn, winter and early spring.

The water balance of a soil profile for an appropriate period of time may be expressed as

$$D = R - Ea - \Delta S_z - Q \qquad (1)$$

where D_z is the drainage below a depth Z in the profile, R is the rainfall, Ea is the actual evaporation, ΔS_z is the change of soil moisture storage above Z, and Q is the runoff. In this study all of the components of the balance are expressed as an equivalent depth of water in millimeters. At Deep Dean there is no surface runoff and the components R, Ea and ΔS_1 can be measured or estimated to derive D_z. The determination of each component will be considered separately.

Rainfall

The rainfall data from the Rimco gauge at the site were used for the water balance from January 1981 until the end of the study. Before January there was no functioning raingauge at Deep Dean and the rainfall had to be estimated from the data from the Meteorological Office gauge at Litlington, 1.3 Km distant. A regression of weekly rainfall catch at Litlington (Lit) on the weekly catch at Deep Dean (DD) for the 3 months February to April 1981 give the relationship DD = 1.104 Lit + 0.21 ($r = 0.997$) and this was used to estimate the rainfall at the site for the period September 1980 to January 1981.

Evaporation

Evaporation from grass is expected to occur at the potential rate when soil moisture deficits are small. For the winter and early spring period therefore, it was intended to use Penman potential evaporation (E_t), calculated from the WRC automatic weather station data. However the station was not functioning for much of the winter and the data was otherwise intermittent or incomplete, so that an alternative source of evaporation data had to be found, and potential evaporation from the appropriate MORECS grid square was used. However, this may represent an overestimate of the potential evaporation from this fairly sheltered site, resulting in a small systematic underestimation of the drainage fluxes for this winter period.

As soil moisture deficits increase in late May and June, actual evaporation may start to fall below potential and the use of the latter in the water balance would not be valid. At this time, however, a zero flux plane (ZFP) begins to appear in the profile and the drainage fluxes can then be calculated directly by the ZFP method. (see below).

Moisture storage

The mean moisture content profiles of access tubes 1 and 2 was used to represent soil moisture storage.

Runoff

Runoff does not occur at Deep Dean and this component was ignored.

b) The Zero Flux Plane (ZFP) Method

This method was used for the late spring and summer periods when a stable zero flux plane could be identified in the soil profile.

Throughout the winter the potential gradient in the profile (measured by the tensiometers) is downward, fluctuating within the shaded area in Fig 7, indicating continuous but varying drainage. However, as evaporation increases in the spring, the matric potential in the upper layer decreases as moisture is abstracted, so that an upward gradient of total potential (indicating upward flux) is created (Fig 7 profile 1). After a few false starts (the newly created upward potential gradient is readily reversed by small amounts of rainfall), this zone of upward flux increases steadily in depth as the summer progresses and the vegetation exploits an ever increasing depth of soil moisture store. Thus, in the upper part of the profile the potential gradient is upwards, while in the lower part it is still downwards. The division between these two zones is marked by the point where the potential gradient is zero; no soil water flow crosses this plane, known as the "divergent zero flux plane". This is shown in the late spring profiles in Figure 7, and the progress of the ZFP down the profile is clearly shown.

Knowledge of the zero flux plane depth can be exploited to calculate water fluxes at any point on the profile; in this case only the drainage at the base of the measured profile is relevant. The calculation of this drainage is simple because it is represented by the water loss (measured by neutron probe) from that part of the profile beneath the ZFP. The calculation of drainage by this method is independent of rainfall and evaporation and its accuracy is therefore dependent only on the neutron probe which, properly used, is capable of very high precision. The drainage rates calculated by this method are therefore expected to be more accurate than those produced by the water balance method.

Calculation of hydraulic conductivities

Hydraulic conductivities were calculated from the drainage fluxes (derived as above) and the measured gradients of total potential using Darcy's law:-

$$Q = k \frac{d\Psi}{dz} \qquad (2)$$

where Q = the moisture flux

K = hydraulic conductivity

Ψ = total potential

z = depth

The calculation of hydraulic conductivities from the water balance (WB) drainage flux data is a somewhat crude approach and the results are inevitably approximate. The WB flux data represent the mean flux for the period between neutron observations (usually a week) during which considerable variations of flux may have occurred (see Fig 2). They therefore give no indication of the distribution of the flux within that time period. Furthermore, the potential gradients respond sensitively to change in moisture flux and errors arise because the mean potential gradient for the period (calculated from weekly observations) may not correspond with the mean flux. This is particularly serious when the mean flux increases abruptly (e.g. Fig.2:10 October 1980 and 27 February 1981): such data have been omitted from hydraulic conductivity calculations.

The hydraulic conductivities calculated from drainage rates derived by the ZFP method are much more reliable, although restricted to the drier end of the seasonal conductivity range. The ZFP derived fluxes, like those derived from the water balance, also represent the mean flux for a period of a week or a fortnight, but a period in which the flux is declining continuously (Fig 2:

5 June onwards). The mean potential gradient therefore corresponds closely with the mean flux.

In spite of the approximate nature of the conductivity data derived from the WB drainage fluxes the data sets produced by the two methods agree extremely well, with little discontinuity.

Profile description

The Coombe Deposit at this site consists essentially of cobbles of chalk infilling what was probably an original vee-shaped valley. These cobbles are sub-angular and partially rounded, fairly equidimensional, and typically about 10 cm in size. This material was seen in a specially dug pit in something like its original condition, the cobbles of chalk having open voids between them and being coated in chalk sludge and secondary crystalline $CaCo_3$ "fluff"; this occurred in the depth range 2.65-4.4(+)m. Such an open void structure is unusual from the soil physical point of view, presenting an extreme form of a bipore flow system. Inspection suggested that two water flow mechanisms might occur: intermittent and rapid, thin film flow on the surfaces of the cobbles above some critical value of matric potential, and a continuous, very slow flow through the matrix of the chalk and the sludge coatings. The conductivity of this material at high potentials would be expected to be very great indeed, the only adjustment necessary to accommodate a wide range of flows being the thickness of the water films, the voids remaining empty under normal conditions.

At about 2.65 m there is a transition into the zone above, where the cobbles are similar but in which there is some infilling with loamy material. However, some open voids remain.

At about 2.0 m there is another upward transition into similar cobbles but with no visible voids remaining unfilled. There are a few decayed roots in this zone.

At 1.2 m there is a well defined interface, the profile above consisting of conventional A and B soil horizons.

The soil at the top is brown-black silty loam grading down through pale red-brown to red-brown. Roots are present throughout, although concentrated in the top 30 cm. Small stones are common in the middle of this sequence, and open pores and root channels are visible. The structure is medium-fine, subangular, blocky.

The sward consists of natural, uncropped grass and wild plants.

It is probable that the thickness of the various soil layers is laterally quite variable, because the valley is very narrow and deposition of colluvial material is related to position on the slope of the valley sides and to the slope profile. There was some evidence for this from sets of tensiometers installed up-valley and across-valley from the measurement site. However, the general principles of the flow mechanisms determined at the measurement site may be assumed to apply to the WRC experimental plots, which are aligned along the valley in the same slope contour as the IH site.

