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Estimating groundwater recharge through glacial till at Bacon Hall, Shropshire

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The National Rivers Authority

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EXECUTIVE SUMMARY

A study was undertaken to obtain estimates for recharge to groundwater through glacial till. The work was carried out in support of the Hydrogeological Classification of Superficial Clays programme; a co-funded programme of research between BGS and the National Rivers Authority.

Estimates were made using data from Bacon Hall, one of a series of sites used to monitor the Shropshire Groundwater Scheme. The sites are instrumented to measure the effect on soil moisture due to the pumping of wells, installed to enhance flows in the River Severn during dry periods. Each site consists of two piezometers, two neutron probe access tubes and a nest of tensiometers.

A value of 167 mm of groundwater recharge was obtained for 1989-90. This is 28.8% of the annual rainfall. However, doubts about the hydrogeological system at the site and the interval at which data was available, both in time and depth raises questions about the accuracy of the estimates.

1. AIMS

This report describes a study undertaken to obtain estimates for recharge to groundwater through glacial till. The work was carried out in support of the Hydrogeological Classification of Superficial Clays programme; a co-funded programme of research between BGS and the National Rivers Authority.

The work has been restricted to one data set obtained from one of the series of sites used to monitor the Shropshire Groundwater Scheme. The sites are instrumented to measure the effect on soil moisture due to the pumping of wells, installed to enhance flows in the River Severn during dry periods. Each site consists of two piezometers, two neutron probe access tubes and a nest of tensiometers. Two of these sites are underlain by glacial till, but only one, Bacon Hall, is monitored throughout the year.

2. METHODOLOGY

The method to calculate recharge uses measurements of the moisture content and the water potential of the soil profile: it is described in Cooper (1980).

When a zero flux plane (ZFP) exists in the soil profile, which will most likely be in the summer months, the water moving upwards towards plant roots can be separated from water moving downwards. Changes in moisture content below the ZFP will then define the volume of water draining downwards. This drainage is an estimate of recharge to the water-table. No meteorological data is required. The ZFP is identified from the soil-water potential curve at the point where the potential gradient changes from negative to positive.

In the winter months when no ZFP is generally present, water flows downwards throughout the profile. The recharge is calculated using a water balance for the unsaturated zone. As the soil moisture deficit is expected to be small a reasonable estimate of evaporation can be made. The change in the soil water storage is obtained from examining the change in the soil moisture content profiles with time.

3. BACON HALL SITE

Only one site which is monitored throughout the year, within the Shropshire Groundwater Scheme, is underlain by till; this is Bacon Hall. Here a thickness of approximately 12 m of till overlies Permo-triassic sandstones. The two piezometers on the Bacon Hall site reach depths of 5.3 m (last 1.3 m open) and 2.85 m (last 1.0 m open). The logs of these piezometers are as follows:

Shallow		Deep	
0 - 0.9 m	pebbly loam	0 - 0.9 m	loam
0.9 - 2 m	sand	0.5 - 2 m	sand
2 - 2.5 m	sandy clay	2 - 3.5 m	clay and sandy clay
2.5 - 3.5 m	clay	3.5 - 3.6 m	silty clay
		6 - 7.5 m	sand

The Bacon Hall site has been monitored since 1983. The more recent groundwater level data taken from the two piezometers is plotted in Figure 1. This shows two very similar hydrographs with water-levels separated by approximately 2.5 m: the higher water-level is in the shallower piezometer. It is likely that the upper water-level is caused by a perched water-table. If the layer below was recharged by leakage from this perched water-table there should be a lag in the fluctuation of the lower water-level. This is not the case, no lag is evident. It suggested, therefore, that water is recharging the lower level laterally from an area where the upper confining layer does not exist. The question arises, is the lower level the regional water-level or also a perched water-table? The regional hydrogeologist from the Severn-Trent NRA

suggested that, if this was the regional water-level, a greater recession would have been seen during the drought of 1992 than is evident on the hydrograph. It is therefore likely that the lower level is also a perched water-table.

However, as the neutron probe access tubes are completed at a depth of 2.8 m and the tensiometer at 2.4 m, the only option at the site was to estimate the recharge to the shallower of the two perched water-tables.

4. DATA ANALYSIS

Water-level, rainfall, soil moisture content and tensiometer data were output from the Severn-Trent NRA database in the form of dBase files. This was converted into Lotus 1-2-3 spreadsheet format using the dBase IV package. The records within the Lotus 1-2-3 file were sorted on the station number, allowing the data for Bacon Hall to be abstracted. A file exists for each type of data for each year. The monitoring sites exist to identify any water stress caused to crops due to groundwater abstraction for river augmentation. As such the interval between readings is greatest during summer months (weekly) and smallest during winter months (monthly). Data were abstracted for 1989 and 1990. Figures 2 and 3 show the rainfall for this period.

Figures 4a-h show the soil moisture profiles for one of the access tubes on site, N052. The drop in soil moisture at the top of the profiles is due to ground surface effects. The soil moisture content is measured at intervals of 0.1 m to a depth of 1.4 m and at 0.2 m from here to the base of the access tubes, at 2.8 m.

Figures 5a-h show the tensiometer data. The soil-water pressure is measured at intervals of 0.1 m to a depth of 2.4 m. The gravitational potential line is drawn on each plot. The water-level in the vicinity of the tensiometer set is identified by the point at which the pressure reading equals the gravitational potential. The estimated position of the ZFP is marked on each plot, where present.

5. RESULTS

Using the method set out in chapter 2, the quantities of groundwater recharged between the monitoring dates were calculated. During periods when no ZFP existed, the unsaturated zone water balance was estimated using soil moisture and rainfall measurements along with evapotranspiration data obtained from the Meteorological Office Rainfall and Evaporation Calculating System (MORECS). Tables A.1 and A.2 in Appendix A show the values of recharge for 1989 and 1990.

