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WOBURN SOIL MOISTURE STUDY

Report to
The Water Research Centre

March 1983

M G Hodnett

Institute of Hydrology
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
UK

Tel: 01491 838800
Fax: 01491 692424
Telex: 444293 ENVRE G

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REPORT

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1.0 INTRODUCTION AND OBJECTIVES

This study was carried out under contract to the Water Research Centre as part of a larger scale EEC funded project to investigate nitrate pollution of the Lower Greensand aquifer in Bedfordshire.

The objectives of the study were to:-

Study the variation of soil moisture content and potential under a grass plot on the Lower Greensand throughout an annual cycle.

2. Measure the amount and timing of recharge to the aquifer.

3. Investigate the unsaturated flow processes occurring in the Greensand.

The work was carried out between September 1982 and the beginning of November 1983.

2.0 LOCATION, GEOLOGY AND SOILS

2.1 Location

The experimental site (NGR SP950341) was on the Woburn Farm of the Rothamsted Experimental Station, about 1km North West of the town of Woburn, in Bedfordshire. The plot was located at the southern end of Stackyard field (see Fig.1) on an area which had been under grass for some years.

2 Geology

The field and site are situated on the outcrop of the Lower Greensand, which, in this area, has a thin cover of Quaternary deposits (chalky boulder clay, glacial gravel and colluvium). Colluvium is the most extensive of these deposits locally and is typically about 0.5 - 1.5m thick.

The Greensand beneath these deposits consists of yellow and brown sands or loamy sands with occasional thin bands of light grey clay. These clay bands are usually 1 - 3 cm thick. Redder, more ferruginous layers also occur in the Greensand and are most common either immediately above or below the clayey horizons. (Catt et al. 1974,1976 and 1979)

A borehole drilled by the shell and auger method for the installation of a water level observation tube in early December 1982, reached the groundwater table in the Greensand at 11.9m below the ground surface. The hole reached a total depth of 16.5m, penetrating prominent laminated clay and sand layers at 10.5 and 13.0m. (Narrow clayey zones are unlikely to be observed using this method of drilling.) The final depth of the observation tube was 13.8m, the reduction in depth being caused by considerable problems with running sand.

2.3 Soils

The soils of Stackyard field have been studied in considerable detail by Catt et al. (1979) and the soil at the site is described as a colluvial brown earth of the Stackyard series. This, and the sandier textured Cottenham series are the predominant soils of the field.

The soil type may influence the amount of recharge in two main ways: firstly, through the available water capacity, affecting the maximum deficit that can occur, and secondly, through the surface permeability, affecting the occurrence of runoff. The latter will also be influenced by cropping patterns and agronomic practices.

The profile at the site is similar to that described by Catt et al. at a location about 40m away from the site.

The main features of the profile are described below:-

Depth (m)	
0.00 - 1.10	Dark brown sandy loam, becoming paler and sandier with depth.
1.10 - 1.50	Yellowish brown fairly loose sand.
1.50 - 1.85	Lightly to heavily mottled reddish brown sand. Mottles up to 2cm in diameter, and greyish olive in colour.
1.85 - 1.87	Pale grey clay.
1.87 - 2.25	Reddish brown loamy sand with pale grey clay laminations (1-2mm). Some small pieces of very weathered ironstone (up to 1cm) below 2.15m.
2.25 4.00	Variable colour banded (reddish brown, brown and yellowish brown) sand and loamy sand.

The narrow clay band at 1.85m, and the reddish brown clayey horizons above and below the band are typical of the Lower Greensand of the area. The mottled zone from 1.50 - 1.85m implies that seasonal waterlogging occurs, indicating that the clay band may be fairly impermeable.

3.0 INSTRUMENTATION AND EXPERIMENTAL PROCEDURES

3.1 Instrumentation

The instrumentation on the plot consisted of:

3 neutron probe access tubes, read at 0.10m below the ground surface, and then at 0.2m depth intervals to 3.6m.

A set of 12 mercury manometer tensiometers installed at 0.2m depth intervals from 0.2 - 1.2m, and then at 0.3m intervals from 1.5 - 3.0m.

A set of 9 pressure transducer tensiometers (PTTs) installed at 0.3m intervals from 0.3 - 2.4m with the last at 3.0m.

A tipping bucket raingauge and a storage check gauge. (Both standard exposure)

A 13.8m deep, 4" dia. water level observation borehole.

3.2 Frequency of observations

The PTTs were connected to a logging system which recorded data onto solid state 'stores' at 2 hourly intervals. Rainfall totals were logged at 3 hourly intervals. The solid state stores were changed each time the site was visited.

The access tubes, mercury manometer tensiometers and borehole water level were read at weekly intervals from 24 September 1982 until late June 1983, and then at fortnightly intervals until the final observations on 3 November 1983. The start of fortnightly observations was deferred from the planned time at the end of April because of the very wet April and May following a fairly dry winter.

3.3 Plot management

The grass on the plot was cut at the start of the work and in June and September 1983. The cuttings were removed. The plot was not fertilised.

3.4 Neutron probe calibration.

Two calibrations were used to convert standardised neutron probe count rates (R/R_w) to volumetric moisture content (θ):-

$\theta = 0.790\ R/R_w - 0.024$ for all depths except 0.1m.

$\theta = 0.988\ R/R_w - 0.008$ for the 0.1m depth only.

A special calibration was derived for the 0.1m reading depth as the normal calibration cannot be used near to the ground surface. The gravimetric procedure detailed by Bell (1976) was used.

Calibration samples were also taken from depths below 0.2m to confirm that the use of the 'standard' sand calibration (1) was valid.

The mean moisture content for each depth was calculated from the count rate data from the 3 access tubes. These mean data have been used throughout this report.

3.5 Calculation of drainage fluxes in the unsaturated zone

When there was no zero flux plane (ZFP) in the profile, drainage fluxes were calculated using the profile water balance equation (1) below:-

$$P = R - E \quad D_d - \Delta S_d$$

Where P is the rainfall,
R is the runoff,
E is the actual evaporation,
D_d is the drainage below depth d,
and ΔS_d is the change in moisture storage above depth d, during the period concerned.

The rainfall data from the tipping bucket gauge at the site (or from the Meteorological Office gauge at Crawley Mill Farm, about 1.5km distant, when the site gauge was inoperative) was used. These data were corrected to ground level (true) readings using a factor of +4%, which is fairly typical of sites in Central England. (Smith 1983 Pers. Comm.)

Runoff was not observed to have occurred on the grass plot, although it is a fairly frequent occurrence on these soils after recent cultivation, and to a lesser extent under annual crops. For the purpose of these calculations, the runoff was assumed to be zero.

For the period when the water balance method was used, the crop was well supplied with water and it has been assumed that evaporation occurred at the potential rate. Potential evaporation for the appropriate periods was interpolated from the data presented in the weekly MORECS bulletins.

The change in profile moisture content was calculated from the neutron probe readings made in all 3 access tubes.

The drainage component of the balance (the recharge) was derived by difference.

When a ZFP was established for a long enough period, the ZFP method was used to calculate drainage fluxes.