RESULTS

Drainage Fluxes at 2.85 m

Mean daily drainage fluxes calculated for the base of the measured profile at 2.85 m are shown in Fig 2, together with daily rainfall data. As only weekly moisture content data were available it was not possible to calculate fluxes for individual days. Clearly therefore, there must at times have been much higher transient rates of drainage which could not be resolved, and this is discussed later. Prior to 5 June 1981 the fluxes were calculated from the water balance. These data should be regarded as estimates only due to the assumptions inherent in the method, ie that:-

the rainfall predicted for the site from the Litlington data represented the rainfall at the actual site (prior to 30 January 1981, when the IH raingauge at the site became operative).

ii) the MORECS potential evaporation used in the water balance was substantially correct for the Deep Dean site. This may not be so because the site is very sheltered and in winter may be a frost hollow. Evaporation might therefore be expected to be suppressed, causing a small under-estimate of drainage.

iii) actual evaporation was the same as potential evaporation in the "winter" period.

Thus, there must be an element of 'noise' on the drainage histogram, probably equivalent to about 0.5 mm/day on the weekly mean values, and possibly also a bias towards a slight underestimate.

The date calculated by the zero flux plane (ZFP) method from June onwards are much more reliable, limited only by the accuracy of the neutron probe readings, equivalent to an error on the mean daily drainage rate of about 0.2 mm.

Several points of interest emerge from figure 2.

i) At a depth of 2.85 m there was continuous drainage throughout the study although this fell below 0.1 mm/day after the end of July 1981; the previous summer was wetter and the mean drainage rate during September did not fall below 0.25 mm/day.

ii) Weekly mean rates of up to almost 4 mm/day occurred following periods of heavy rainfall in the winter and short term rates within these periods were probably much higher than 4 mm/day.

iii) The average drainage rate throughout the winter period (October - May incl) was about 1.6 mm/day.

iv) Excluding the October data when the profile was still rewetting, there appears to be up to 4 or 5 days time lag between rainfall and a response in the drainage rate at 2.85 m.

v) Once a ZFP was established the drainage at 2.85 m declined smoothly from about 1 mm/day in early June to less than 0.1 mm day by August.

vi) Summer storms were not sufficient in 1981 to overcome the storage deficit above the ZFP to create renewed through-drainage.

Unsaturated hydraulic conductivity

For various technical reasons, and because of the limited scope of the project, it was not possible to determine the unsaturated hydraulic conductivity characteristics by the usual methods. A somewhat crude method was used and although this was successful for the lower profile, it was not possible to determine the charactistics for the upper profile with any confidence. Data are therefore presented only for the zone between 1.5 m and 3.0 m. This is the chalky rubble observed in the pit section below 1.2 m. The pit was located about 100 m down the valley from the measured profiles and hence there may be differences, particularly in the thicknesses of the different layers, but the general picture is probably well represented by the pit section (Table 1).

As described earlier the unsaturated hydraulic conductivity characteristics for a range of depths were determined at Deep Dean by a combination of two methods; the water balance method and the zero flux plane method. The curves are presented in figures 3 and 4, the first showing conductivity as a function of matric potential, the second as a function of water content.

Unsaturated hydraulic conductivity is a function of the volumetric water content, θ, of porous material and hence, indirectly, of the matric potential (tension), Ψ_m. As the water content of a soil decreases, the matric potential falls and successively smaller water-filled pores becomes empty and cease to contribute to the conductive pathway. Conductivity therefore decreases rapidly, depending on the pore size distribution and geometry. Thus, the form of the curve provides information about the volume of the pores that are conducting water under any specific range of water content or potential. These curves are therefore particularly useful in interpreting the importance of macropore or fissure flow in a given soil under a given soil moisture/ rainfall regime, and for estimating the velocity of individual molecules of water or solutes (the molecular velocity): see 8 below.

The following features of these curves are significant:

i) There is a remarkably smooth transition between the sets of data points derived by the two methods although there is a greater scatter in the WB flux derived set. This tends to support the validity of the water balance calculations and hence the validity of the estimates of winter fluxes seen in Fig. 2.

ii) The curves form an ordered sequence, being of the same general shape but being displaced progressively with depth towards lower conductivity for any selected value of water content or potential.

iii) The K-Ψ curves (Fig 3) tend to become nearly parallel with the K axis at high potentials (this is best seen in the case of the lowest two depths, but probably applies to all depths below 1.5 m). This shows that as the soil becomes wetter there is a rapid increase in conductivity, and this is accompanied by only a very small increase in matric potential.

iv) The K-θ curves (Fig 4) show that the changes in water content over the range of conductivity determined are also very small, particularly towards the wet end of the range. For example, at 2.85 m, the lowest depth for which K was calculated, a volumetric moisture change of about 0.0015 volume fraction (0.15% V/V) accompanies a change in conductivity from 1 to 5 mm/day, Fig. 4) and the equivalent change in potential is only 4 cm water head (Fig 3).

These data show that for the lower 1.5 to 3.0 m, in the winter period when the profile is draining throughout the matric potentials are close to zero, only very small changes of water storage and potential are necessary to permit the drainage rate to increase from a background rate of (say) 1 mm/day to at least 5 mm/day, and probably very much higher. Thus, we would expect that in winter conditions very short term and rapid pulses of drainage would pass through the lower profile following each rainfall event; this is supported by the pressure transducer tensiometer data discussed later.

Molecular velocities

In a soil, the molecular velocity associated with a given moisture flux must always be higher than that flux, which is defined as the volume of water per unit time passing through unit cross sectional area of the soil. However, the water flow in a soil restricted to those pores which are filled with water so that the average molecular velocity of the water is the flux divided by the proportion of unit area of the soil occupied by water filled pores (which is the same as the volumetric moisture content).

The average molecular velocity (V) of the water is therefore given by the expression

$$V = {}^{Q}/_{\theta}$$

where Q = flux
θ = volumetric moisture content

If the K-θ and K-Ψ relationships are known, a given increase in conductivity (and therefore flux, if the potential gradient is known) can be attributed to a specific increase in moisture content (ie an increase in the cross section area of the conductive pathway).

Taking the example in (iv) above at the 2.85 m depth, the conductivity increases from 1 to 5 mm/day when the matric potential increases from -10 to -6 cm water head. This corresponds to an increase in moisture content of 0.0015 MVF (0.15%). Assuming a potential gradient of unity, the flux change associated with this moisture content change is 4 mm/day and this flux must be transmitted through the 0.15% of the total soil cross sectional area indicated by the moisture content increase. Using equation (3) this implies a molecular velocity of $\frac{4}{0.0015}$ = 2700 mm/day through this increment of cross-sectional area or about 2150 mm/day at a gradient of 0.8, the lowest likely under those conditions.

Similar calculations for depths above this show that the molecular velocities decrease progressively upwards for the same change in conductivity (assuming a potential gradient of 1.0) so that at 1.65 m the molecular velocity would be about 290 mm/day.

These are only rough estimates but the implication is clear that with heavy rainfall during winter a water molecule or solute molecule can easily be transmitted through the lower metre of the profile within a day and probably from 1.5 to 3.0 m within 2 days.

Water Release Curves

Moisture content and potential data measured in situ during a continuous drying cycle (between 4 June and 4 September) were used to derive Figure 5. The moisture content data used were smoothed in time series form for this purpose to reduce scatter. The principal point of interest is the decreasing gradient of the curves (specific detention) with depth.