To obtain groundwater recharge as a percentage of rainfall, a period within 1989 and 1990 was defined that encompassed one full recharge cycle, 31 October 1989 to 7 November 1990. The total recharge in this period was estimated as 167.0 mm which was 28.8% of the rainfall during that period.

6. DISCUSSION

The value of recharge as a percentage of rainfall over the period of a year appears reasonable. It compares well with estimates of recharge through sandy till made by Johansson (1987,1988) in a region of similar annual rainfall. Doubts were, however, raised during the analysis about the method used to calculate recharge. Two areas of potential error are highlighted here.

a) During the periods within 1989 and 1990 when ZFPs exist, the depth from the ZFP to the water-level in the upper perched water-table ranges from 0.0 m to 1.0 m. During the periods when no ZFP exists the depth from ground surface to the water-table ranges from 1.0 m to 1.8 m. In both cases the thickness of the unsaturated zone over which water balance calculations are made is

small in relation to the measurement interval of the tensiometer and the neutron probe and sometimes unrealistic. It is likely that significant errors will be introduced as a result. These errors may be greatest when using the tensiometer data to locate the ZFP. Small variations in pressure over a number of tensiometer readings can mean finding its exact position is difficult. The value of recharge is sensitive to the location of the ZFP.

b) The appearance of the water-table within the soil moisture profile negates the assumption that the water contained within the profile is moving only vertically as it is likely that lateral movement of water takes place within the saturated zone (see section 3). This lateral movement will tend to reduce the estimate of recharge both during periods with and without ZFPs and as shown in Appendix A can cause the recharge to be negative.

7. CONCLUSIONS

The estimate of groundwater recharge, of 28.8% of the annual rainfall, made at the Bacon Hall site does appear reasonable. Time restrictions limited the analysis of data to only one season of recharge. However, the doubts about the hydrogeological system at the site and the close proximity of the (perched) water-table to the surface have raised questions about the validity of the estimates, and as such, preclude further analysis.

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ACKNOWLEDGEMENTS

Many thanks to Kevin Voyse of Severn-Trent NRA for his help in obtaining the data used in this report.

APPENDIX A RECHARGE CALCULATIONS FOR BACON HALL, SHROPSHIRE

Table A.1 Recharge calculations for Bacon Hall, Shropshire, 1989

	ZFP present	ZFP depth (mbgl)	water-level (mbgl)	recharge (mm)
11-Jan-89	n		1.6	
09-Mar-89	n		1.5	15.5
05-Apr-89	n		1.4	12.3
20-Apr-89	n		1.3	-6.4
09-May-89	y	0.4	1.4	21.6
15-Jun-89	y	1	1.5	33.8
21-Jun-89	y	1	1.6	3.0
28-Jun-89	y	1	1.6	6.2
06-Jul-89	y	1	1.6	5.7
13-Jul-89	y	1	1.7	12.0
20-Jul-89	y	1	1.7	-2.8
28-Jul-89	y	1.2	1.7	9.4
02-Aug-89	y	1.2	1.8	-13.5
08-Aug-89	y	1.2	1.8	-3.9
16-Aug-89	y	1.2	1.8	0.3
22-Aug-89	y	1.2	1.8	1.3
30-Aug-89	y	1.2	1.8	3.8
05-Sep-89	y	1.2	1.8	-6.4
14-Sep-89	y	1.4	1.9	-0.3
19-Sep-89	y	1.4	1.9	3.2
11-Oct-89	y	1.4	1.9	4.4
18-Oct-89	y	1.4	1.9	-0.6
25-Oct-89	y	1.4	1.9	-0.5
30-Oct-89	y	1.4	1.9	-1.5
07-Nov-89	y	1.4	1.9	4.5
13-Dec-89	n		1.8	20.4

Table A.2 Recharge calculations for Bacon Hall, Shropshire, 1990

	ZFP present	ZFP depth (mbgl)	water-level (mbgl)	recharge (mm)
09-Jan-90	n		1.3	26.7
07-Feb-90	n		1	35.3
09-Mar-90	n		1	-14.3
05-Apr-90	y	1.2	1.2	14.7
18-Apr-90	y	0.8	1.3	5.0
08-May-90	y	1	1.4	13.7
23-May-90	y	1	1.5	16.1
06-Jun-90	y	1	1.5	14.5
19-Jun-90	y	1	1.6	9.5
11-Jul-90	y	1	1.7	15.6
25-Jul-90	y	1.2	1.7	5.4
31-Jul-90	y	1.2	1.8	-0.9
08-Aug-90	y	1.4	1.8	1.2
14-Aug-90	y	1.4	1.8	0.8
21-Aug-90	y	1.4	1.8	5.1
30-Aug-90	y	1.4	1.9	-2.8
04-Sep-90	y	1.6	1.9	-0.8
13-Sep-90	y	1.4	1.9	1.2
21-Sep-90	y	1.4	1.9	0.8
04-Oct-90	y	1.2	2	-5.3
07-Nov-90	y	1.8	2	0.7
06-Dec-90	n		1.6	7.4