4.0 RESULTS

4.1 Potential and moisture content profiles

Complete profiles of total potential for 3 different dates are presented in Fig. 2 and profiles of moisture content for the same 3 dates are shown in Fig. 3. These data show the soil profile in its wettest condition (5 May 1983) and on two subsequent dates, when the upper and lower parts of the profile (above and below the clay band at 1.85m respectively) were in their driest condition (31 August and 3 November). Data showing the lower portion of the profile in the driest condition recorded during the experiment (17 November 1982) are also presented for comparison.

4.1.1 5 May 1983: profile in wettest condition

The potential data show a draining profile with high matric potentials (-38 to -25cm H2O) above 1.2m depth, increasing to zero, or saturation at 1.54m. A saturated zone, or perched water table extended down to about 2.30m and was separated from a second saturated zone at the bottom of the measured profile by a narrow unsaturated layer at about 2.40m. The uppermost saturated layer extended 0.3m above the clay band at 1.85m and also included the laminated clay and sand layer down to 2.25m. Potential gradients within the saturated zones indicated that downward flow was occurring. Lateral flow may also have been occurring.

The moisture content data for the saturated part of the profile show values ranging typically from 0.28 to 0.34, but with a marked peak of 0.423 occurring at 1.8m, close to the clay band. In the unsaturated upper part of the profile, the moisture content fell from 0.300 at 0.10m to a minimum of 0.151 at 1.00m and then rose sharply to 0.303 at 1.40m, within the capillary fringe of the water table.

4.1.2 31 August 1983: Upper profile in driest condition

The data for 31 August show the upper part of the profile (above the clay band) in its driest condition.

The potential data showed a well developed zero flux plane (ZFP) at 1.50m, with a very steep upward potential gradient above 1.2m. Potentials above 1.0m were below -800cm H2O, beyond the measuring range of tensiometers.

Below the ZFP, the profile was draining and was unsaturated throughout, apart from a very narrow band at 2.1m where the matric potential was 0.2cm H2O. The matric potential decreased sharply to -53cm H2O at 2.4m and then increased to -10cm H2O at 3.00m. Downward extrapolation of these data imply that the profile was still saturated below about 3.2m.

These results show that by late summer 1983 the upper saturated zone had virtually disappeared and the water table of the lower zone had fallen to about 3.2m.

The moisture content profile shows that between 5 May and 31 August, the moisture content changes were largest at 0.1m (>0.200) and decreased steadily with depth, becoming negligible (<0.005) at 1.6m, just below the 31 August ZFP at 1.50m. This pattern of moisture change is typical of a cropped site.

Within the clayey zone, at 1.8 and 2.0m, where the matric potentials were above -11cm H2O, moisture content changes were negligible. However, below this, at 2.4 and 2.6m, where the potentials were lowest, marked decreases of misture content (0.055 and 0.036 respectively) occurred.

4.1.3 3 November 1983: Lower profile in driest condition 1983

The data for 3 November 1983 show the lower part of the profile in the driest condition measured in 1983, which occurred after the upper part of the profile had begun to wet up.

Total potentials had increased to a depth of 1.0m and were unchanged at 1.2m, indicating the extent to which the wetting had reached. Below 1.2m, potentials had decreased throughout the profile. The largest decrease occurred at 3.0m and extrapolation of the profile to saturation indicated that the water table had probably fallen to about 3.7m.

The moisture data showed a corresponding pattern of changes, with increases of moisture content down to 1.0m, and decreases throughout the remainder of the profile. Changes were again almost negligible between 1.6 and 2.0m, but below this, further large changes had occurred, particularly between 2.4 and 2.8m (see diagram). Between 5 May and 3 November 1983 the total storage change in the layer from 1.80 to 3.6m was 71mm.

These large changes occurred below the ZFP and were entirely due to drainage, most of which occurred in the late summer/early autumn.

Below 2.3m, the profiles of total potential and moisture content for 31 August and 3 November show a typical response to a falling water table; matric potentials gradually fall, causing the profile above the water table to drain. The amount of drainage that occurs is dependent on the moisture characteristic of the material.

4.1.4 11 November 1982: Lower profile in the driest condition recorded in the study

The data for 11 November 1982 show that, as in 1983, the profile below the clay band was driest in early November when the profile above was beginning to wet up. However, potentials were lower than in 1983, and this is clearly reflected in the moisture content data, which indicate that the profile below 1.8m was markedly drier throughout: the profile moisture storage between 1.8 and 3.6m was 30mm less than in November 1983.

4.1.5 Representativeness of the data

The monthly rainfall totals (mm) measured at the site during the experiment are shown in Table 1 below. These data are also expressed as a percentage of the mean monthly rainfalls for Woburn (Crawley Mill Farm) for the period 1941 - 1970.

Table 1.

	1982			1983									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Site	109	84	53	43	27	40	108	111	24	59	20	20	45
% of Woburn Mean	205	135	97	81	63	96	244	209	46	107	30	136	85

Overall, the rainfall during the study period was about 20% above normal, but for the recharge period, in this case from October 1982 to May 1983, the rainfall was 173mm or 43% above normal.

The wettest condition measured (5 May 1983) was therefore the result of a very wet autumn, followed by a slightly drier than average winter and an exceptionally wet spring. Although no other moisture data are available for comparison, it is likely that the profile was wetter than would occur in most winters. However, the profile above the clay layer did not appear to be unusually wet, as on 5 May 1983 the profile storage above 1.8m was 553mm, only 3mm more than on 25 November 1982. The very high storage in the entire profile to 3.6m was the result of unusually high storage in the lower part of the profile.

The wettest condition also occurred much later than usual: normally it would occur between December and March. However, at this time of year, the profile storage could become as high as on 5 May 1983 following a smaller amount of rain, as evaporation losses are much lower. (Typically 10mm in January, compared to 45mm in April).

4.2 Saturated zones

Figure 4 shows the vertical extent of the saturated zones and the depth of the ZFP in the profile during the study period, derived from the manual tensiometer data. The base of the upper saturated zone, or inverted water table (Freeze 1979) was between 2.1 and 2.4m, and may have fluctuated slightly, but has been assumed to conform with the base of the laminated clay and sand layer at 2.25m.

Saturated conditions first appeared in the profile in early November 1982 at about 1.8m, just above the clay band, and the saturated zone then expanded fairly rapidly upward and downward.

Below this zone, a second saturated zone formed briefly at about 2.7m in mid December 1982 and then formed again in early January 1983. This zone then moved down and probably merged with a water table rising from below. This lower water table fell below 3.0m at the beginning of March.

From late March into April, the upper water table rose in response to the heavy rainfall, and between 10 and 15 April, the lower water table rose from below 3.0m up to 2.6m. Both saturated zones reached their maximum extent on 5 May and the water tables did not fall continuously until after 3 June. By 3 August, saturated conditions only remained at about 2.1m, and by early September, the entire profile was unsaturated.