10 Moisture Content Profiles

In the interests of brevity only the wettest and the driest of the observed profiles are presented (Fig 8). These define an envelope within which the profile varied throughout the year. The difference between these two profiles is plotted on the left of the figure. The range of seasonal variation decreases fairly steadily down the profile, with no suggestion of any abrupt discontinuities, which would be expected if there were well defined layers in the profile with different and distinct hydraulic properties. The picture is one of transition down the profile, as is also suggested by the suites of conductivity characteristics (Figs 3 and 4), the water retention curves (Fig 5), and the potential profiles (Fig 6).

1 Potential Profiles

The range of potential profiles which occurred during the project is shown in Fig 6. From 28 May onwards all the observed profiles are shown; winter profiles are not shown as these are constantly fluctuating in response to rainfall inputs. The narrow range of fluctuation is indicated by the stippled area in Fig 6. Transient zero flux planes (also not shown, for simplicity) appeared in the top 40 cm during April-May. The position of the zero flux plane (ZFP) (where present) is indicated in the figure by the letter 'Z'. The first appearance of a stable ZFP was on 28 May at 40 cm and it then moved progressively down the profile to a depth of 2.1 m by 21 August, after which there was very little further downward movement (Fig 7). A wetting front caused by the rainfall between 19 and 26 June produced a convergent ZFP seen in the profile of 26 June, but this did not penetrate deeper than 40 cm or persist beyond a few days.

The main points to note from these data therefore are:

i) During the winter of 1980/81 matric potentials had the least range of variation at the base of the profile, the range at 3.0 m being from -2 to -9 cm water head. Note that this range corresponds to the very steep section of the K-ψ curve (Fig 3) so that these very small changes in matric potential accompany changes in the conductivity between 1 mm and 5 mm/day or more.

ii) During winter the mean potential gradient of the entire profile varied between 0.9 and 0.7.

iii) During summer (ie after late May) there was always a zero flux plane, which became stable at a depth of 2.1 m by August.

iv) No summer rainfall inputs bypassed the zero flux plane to create short term through drainage and thus to boost the declining drainage rate at the base of the profile, this was confirmed by the pressure transducer tensiometer data.

v) There are no obvious discontinuities in the profiles such as would be expected if the profile were composed of layers of markedly different conductive properties.

vi) During the first half of June the ZFP was within the zone occupied by roots and hence some uptake from below the ZFP could have occurred, causing a slight overestimate of drainage during this brief period.

) Pressure Transducer Tensiometers

Weekly or fortnightly manual tensiometer readings give little indication of the short-term response of the profile to individual rainfall events. The pressure transducer tensiometers were installed to investigate these responses and 'fill the gaps' between the manual tensiometer readings. The instruments were installed on 14 April 1981 and were logged hourly until 26 June when the logging interval was extended to 2 hours. Data will be collected until the end of 1981 but this report only covers the period until 1 September.

The date produced were of high quality and no failures occurred. The data agree well with the manual tensiometer data and the minor differences which occur are probably ascribable to small lateral differences in potential between the two sets of instruments which are about 1.5 m apart.

Fig 9 shows the total potential data from the PTTs in time series form from 14 April until the end of July. It is unfortunate that it was not possible to install the instruments until the Spring, since most of the main drainage events occur in the winter. However two small drainage events occurred, starting on 28 April to 10 May respectively, followed by a much larger event caused by a week of heavy rainfall in the week preceding 23 May. The total drainage between 22 and 29 May was about 17 mm (from the water balance) and it is clear from Fig 2 that larger events must have occurred in the winter. The behaviour of the profile during larger events will be similar however, although lower potentials, implying larger fluxes, are likely to have occurred briefly.

The principal features of Fig 9 relevant to this report are as follows:

i) The curves are fairly regularly spaced, reflecting the fact that the potential gradient is generally uniform throughout the profile, except when drainage pulses (corresponding to the peaks) are passing down the profile.

ii) Similar general trends of variation are present in all depths but the amplitude of the variation becomes progressively damped with depth.

iii) Potentials at 0.4 m increase within a few hours following rainfall events as small as about 5 mm/12 hours.

iv) The peaks in the time series curves for each depth show the highest potentials reached in individual events (ie the wettest and therefore most conductive conditions) and indicate the time at which the downward drainage flux must have been at a maximum. The time interval between peaks at successive depths therefore gives an approximate indication of the speed at which the drainage pulses move down the profile.

The time taken for the pulses to traverse the profile between 0.4 and 3.0 m depends on the size of the event and also on the antecedent conditons: for example, the pulse created by the rainfall preceding 28 April took approximately 9 days but the larger pulse in late May (in fact, an amalgamation of several smaller ones) took less than 6 days. The 'velocity' of the pulse appeared to be least between 1.2 and 2.4 m. Between 2.4 and 3.0 m there appeared to be virtually no delay and this confirms the high flow velocities indicated from analysis of the conductivity characteristics.

v.) The data suggest that, because the potentials change rapidly throughout the profile, the drainage fluxes also change quickly. Thus the weekly mean drainage fluxes calculated from the water balance fail to indicate the short term maximum drainage fluxes which may be very high indeed because the conductivities in the lower profile can vary extremely with small changes in water content and potential.

3. Conclusions

The constraints imposed by the severely limited funding available for this project inevitably led to cruder and less quantitative results than would have emerged in ideal circumstances. Nevertheless, considerable knowledge has been gained about the physical processes of drainage at this site, which is important to the interpretation of the movement of water and solutes through the upper 3 m of profile. In particular, the use of the water balance technique to derive weekly mean drainage fluxes and conductivity data has been very successful and such a simple technique could well have wider applications. If data had been available more frequently than weekly, better temporal resolution of the fluxes would have been possible and this would have yielded more accurate conductivity characteristics.

It should be emphasised that the experiment is sited in a deep, shaded valley floor on Coombe deposit which occupies only a narrow strip along the valley bottom. Although the techniques and concepts are applicable almost anywhere, the results gained apply specifically to this site and should not be extrapolated more widely.

The following broad picture of the hydraulic behaviour of this site has emerged.

There was continuous drainage throughout the year at 3 m, with a mean rate of 1.6 mm/day throughout the period of drainage following rewetting of the profile in Autumn 1980, until a zero flux plane appeared in late May 1981; thereafter drainage decreased smoothly to virtually zero by the end of August.

During the former stage the profile responded very rapidly to each rainfall event, weekly mean drainage rates of up to 4 mm/day being observed.

There is considerable evidence that these weekly means included short term flux rates of much greater magnitude, probably over 20 mm/day for short periods; these could not be resolved due to the infrequency of the data observations.

In this rather unusual material, short term rapid increases in flux (pulses) are accompanied by only minute changes in water content. Most of the water comprising these pulses is conducted by a very small fraction of the total pore volume, and hence the actual velocity of movement of any hypothetical molecule of either water or solute is much greater than the flux. While such pulse events are taking place, molecular velocities of 2 or 3 m per day may be attained in the lower part of the profile, below about 2.5 m.

Velocities for the middle part of the profile are less but not insignificant, up to 0.5 m/day being quite feasible. Velocities in the upper profile appear to be higher than the middle profile but could not be estimated.

While the pulses of rapid drainage are intermittent, slow continuous fluxes occur with the smaller pore pathways with a daily rate of 0.5 - 1.0 mm per day, with associated molecular velocities of not more than about 1.5 - 3 mm/day, and probably less.

The extent to which nitrate solutes are carried by these two semi-distinct flow processes, and the degree to which exchange occurs between them is a matter for speculation.