FIGURES

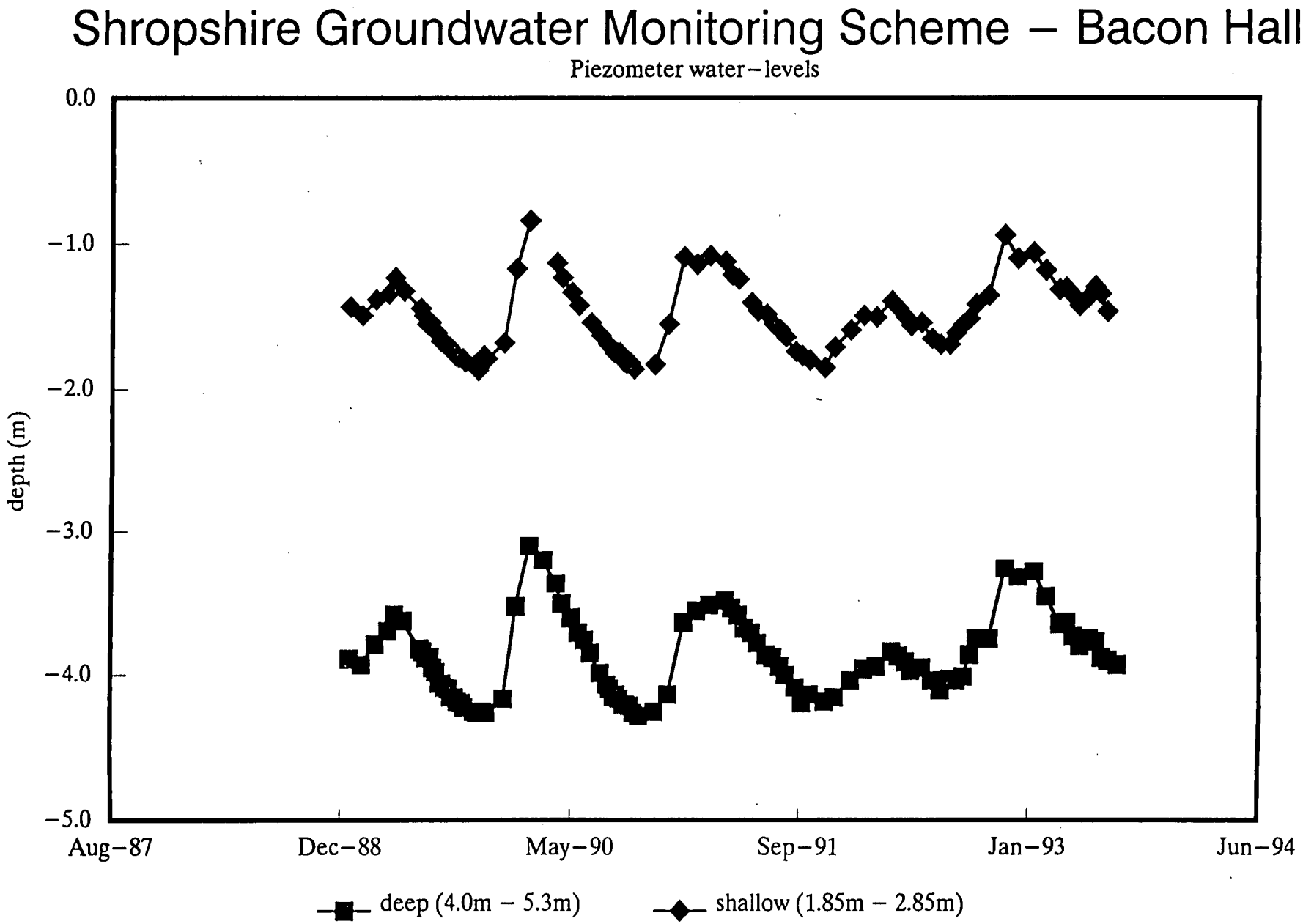

Figure 1 **Piezometer water-levels 1989-93, Bacon Hall site**

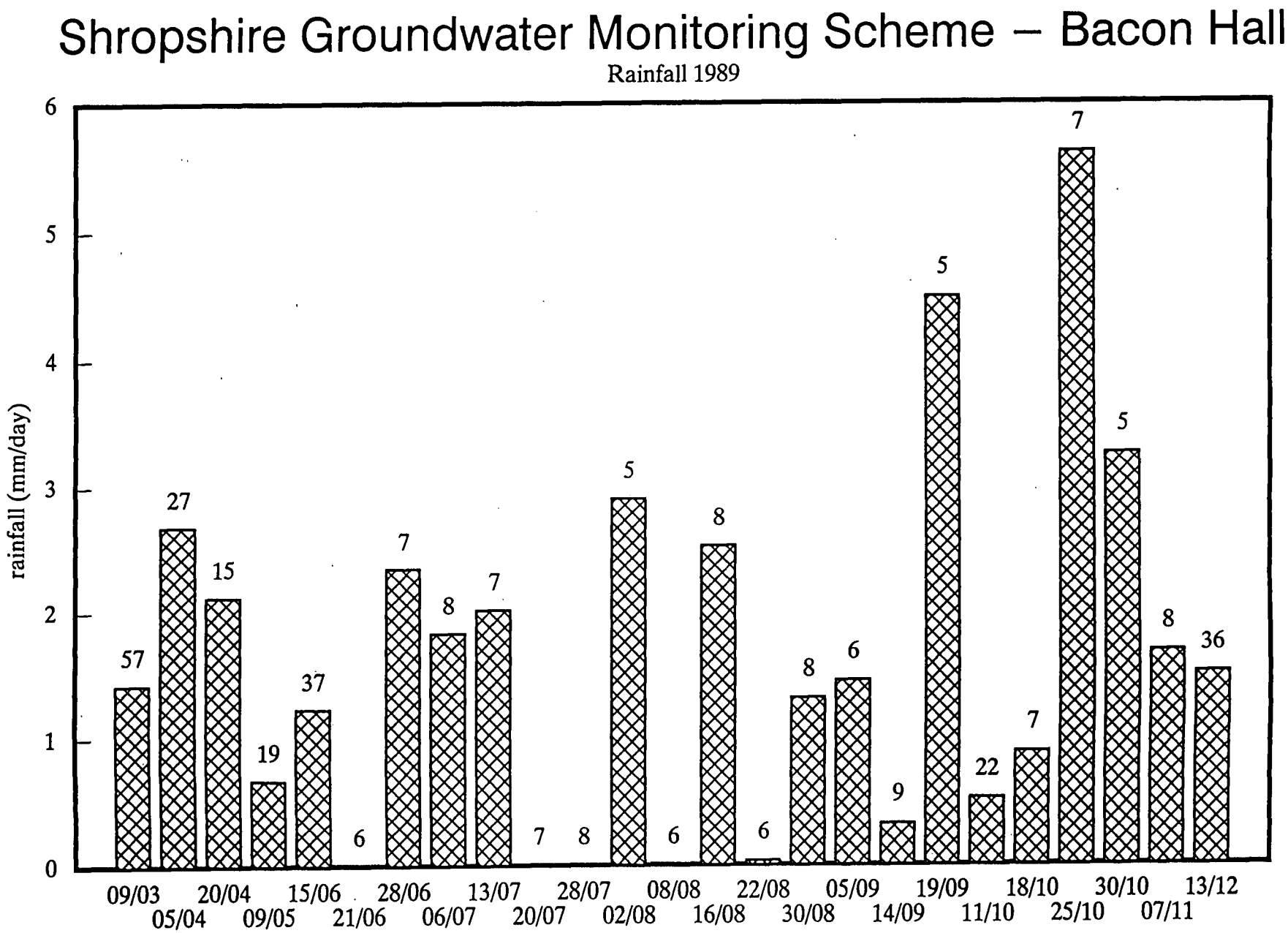

Figure 2 **Rainfall 1989, Bacon Hall site. Rainfall expressed as mm/day over the period between measurements - no. of days between measurements is given at the top of the each bar.**