The first appearance of saturated conditions at 1.8m indicates that the clay band impedes drainage, causing ponding above. The downward expansion of the saturated zone to 2.1m showed that some drainage was passing through the clay band. It also showed that the laminated clay and sand layer down to 2.25m also had a very low conductivity, needing to be saturated to have sufficient conductivity to transmit the downward flux. The presence of the lower saturated zone indicated the presence of a further impeding layer deeper in the profile, probably below about 4.0m. This was the maximum depth reached while installing access tubes and no further clayey layers were observed.

The lower water table responded in unison with the upper one and this implied that inputs (lateral and vertical) to this saturated zone were reaching it with little delay.

4.3 Zero Flux Plane Depths

Shallow zero flux planes existed in the profile for brief periods in March, May and June but were soon eliminated by rainfall, restoring through-drainage. A stable ZFP did not form until mid July. The maximum depth reached by the ZFP was 1.5m, in mid September and it remained at this depth until the end of the study. The maximum depth of the ZFP in 1982 was also 1.5m.

4.4 Water movement through the upper saturated zone

Figure 5 shows the mosture content at 5 depths (1.8, 2.2, 2.4, 2.8 and 3.6m) plotted in time series over the study period. These data show that the profile below the upper saturated zone wetted sequentially downward and indicated that the lower saturated zone must have been to a large extent supplied by vertical drainage from the upper zone.

The data show that up to 17 November 1982, the moisture content at all of the depths was decreasing, particularly at 2.8 and 3.6m. After 17 November, the moisture content at 2.2 and 2.4m began to increase rapidly, although at 2.8 and 3.6m the moisture content continued to decrease. After 25 November, the moisture contents at 2.8 and 3.6m began to increase slowly and only increased rapidly after 9 December, when the depths above had almost completed wetting.

The 3.6m depth must however have been close to the implied lower water table and the increase in moisture content here may have been the result of the rise of this water table and not due to the downward movement of a wetting front.

4.5 Recharge

The drainage (recharge) was calculated from the profile water balance using equation (3) when there was no ZFP in the profile. Once a stable ZFP had developed, the drainage was derived using the ZFP method.

The water balance equation assumes vertical continuity and drainage could therefore not be reliably calculated for depths below the level of the upper water table, as any lateral gains or losses could not be quantified.

The drainage flux was therefore calculated for the 1.5m depth as the upper water table only briefly rose above this, and because 1.5m was also the maximum depth of the ZFP during the study.

Cumulative drainage flux data for the 1.5m depth are shown in Fig. 6, together with storage in the profile between 1.5 and 3.6m, and the regional water table levels measured in the observation borehole.

The total cumulative drainage flux during the study period (24/9/82 - 3/11/83) was 277mm.

There was no drainage until mid October 1982 (when the ZFP was eliminated) and drainage had ceased by mid August 1983. Most of the drainage occurred in two main periods, December - January and April - June when drainage rates generally exceeded 2.0mm/day. Between the two main drainage periods, in late March, the drainage became almost negligible and the profile was therefore at 'field capacity'.

4.6 Storage changes in the profile below 1.5m.

These data show that 105mm of the drainage through the 1.5m depth was taken into storage within this zone, mainly at the start of the recharge period. After the drainage through 1.5m had almost ceased, at the end of June, the storage began to decrease as the zone drained, falling by 78mm by the end of the study.

The impeding layers therefore considerably modify the timing of drainage.

The storage data in Fig. 6 show that up to mid October 1982, this part of the profile was draining slowly. Storage began to increase after 17 November, but the data in Fig. 5 show that up to 2 December the upper layers of this zone were wetting while the lower layers were continuing to drain.

The storage changes were closely related to the drainage flux through 1.5m, the main storage increases occurring when the flux at 1.5m was greatest.

In the first of the two main recharge periods (17 November 1982 - 3 March 1983), the storage increased by 79mm when the total flux through 1.5m was 136mm, but in the second period (7 April - 30 June), the storage increased by only 23mm, when the total flux through 1.5m was 115mm.

Storage increases were always less than the flux at 1.5m, indicating that there were no large lateral inputs below 1.5m.

Between 25 November 1982 and the end of May 1983, the storage in the profile between 1.5 and 3.6m increased by a total of 106mm, taking up the equivalent of 43% of the drainage through 1.5m up to that date. After the end of June, this storage began to decrease as lateral inputs and the vertical drainage input from above 1.5m declined.

From the end of June until the end of the experiment, the storage decreased by 78mm, of which the largest contribution came from the layer between 2.4 and 3.0m (see Fig. 3). It was not possible to partition this loss into lateral and vertical drainage components.

4.7 Water level data

These show a very small range of fluctuation of 0.23m, despite the large amount of recharge. If a specific yield of 10% is assumed, the total storage change was only 23mm.

Between December 1982 and February 1983, the water level remained virtually constant although the total drainage flux through 1.5m was 107mm. The level fell very slightly in March, when the drainage flux at 1.5m was negligible and then rose a total of 0.07m between mid April and mid June. The timing of this rise corresponded well with the increased drainage flux through 1.5m. After mid June, the level fell continuously until the end of the work.

The water level probably did not rise in the period from December 1982 to February 1983 because much of the flux through 1.5m was taken up by storage in the intervening layers. (See Fig. 6). However, some recharge must have been reaching the regional water table as the level did not fall.

4.8 Pressure transducer tensiometer data

Time series graphs of total potential measured by the PTTs for the period from 2 December 1982 to 9 June 1983 are shown in Fig. 7 together with the daily rainfall (Met. day basis). The potential data has been plotted at 4 hourly intervals.

These data show in detail the response of the profile to rainfall events, 'filling' in the gaps between the manual tensiometer readings.

The key points shown by these data are:

1. They confirm the manual tensiometer data.
2. Water movement through the profile above the upper water table is rapid when the profile above is wet (eg December and April): the water table begins to respond within about 30 hours of sufficient rainfall.
3. Drainage fluxes through this part of the profile may be very high, but saturation does not occur. The very sharp peaks in the PTT data show that the pulses of flux pass through very rapidly.
4. When the profile is very wet and evaporation rates are low, the PTTs respond to rainfall inputs as low as 2mm (eg 14 and 22 - 23 December), showing that the upper 60cm of profile is very conductive at matric potentials of about 30cm H_2O. These very small inputs are therefore 'hydrologically effective' and contribute to recharge.
5. The upper water table rose a few cm. above 1.5m on 3 occasions, in December, April and May, but fell again within a few days. A small amount of the recharge calculated for the 1.5m depth may therefore have been lost as lateral drainage.

The data from the PTTs at 1.8m and below show a matching pattern of irregular fluctuations of up to about 16cm H_2O which are not shown by the PTTs above. These fluctuations sometimes correspond with rainfall events (for example, between 10 and 20 December) but the response is different to that of the PTTs above.

Fig. 8 shows the data for two of these PTTs, at 1.8 and 2.1m, plotted at hourly intervals for a three week period from 30 December 1982, together with hourly atmospheric pressure data from the RAE at Bedford, about 10km away. The units used are almost directly comparable although the pressure data has been plotted 'inverted' to aid comparison.

The PTT and pressure data show a very remarkable similarity, although the response at 2.1m was somewhat attenuated. When pressure changes were rapid, (eg on 4 and 11 - 14 Jan.) the correllation of the data was particularly marked. The correllation was less good when pressure changes were slow.