It is evident that following heavy winter rainfall there is scope for much solute to be transported within days right through the Coombe Deposit. Such solute would be lost from any mass balance calculation and would not be recovered in core sample extracts. The validity of attempting to correlate nitrate profiles taken by core sampling at six month intervals should also be examined, in view of the rapidity of the mass flow processes revealed to occur at this site.

TABLE 1: Deep Dean Soil Profile in Coombe Floor Deposits: 11 November 1980

Coarse grass sward

0.30 cm	A moist, brown black silty loam with a few small fragments of chalk. Many fine fibrous roots. 0.10 cm crumb structure. 10-30 cm moderate fine, subangular blocky structure.
30-86 cm	Merging boundary distinguished by increase in quantity of chalk fragments. Pale red brown with gritty texture Stones common; 0-0.5 cm in size a few up to 3 cm. Moderate fine, subangular blocky structure. Roots quite common. Visible pores common.
86-120 cm	Indistinct boundary to medium red brown horizon similar, but for colour, to horizon above.
120 cm	Distinct Interface
120-200 cm	Subangular fragments of chalk of up to 8 cm long axis in soft matrix. Matrix loamy texture with moderate fine subangular blocky structure. Few roots and very few large (ie visible) pores.
200-265 cm	Subangular cobbles of chalk up to 15 cm long axis with some interstitial material as described in 120 - 200 cm layer. Also voids of up to 2 cm diameter between fragments. Fluffy deposits of $CaCo_3$ on faces of chalk. Very occasional roots.
265-440 (+) cm	Subangular pieces of blocky chalk up to 30 cm long axis with little interstitial material. $CaCo_3$ fluffy deposit on chalk surface very prevalent.
440 cm	Base of pit