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Rainfall 1990

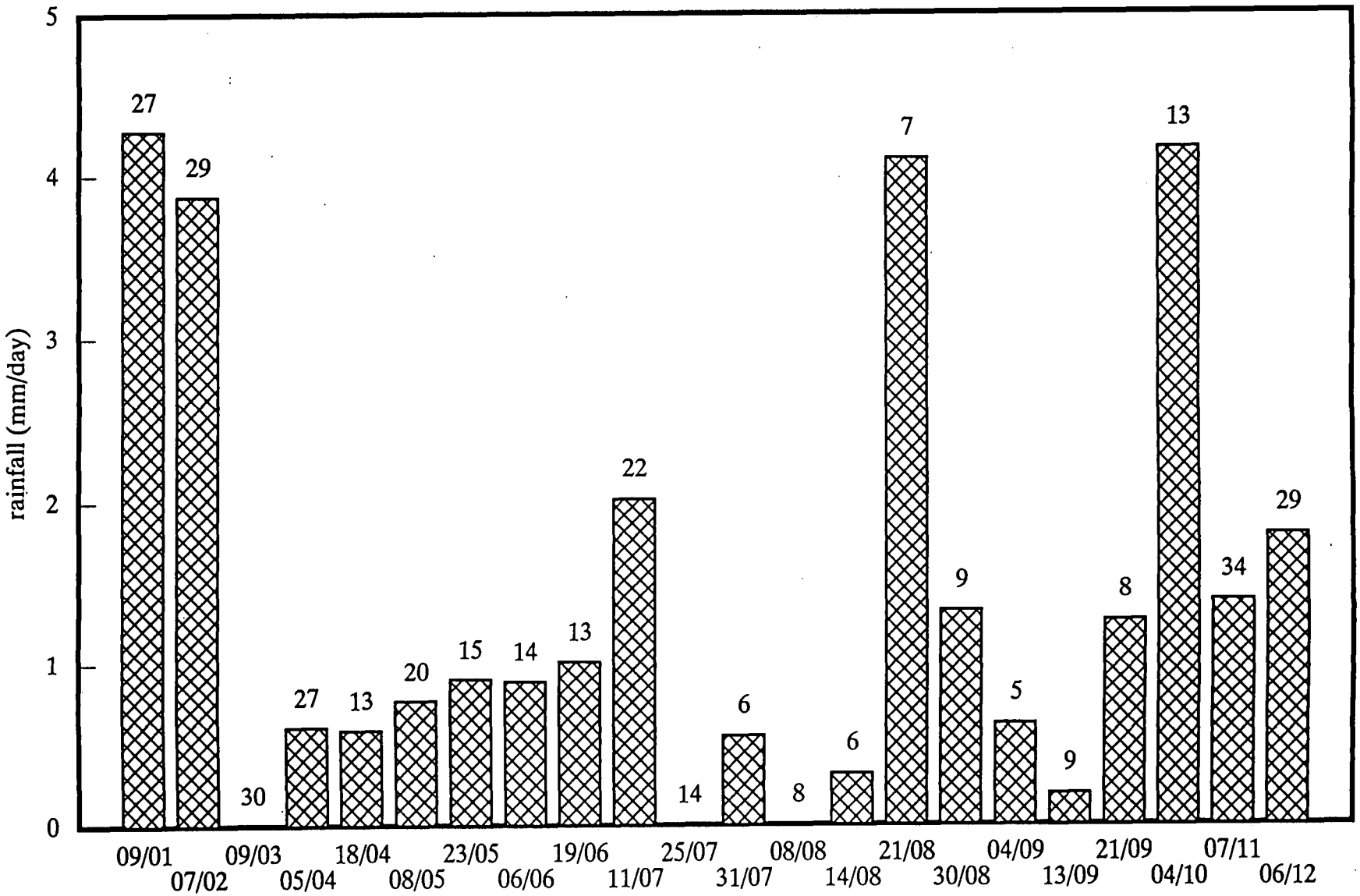


Figure 3 **Rainfall 1990, Bacon Hall site. Rainfall expressed as mm/day over the period between measurements - no. of days between measurements is given at the top of the each bar.**