The PTTs measure the matric potential in the soil relative to atmospheric pressure (the chamber behind the diaphragm is vented to the atmosphere via a narrow bore tube in the cable). The PTTs above the clay band at about 1.85m show no response to atmospheric pressure, indicating that air pressure in the soil equilibrates almost instantly with atmospheric pressure changes. The PTTS below the clay band respond closely with atmospheric pressure changes indicating that this equilibration is very slow, and varies with depth. The pattern of atmospheric pressure changes is therefore superimposed, in an attenuated form, on the more slowly changing pattern of matric potential changes.

These results show that the air, and therefore water, permeability of the clay band is very low. The effect of the pressure difference across the clay band, imposed by atmospheric pressure changes, is not known.

5.0 DISCUSSION

5.1 Other recharge data

The mean annual recharge for areas without boulder clay cover has been calculated to be 183mm. (Monkhouse, 1974). This value was derived by Grindley's method, for composite land use, and as such is not directly comparable with the result of this study, which was for permanent grass. However, there is little doubt that the recharge in the study period was considerably higher than normal.

Recharge is likely to be greater in areas with soils of lower available water capacity (eg Cottenham Series), and under annual crops. Recharge will be less in areas with soils of greater AWC and in areas of woodland.

5.2 Processes

It is evident that the behaviour of the 'unsaturated' zone above the regional water table is dominated by the presence of the impeding layers. Such layers are not infrequent in the Lower Greensand sequence (two further clayey layers were noted in the drilling log of the observation borehole) and they vary considerably in thickness and areal extent. They may take the form of thin clay lenses, thicker layers of laminated clay and sand, or Fuller's Earth beds and their areal extent may vary from a few hundreds of square metres to many square kilometres. The sequence of impeding zones will therefore be locally variable.

For much of the year, the profile above the regional water table probably consists of an alternating sequence of saturated and unsaturated zones, each associated with an impeding horizon.

The delaying effect of the impeding layers within the 3.6m depth of profile studied has been shown, and it is likely that further impeding zones will add to this delaying effect, tending to spread the drainage flux reaching the regional water table evenly through the year. This may explain the very small water level fluctuations recorded. It is possible however, that the recharge measured at the site may be 'intercepted' by a particularly impermeable layer so that the regional water table is largely isolated from inputs.

The route by which recharge fluxes reach the water table will complex and variable, depending on the saturated permeability and thickness of the various impeding layers. Considerable lateral movement may occur in the thick saturated zones which will build up above the more impermeable layers, and water may 'cascade' from clay lens to clay lens.

The probable complexity of the system should be taken into account in the interpretation of nitrate profiles and the mechanisms of nitrate movement.

5.0 CONCLUSIONS

The study was carried out in an abnormally wet year.

. Over much of the winter/spring period , there were two saturated zones in the top 3.0m of the profile.

The upper of the two saturated zones was caused by clayey layers within the profile impeding downward movement and causing ponding. The lower saturated zone was probably similarly caused, but by an inferred impeding layer below the maximum depth of measurement.

. During the study period (24 September 1982 to 3 November 1983) the drainage (recharge) through the 1.5m depth was 277mm. All of this drainage occurred between mid October 1982 and mid August 1983.

5. 94% of the total drainage of 277mm occurred between mid November 1982 and the end of June 1983.

The impeding zones create delaying storage in the profile. The moisture storage in the profile between 1.5 and 3.6m (including the 2 saturated zones) increased by 106mm during the recharge period, taking up 43% of the flux through 1.5m. 84mm of this storage was released between the end of June and the start of November 1983.

. Further impeding zones in the profile will add to this delay so that inputs to the regional water table will be spread almost evenly through the year.

8. The 'unsaturated zone' above the regional water table probably consists of an alternating and locally variable sequence of saturated and unsaturated layers, the flow process through which will be very complex. There is scope for considerable lateral movement of recharge.