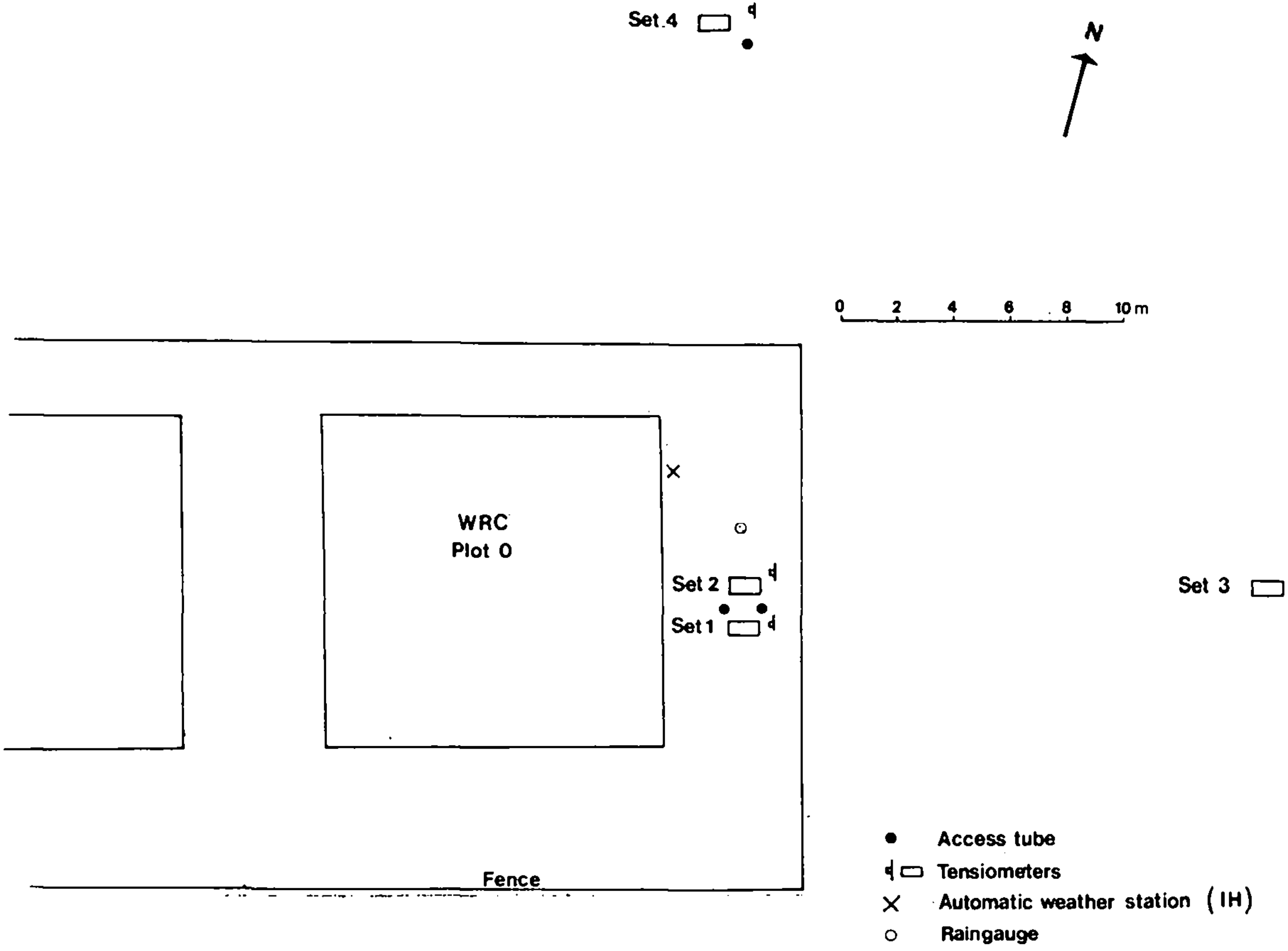

Fig 1 Site Plan

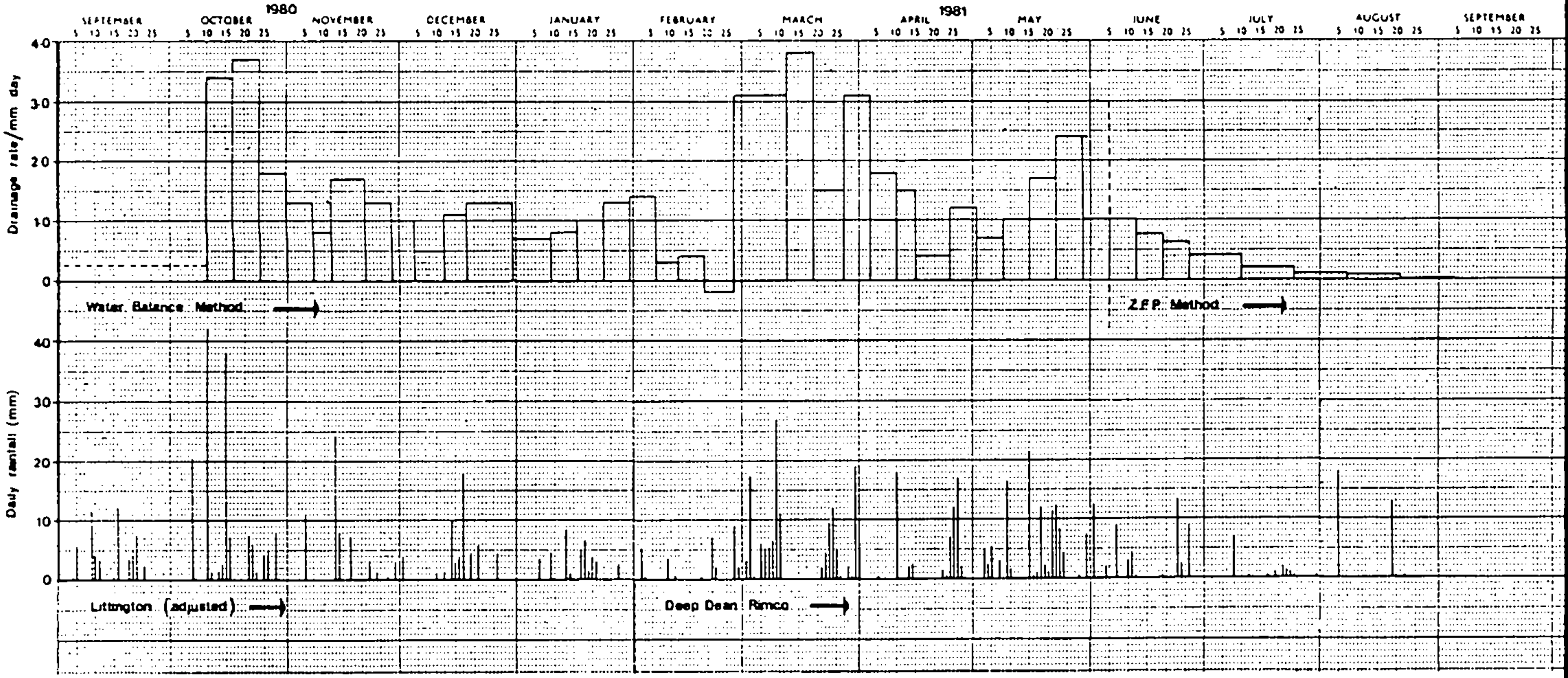

Fig 2 Daily drainage fluxes at 2.85 m depth, September 1980 - September 1981 and daily rainfall.

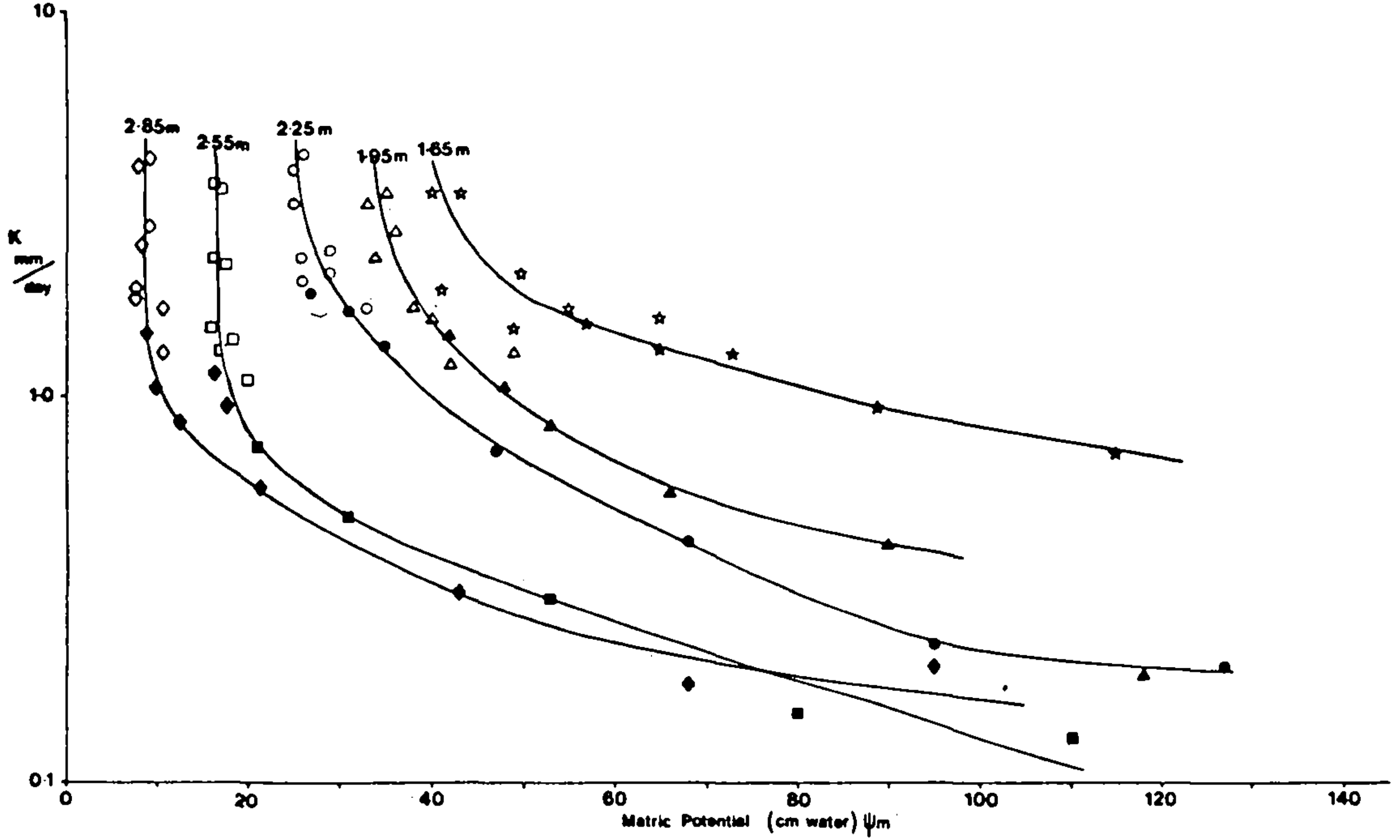

Fig 3 Unsaturated conductivity characteristics K-Ψ m
Open symbols denote water balance derived data points
Solid symbols denote zero flux plane derived data points