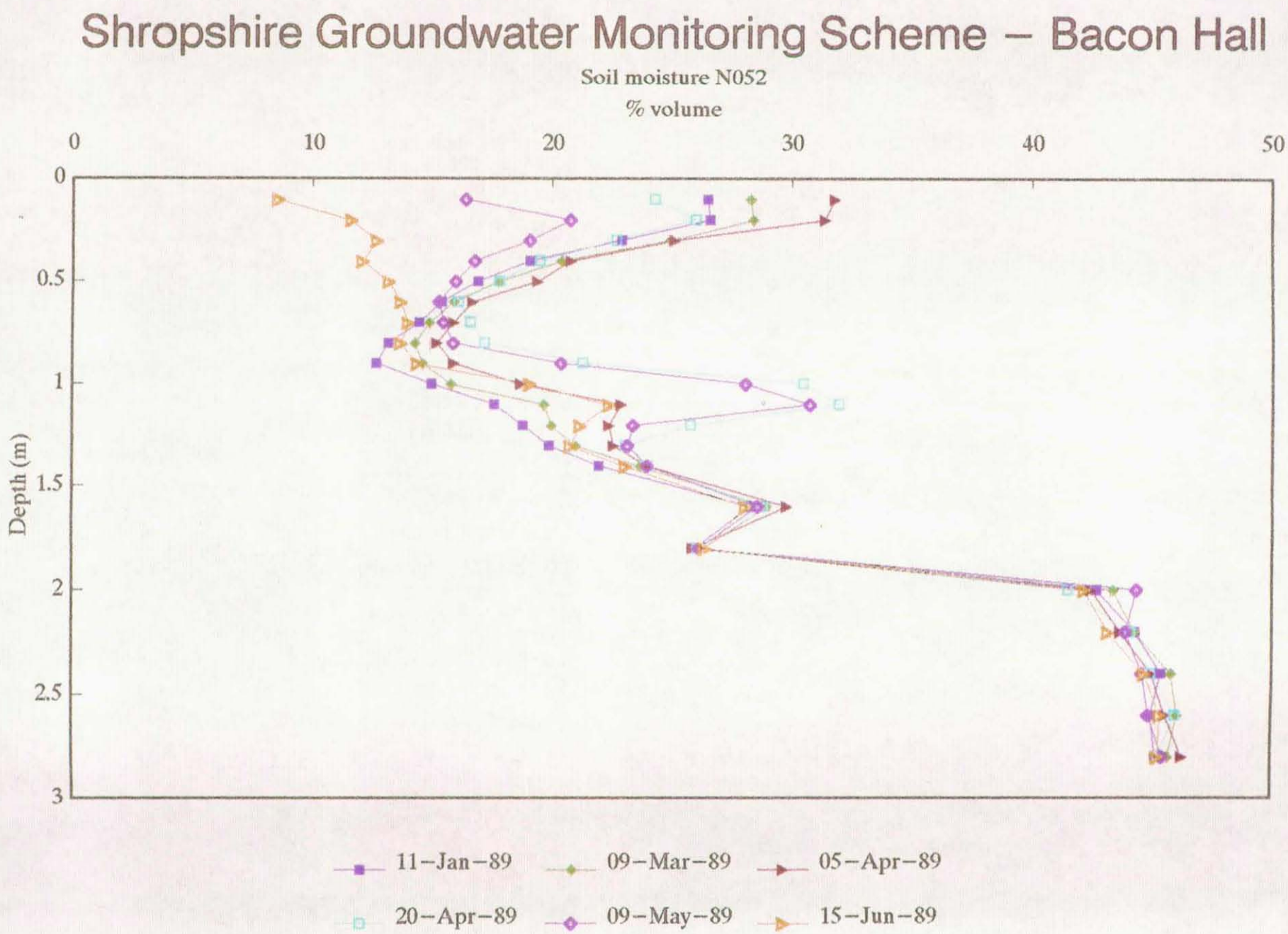


Figure 4a **N052 soil moisture content profiles 1989-90, Bacon Hall site**

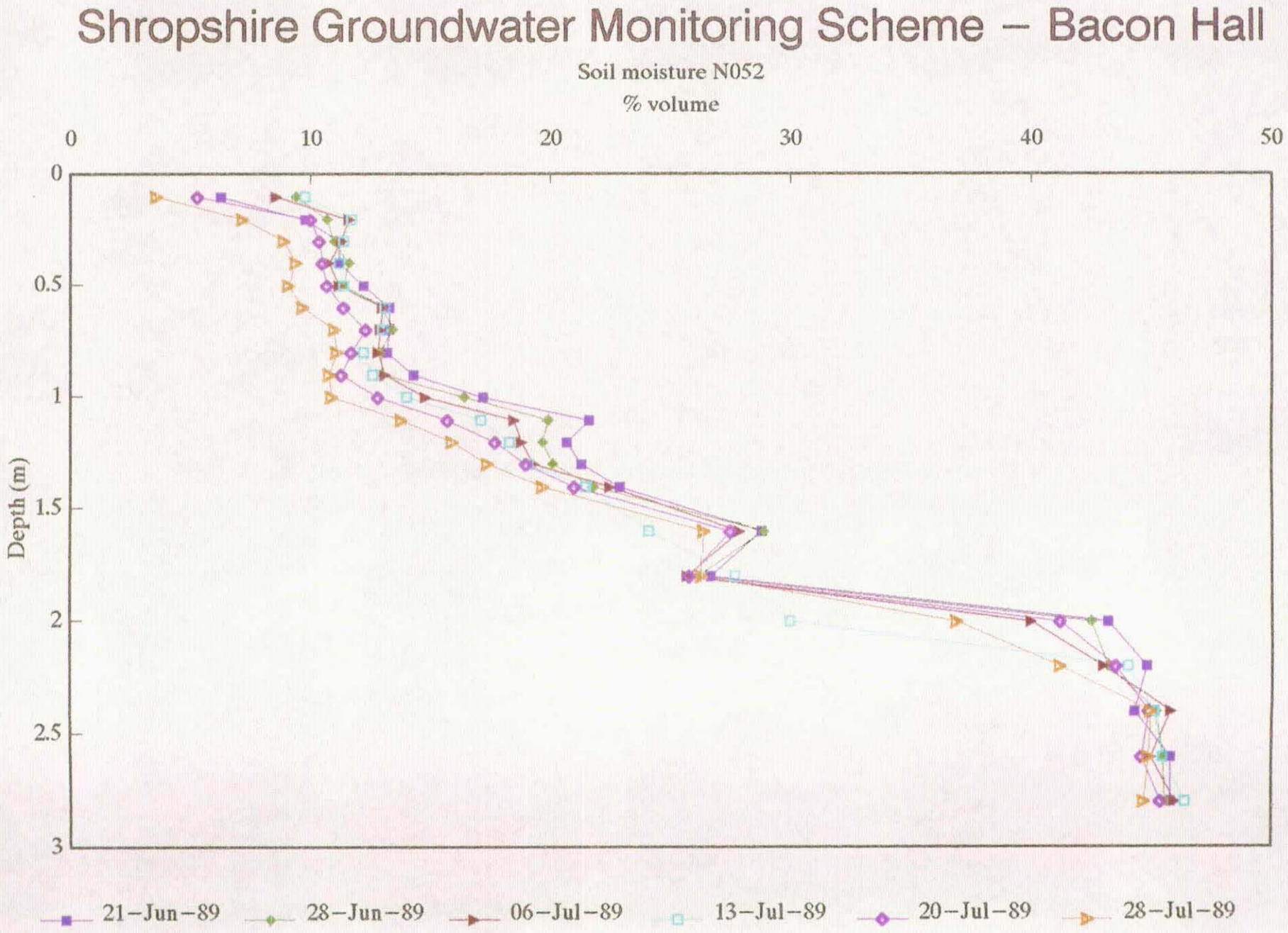