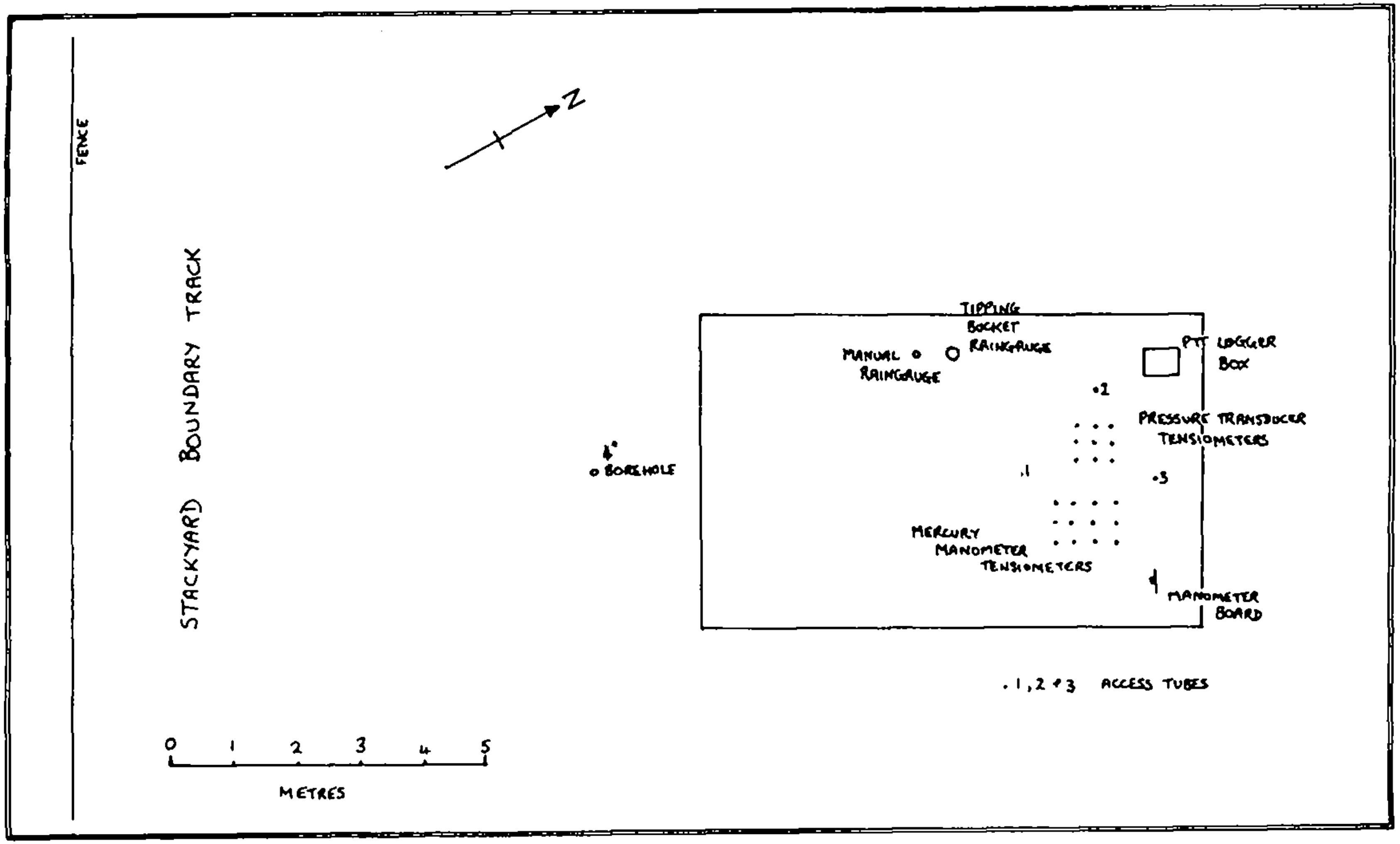

Figure 1. Site plan

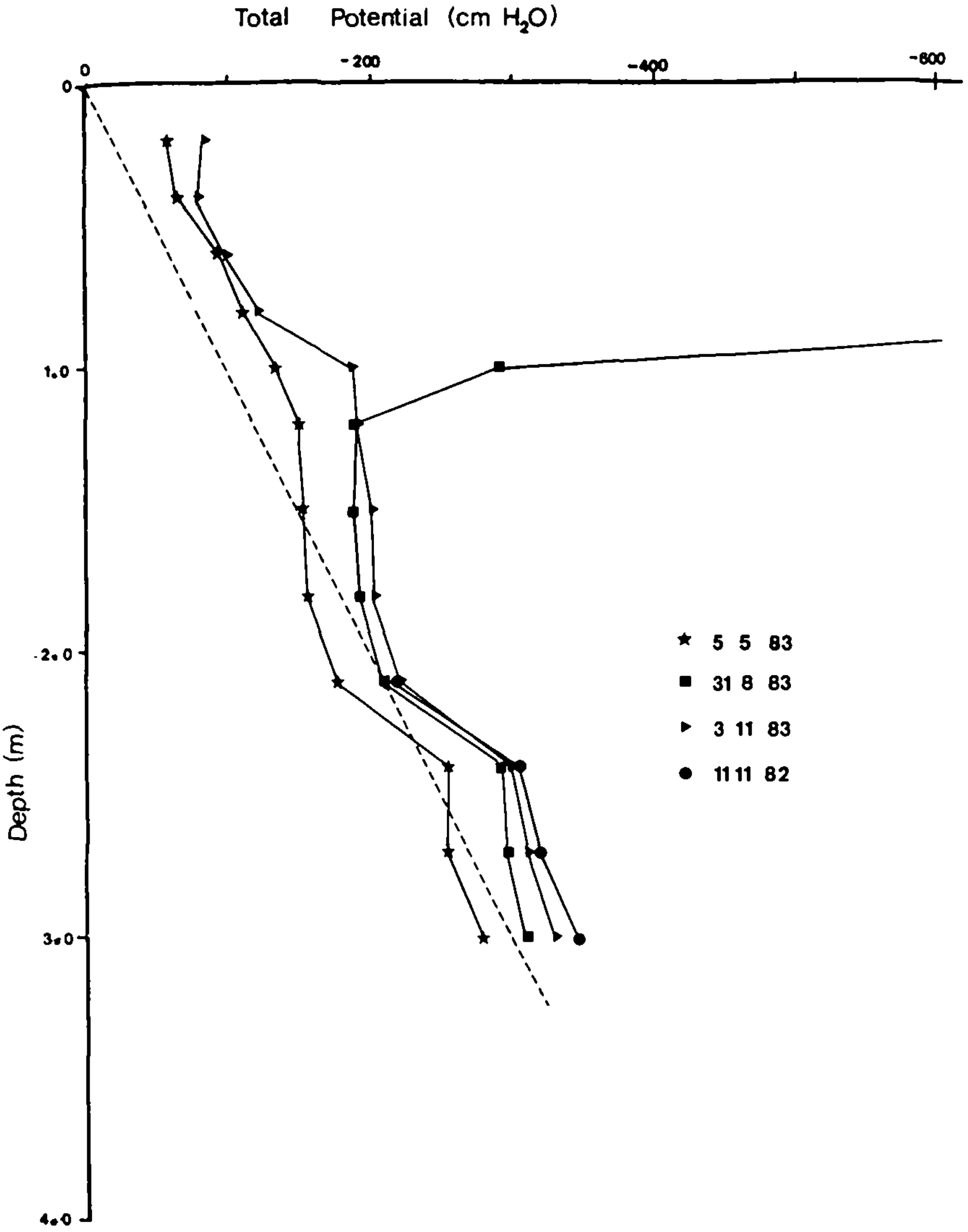

Figure 2. Profiles of total potential measured by mercury manometer tensiometers on the dates shown