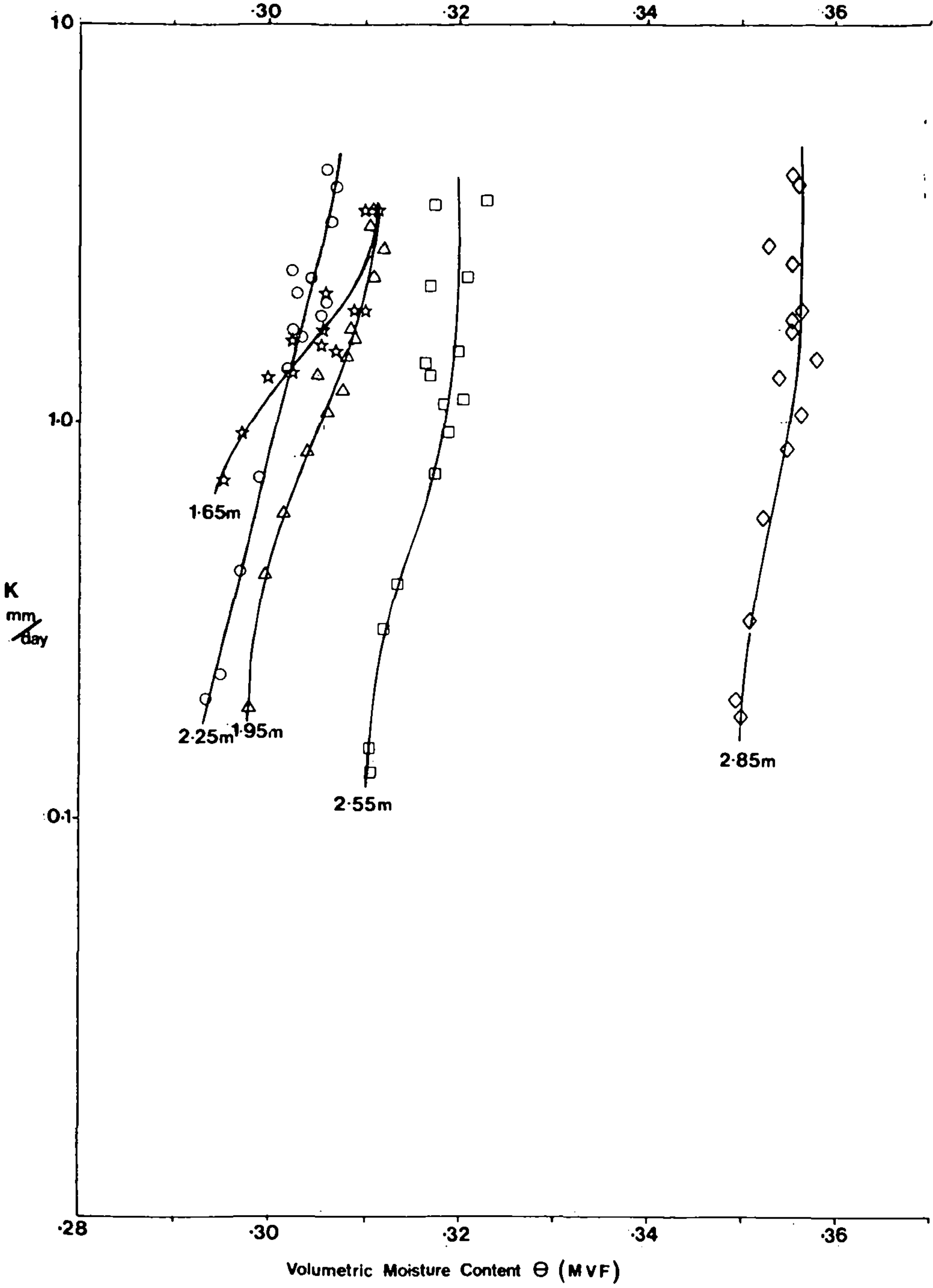

Fig 4 Unsaturated conductivity characteristics K-θ

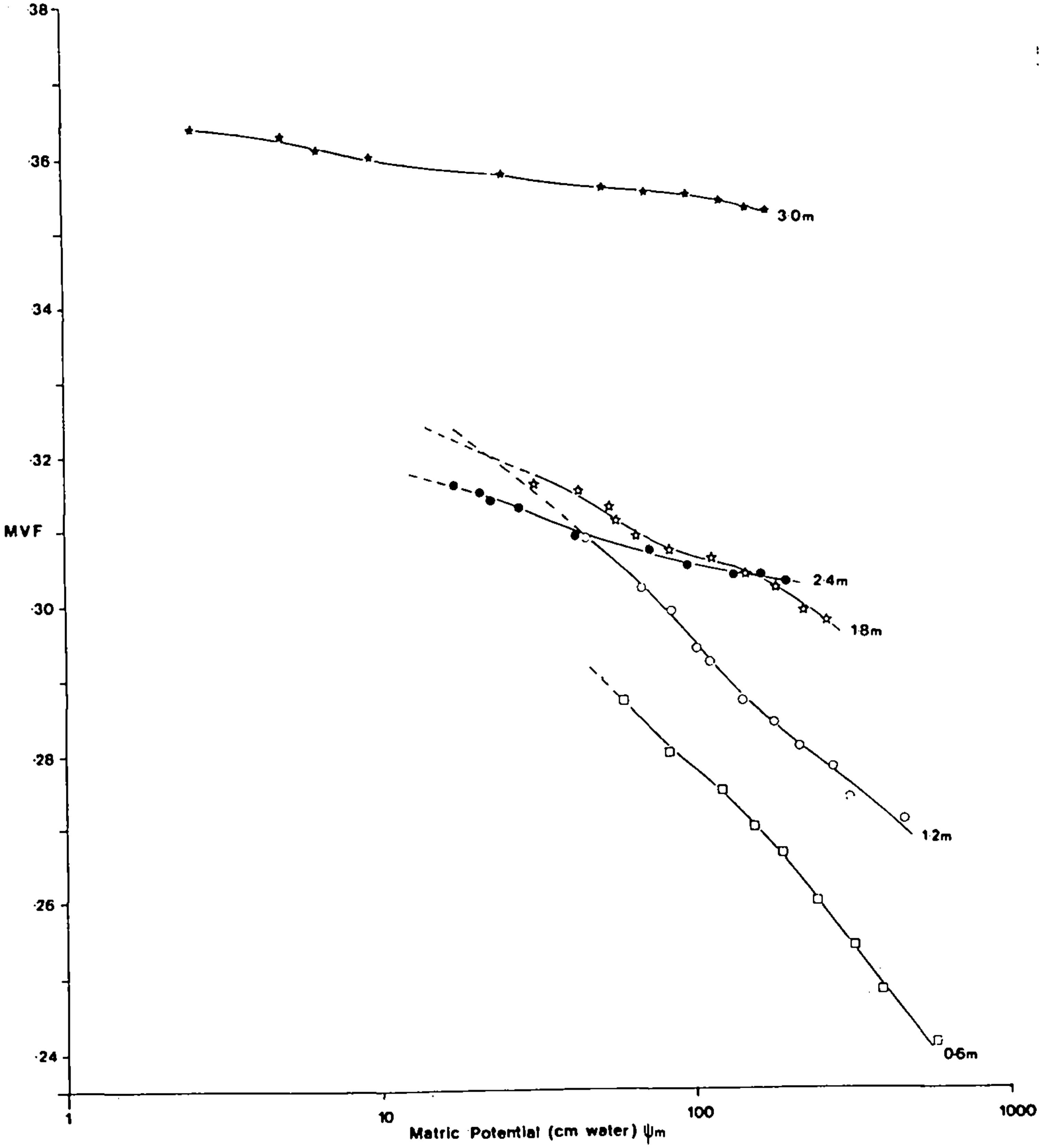

Fig 5 Water Release Curves (θ-Ψ) for depths between 0.6 and 3.0 metres (Data from drying cycle using smoothed MVF data)