Figure 4b **N052 soil moisture content profiles 1989-90, Bacon Hall site**

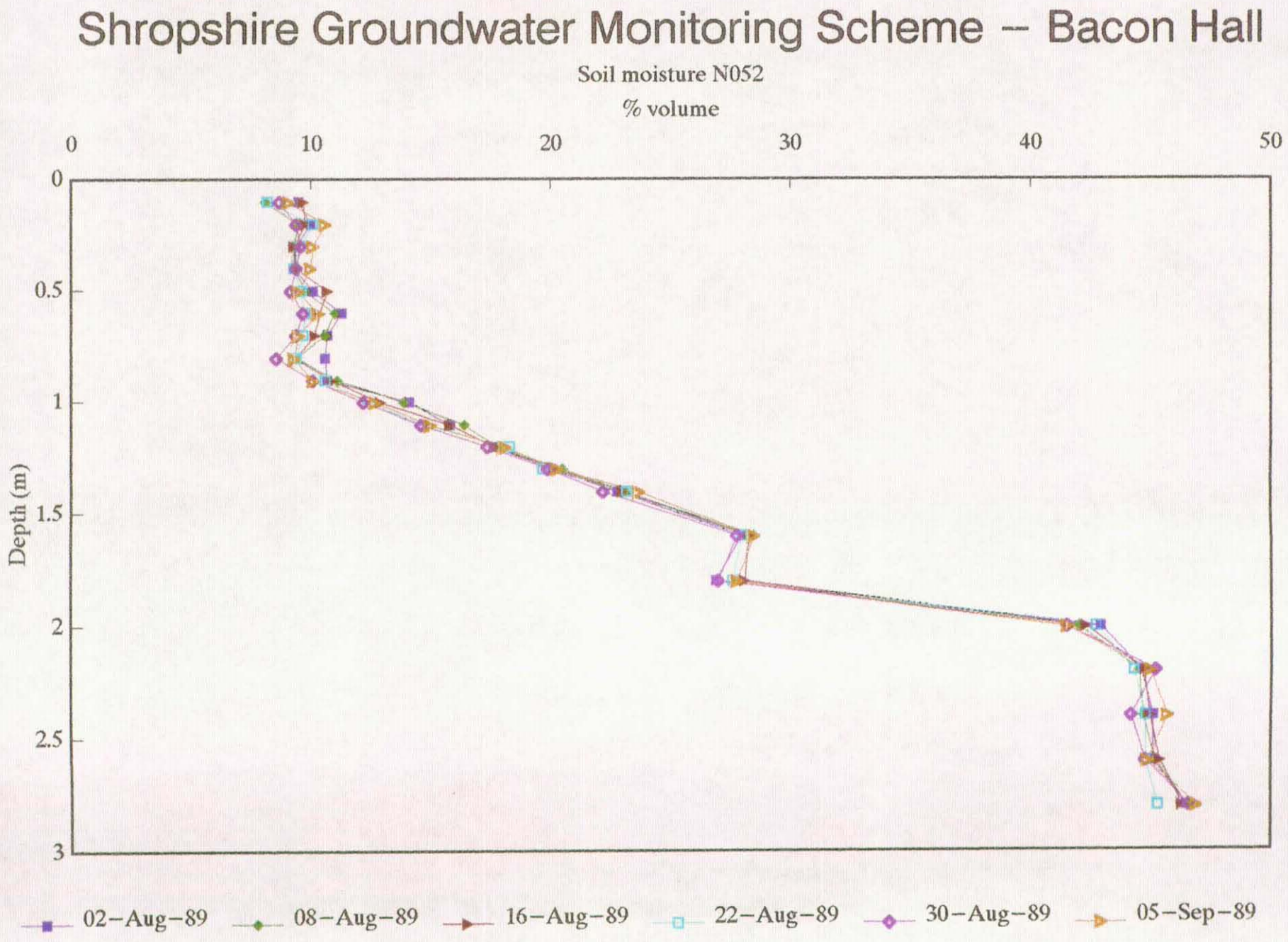