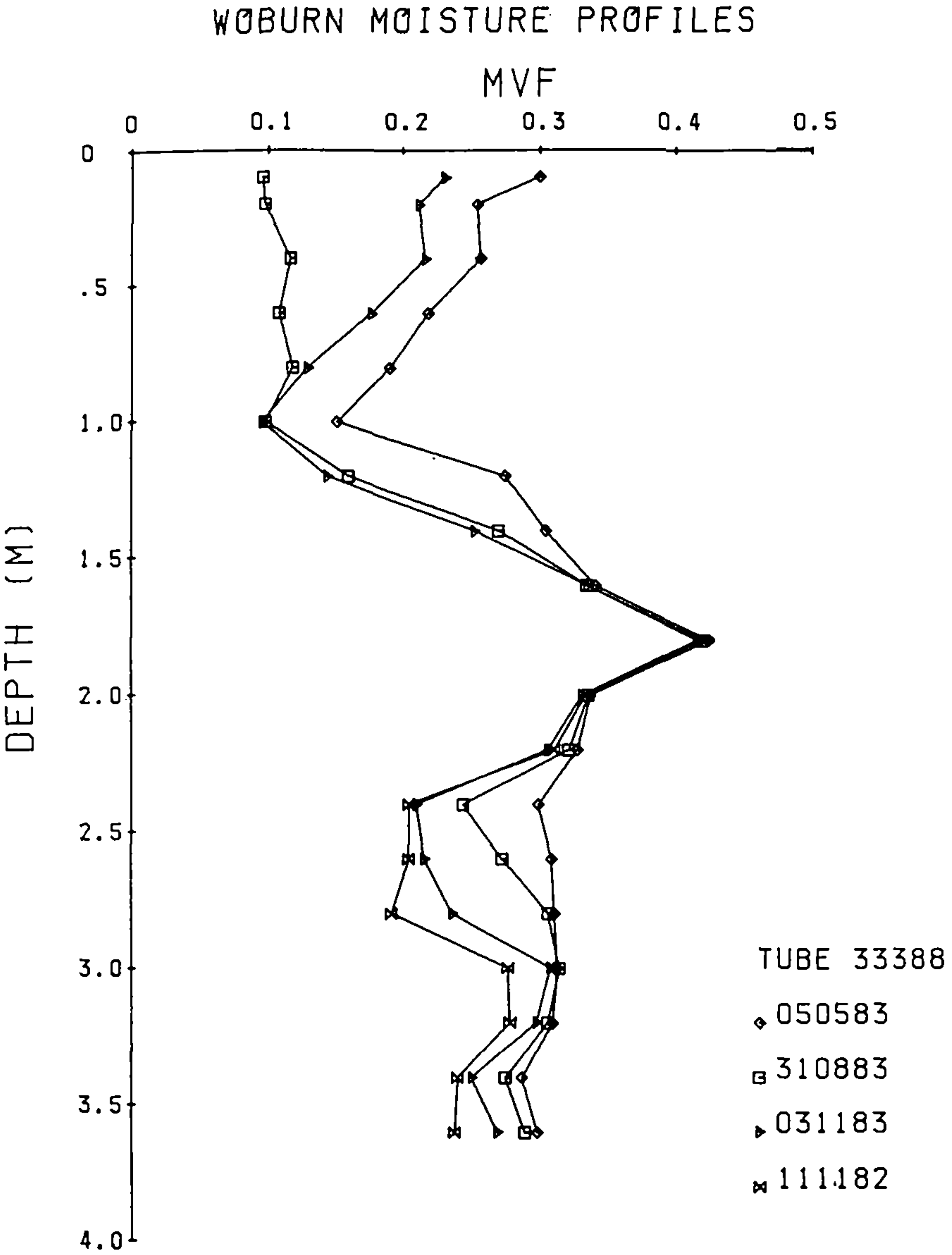

Figure 3. Profiles of volumetric moisture content for the dates shown

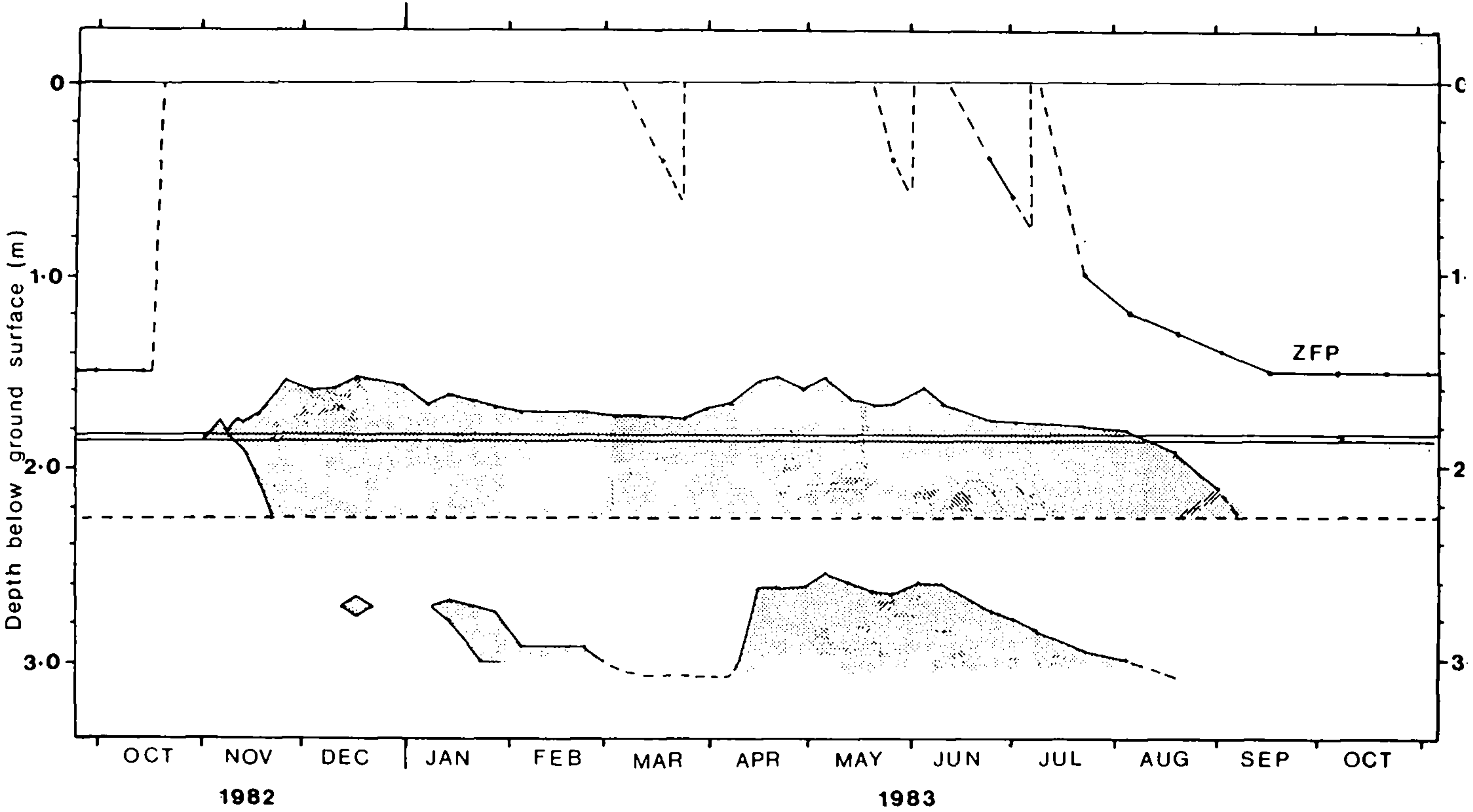

Figure 4. Vertical extent of saturated zones and the depth of the zero flux plane in the profile derived from tensiometer data. Dotted lines show inferred data.