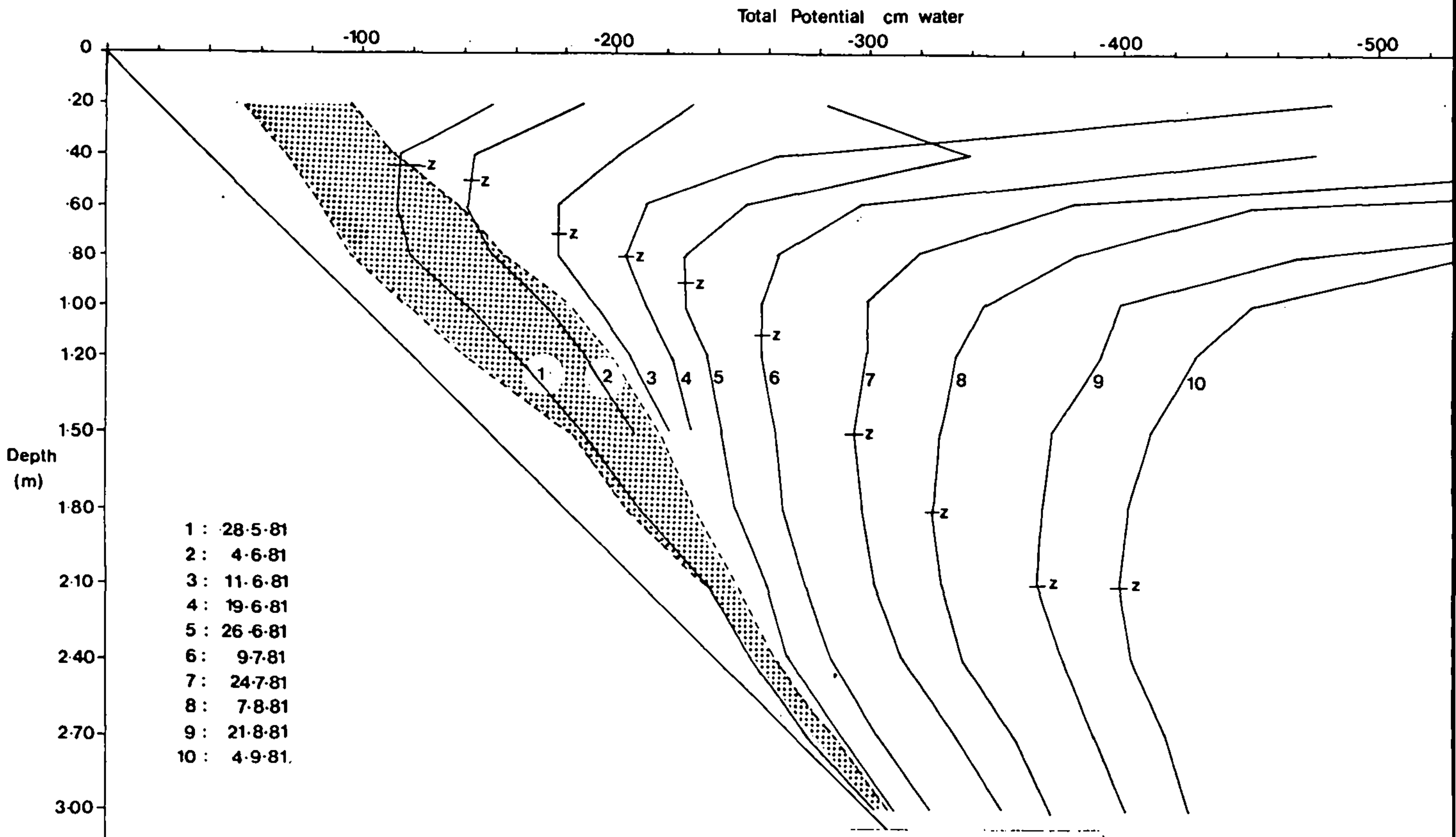

Fig 6 Successive profiles of total potential during the drying phase 1981.
The shaded area shows the extent of the zone in which total potentials fluctuated during the winter of 1980-81.
The positions of the zero flux plane (when present) are shown (Z)

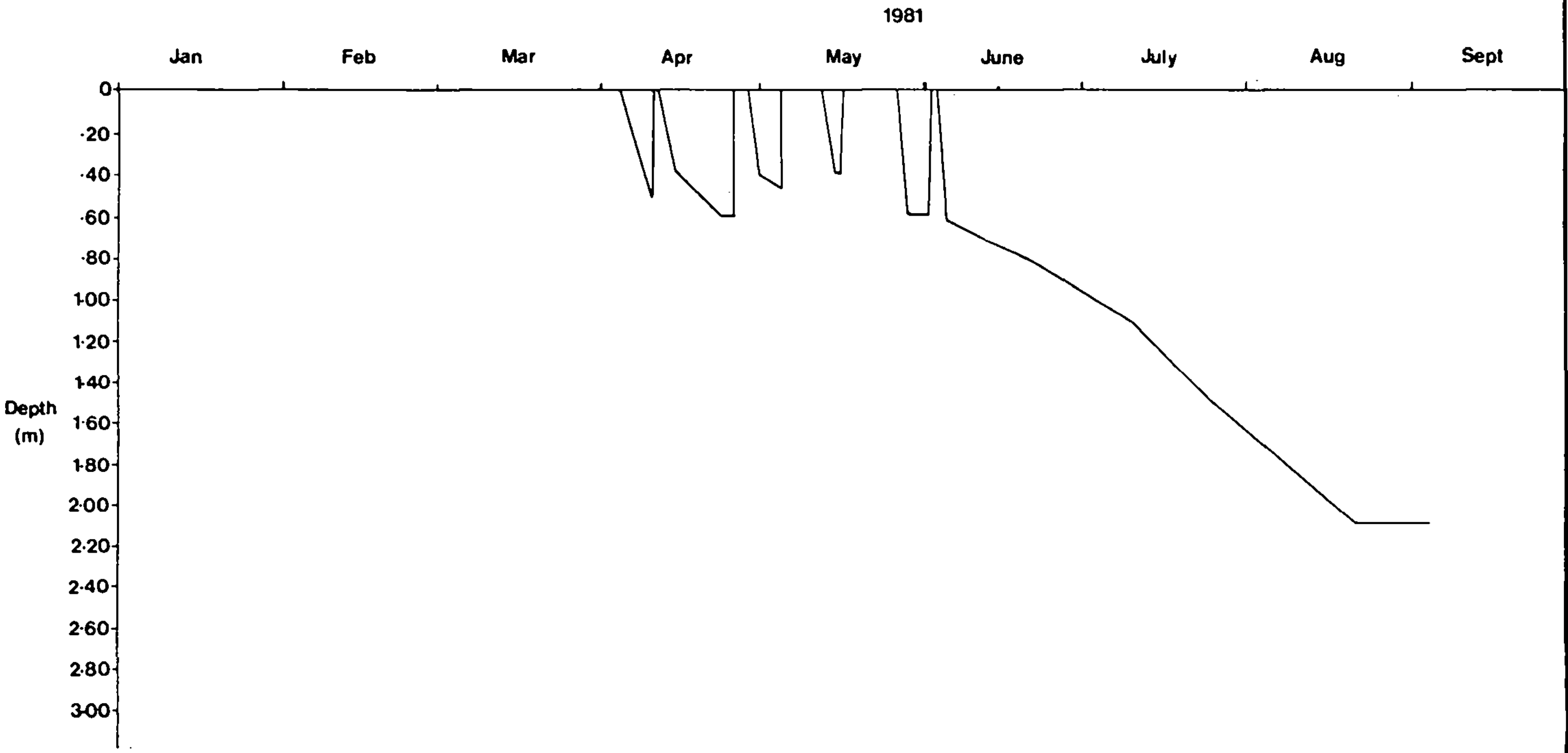

Fig 7 Seasonal fluctuation of the depth of the zero flux plane.