Figure 4c **N052 soil moisture content profiles 1989-90, Bacon Hall site**

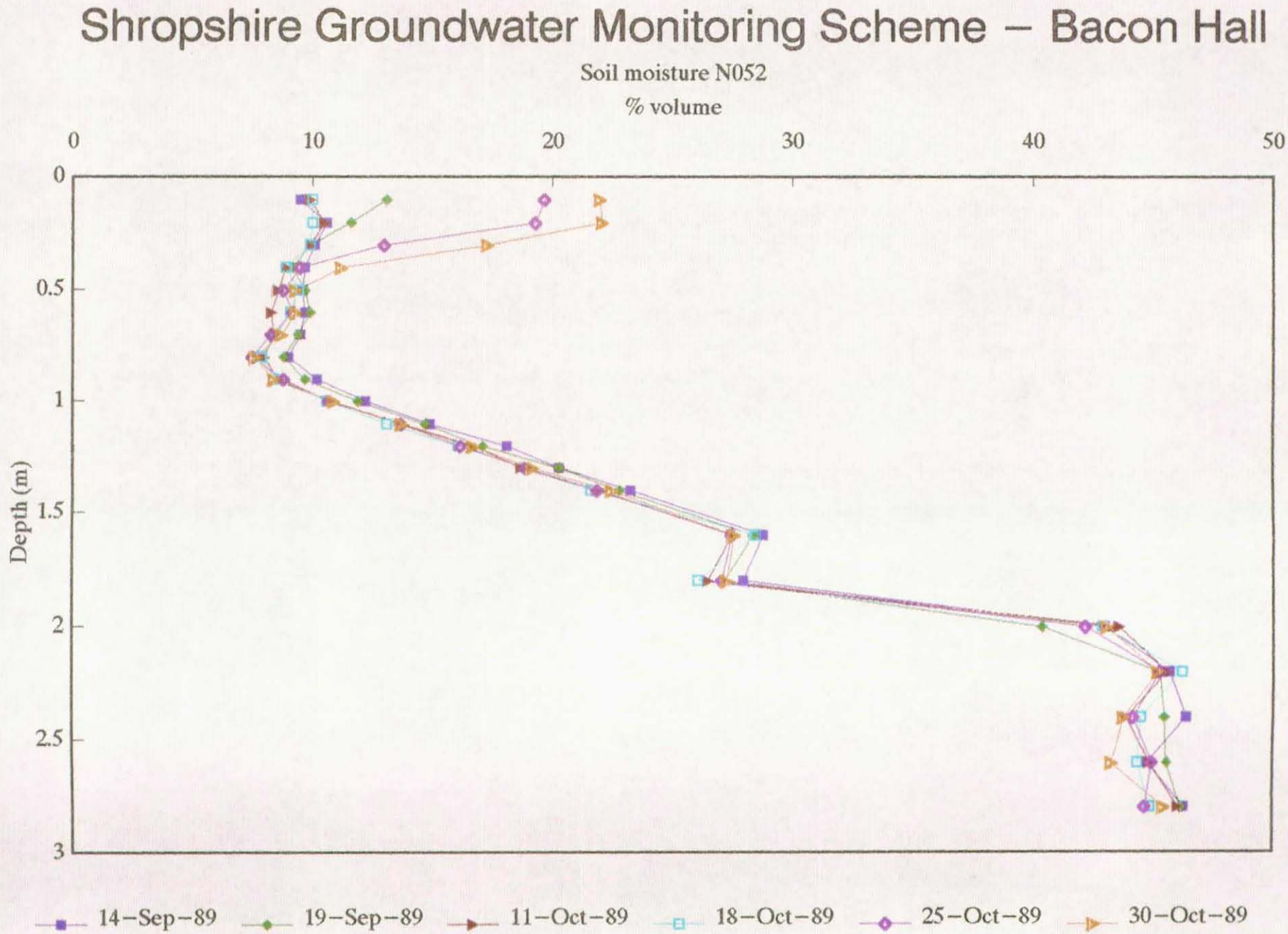
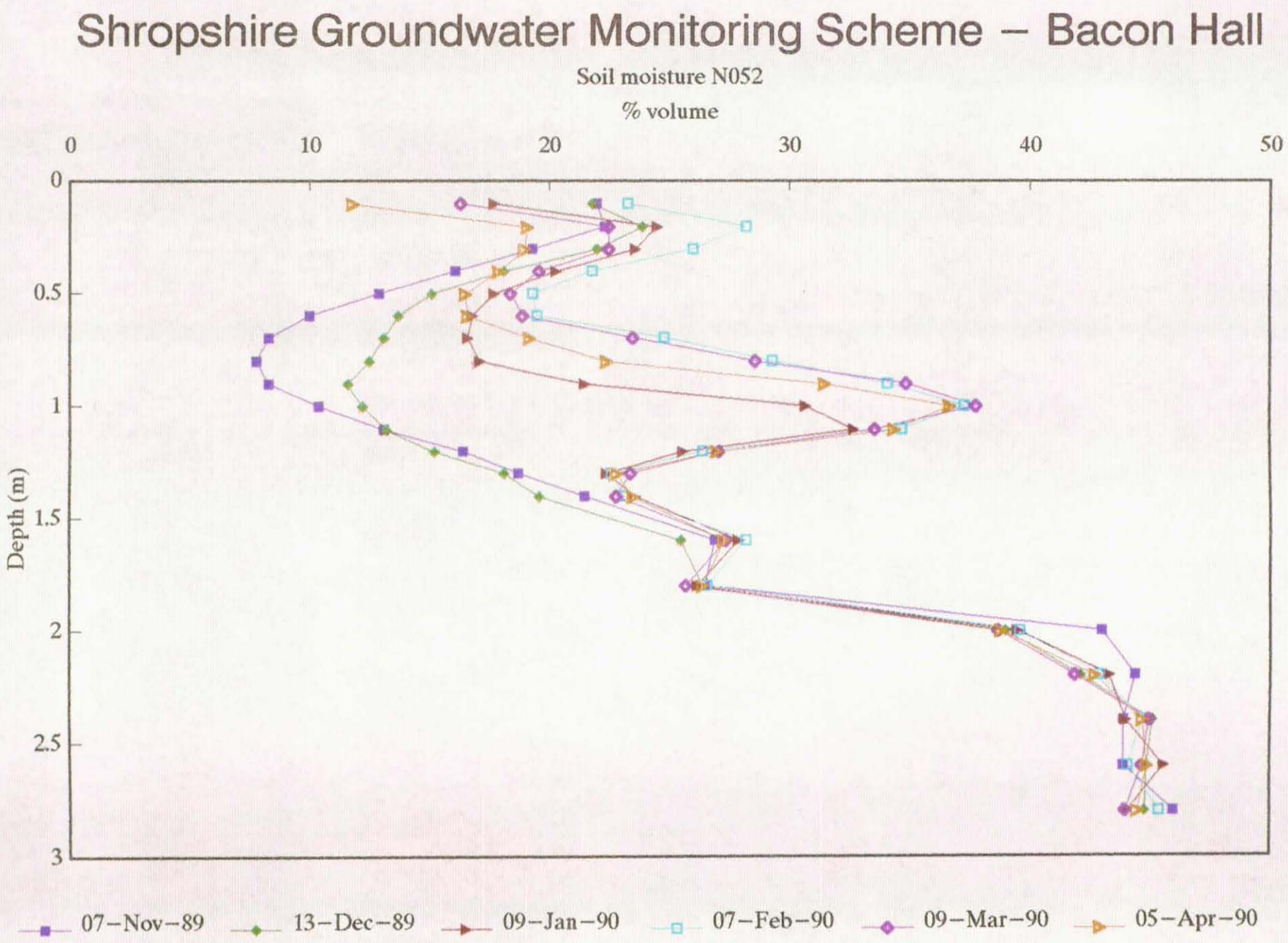