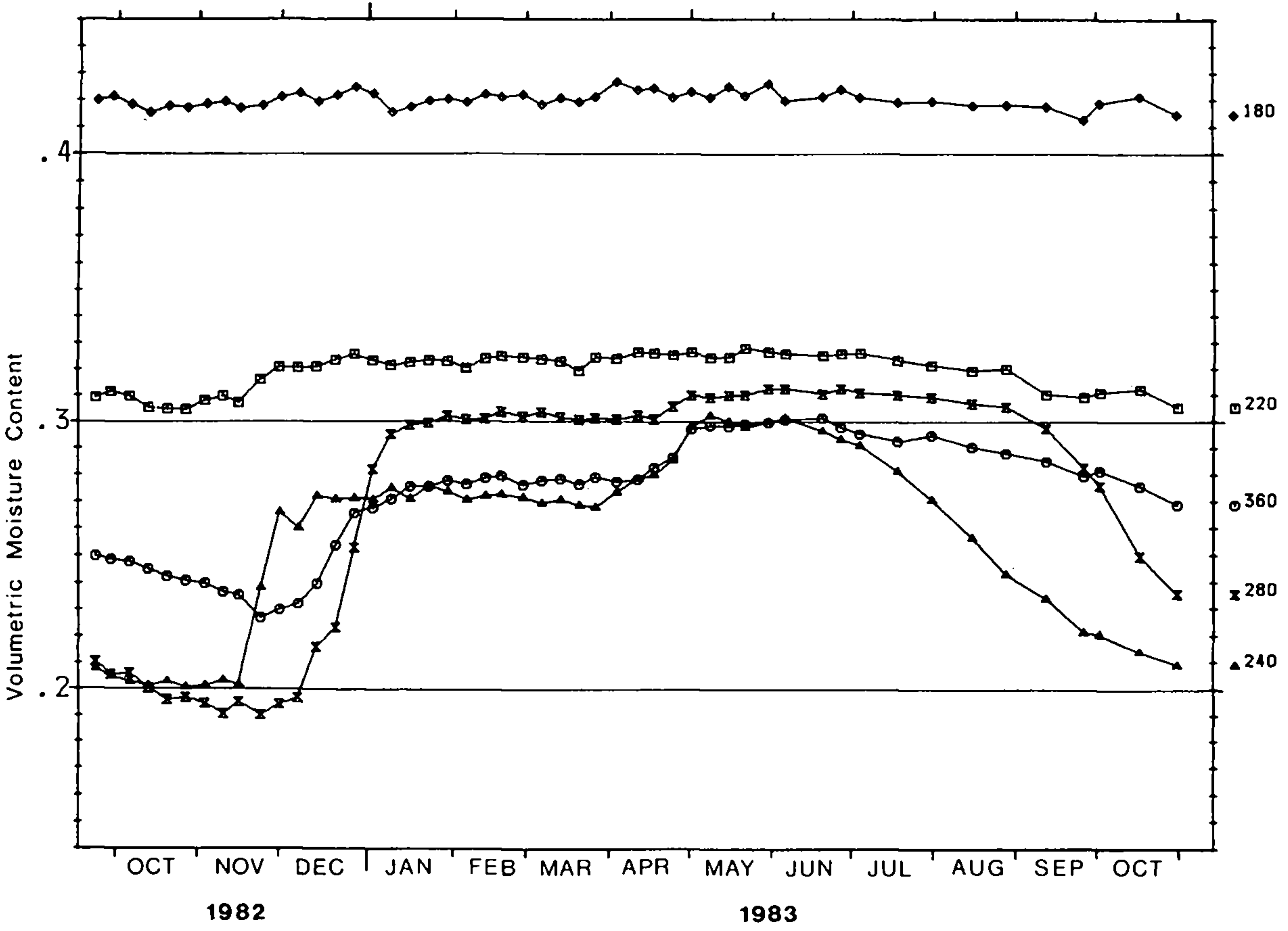

Figure 5. Time series graphs of volumetric moisture content at 5 depths below the clay band.

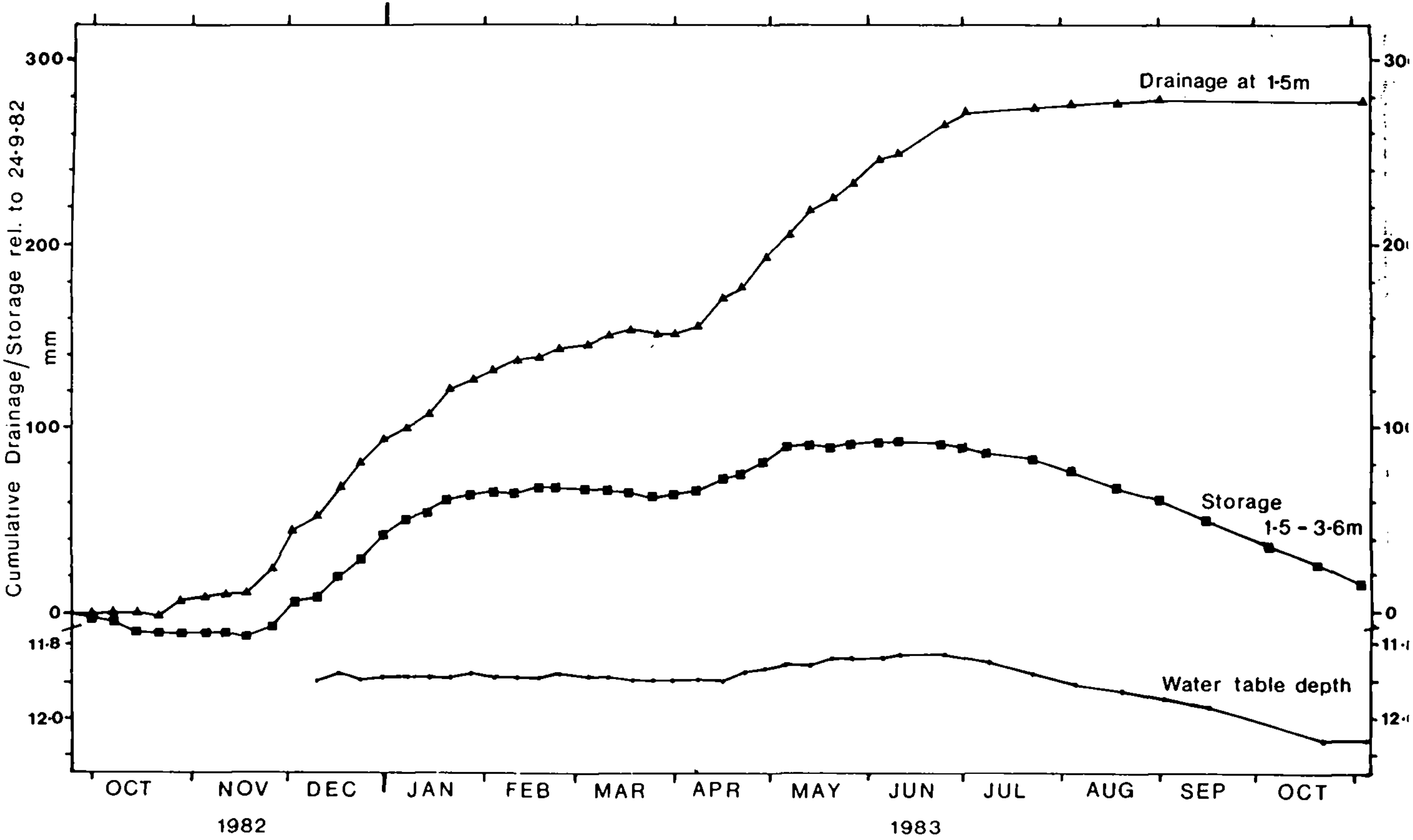

Figure 6. Cumulative drainage fluxes through the 1.5m depth, moisture storage in the profile between 1.5 and 3.6m and regional water table levels.