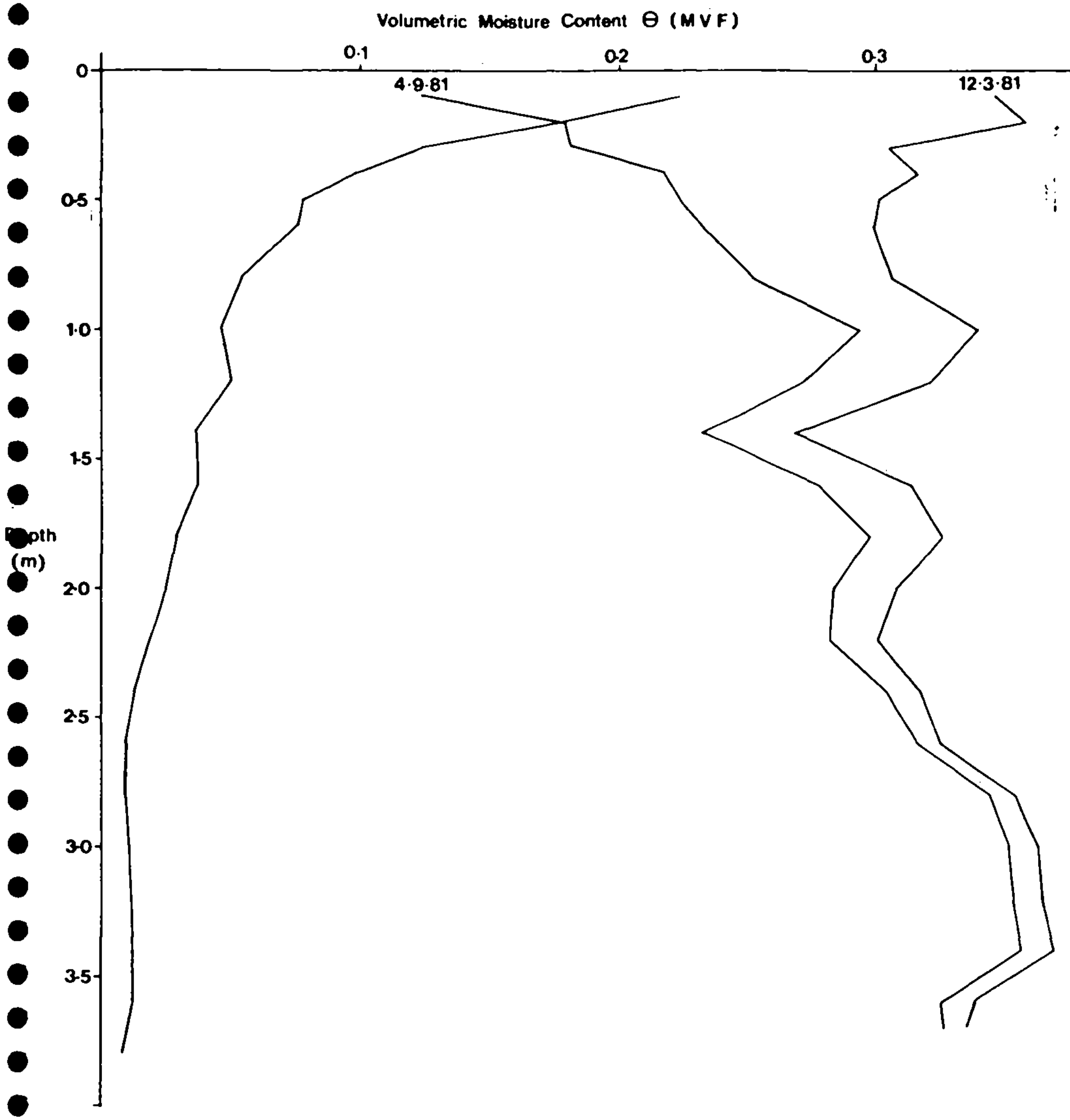

Fig 8 Wettest and driest moisture content profiles 1981.
The profile on the left shows the moisture content difference between the wettest and driest states.

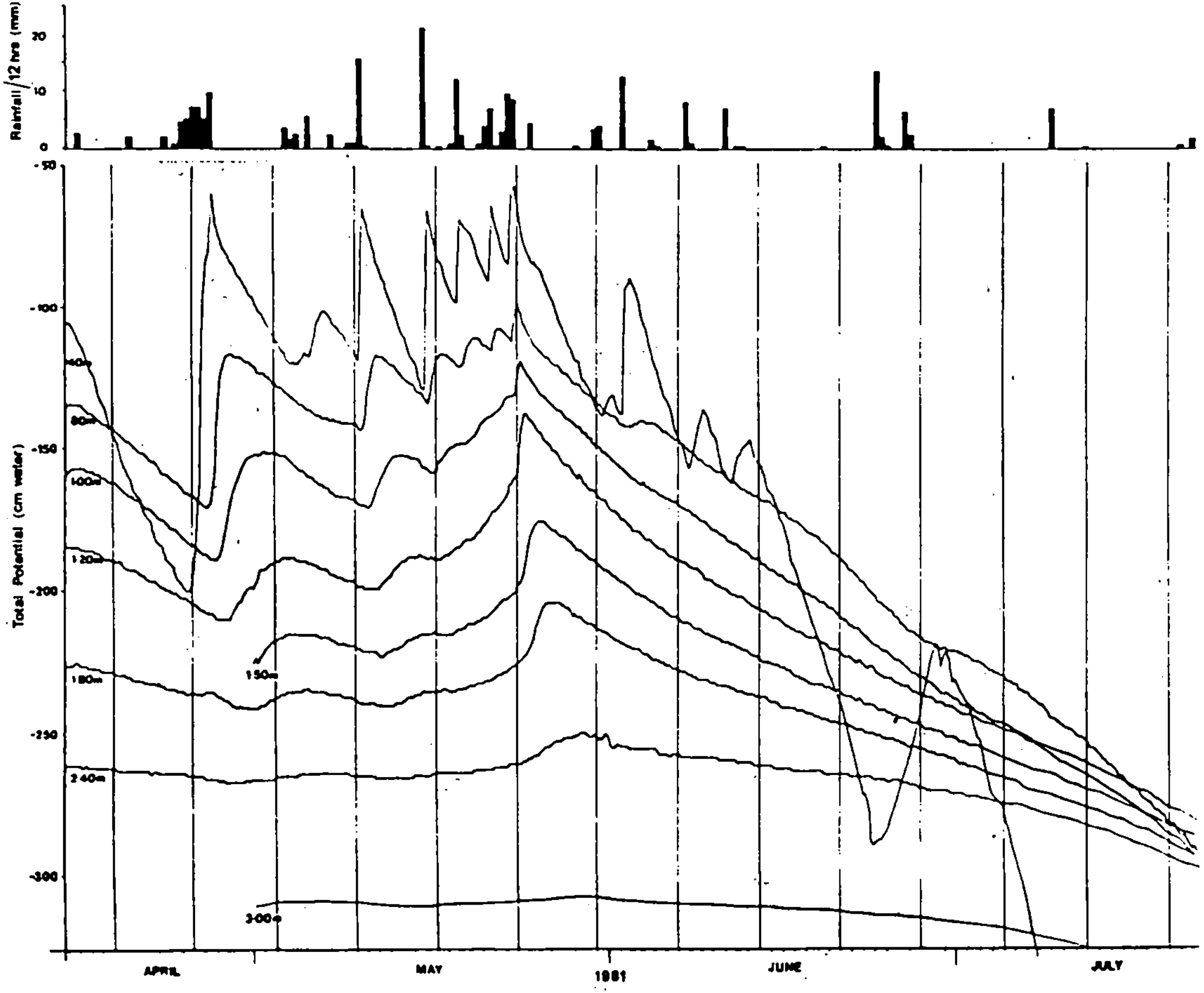

Fig 9 Pressure Transducer tensiometer total potential time series and 12 hourly rainfall mid April - mid July 1981. The vertical lines are at weekly intervals.