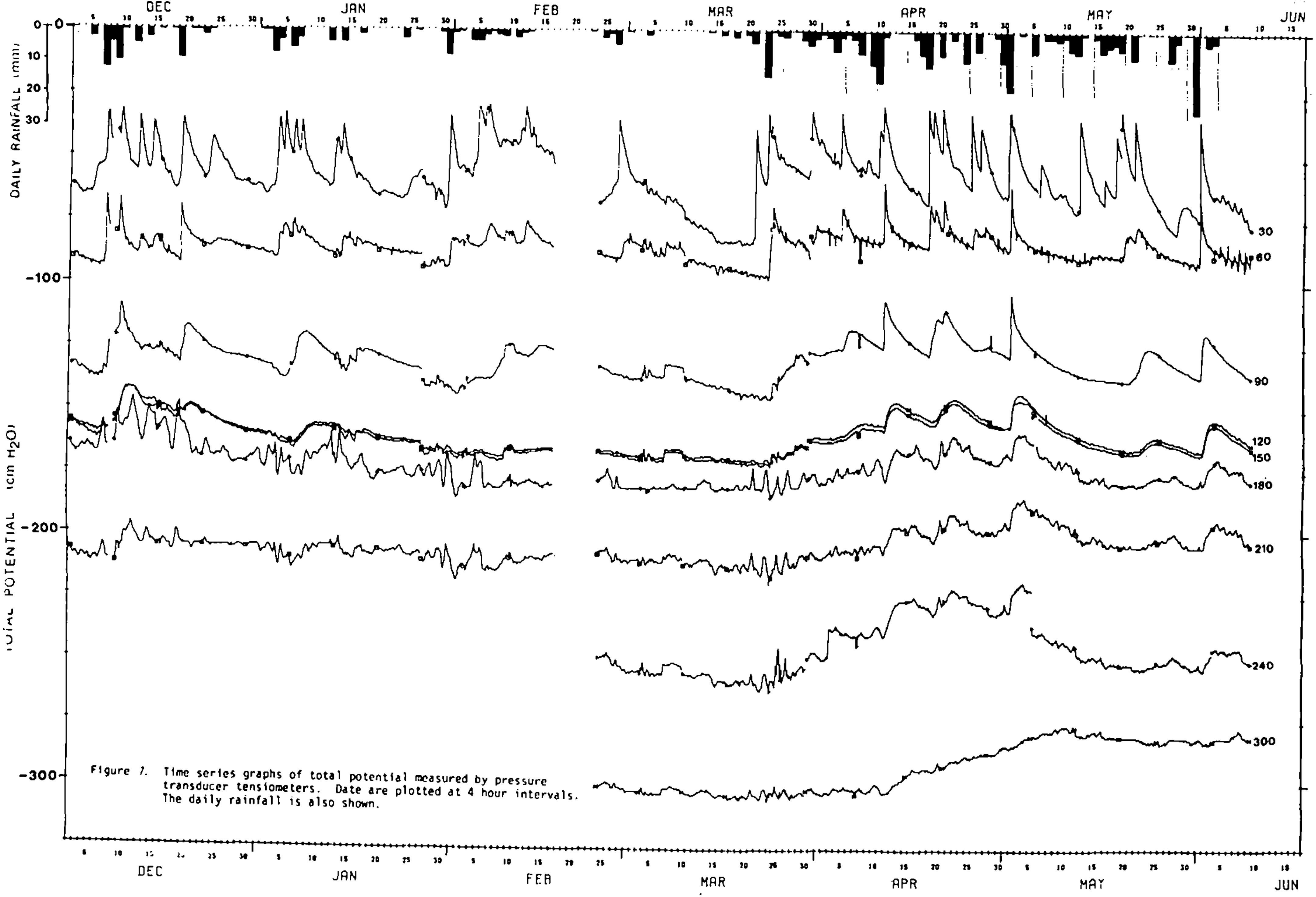

Figure 7. Time series graphs of total potential measured by pressure transducer tensiometers. Date are plotted at 4 hour intervals. The daily rainfall is also shown.

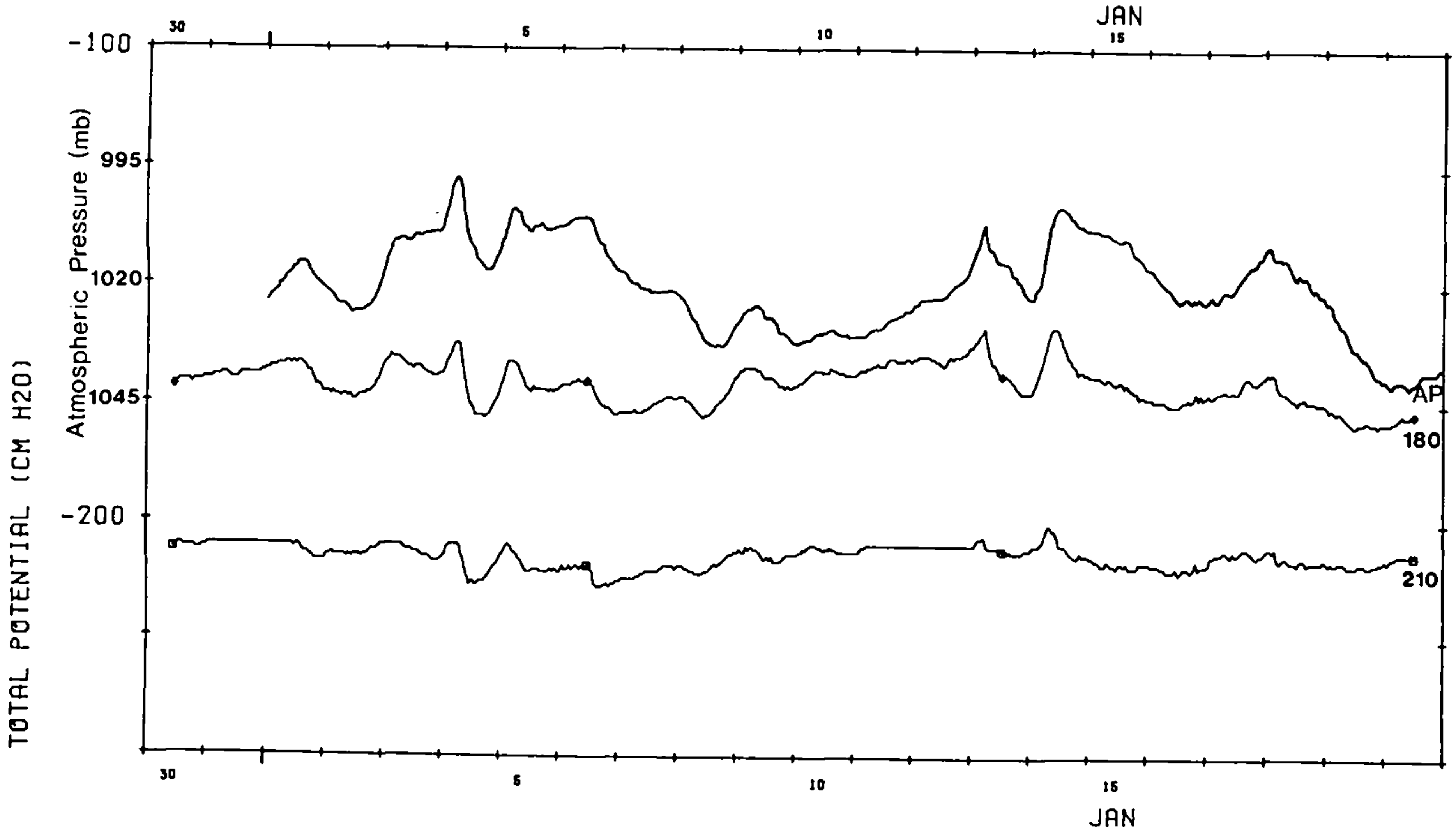

Figure 8. Time series graphs of total potential plotted at hourly intervals for the 1.8 and 2.1m depths, compared with atmospheric pressure variations measured at the RAE, Bedford. (N.B. The pressure scale is inverted).

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