Figure 4d **N052 soil moisture content profiles 1989-90, Bacon Hall site**



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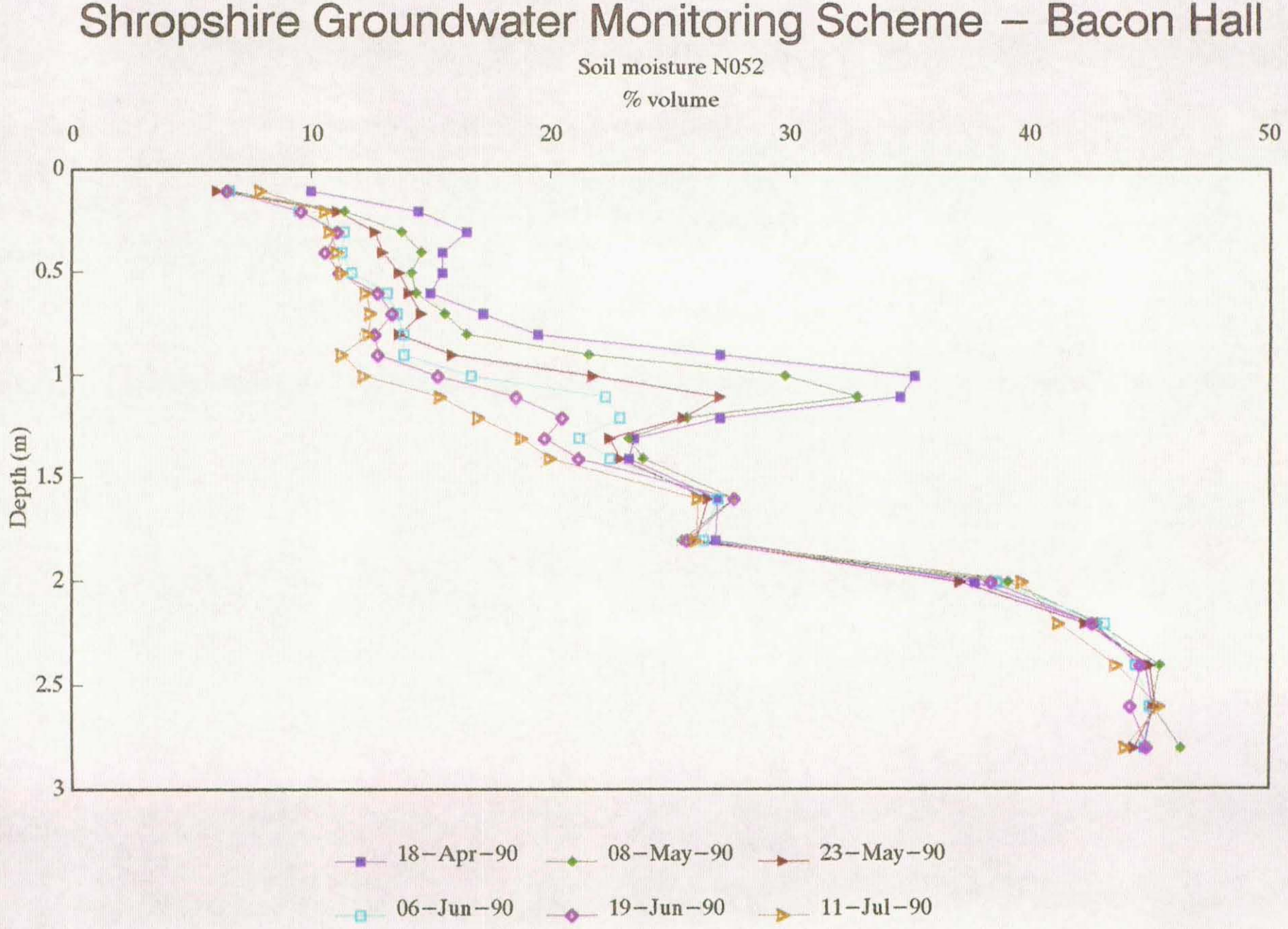
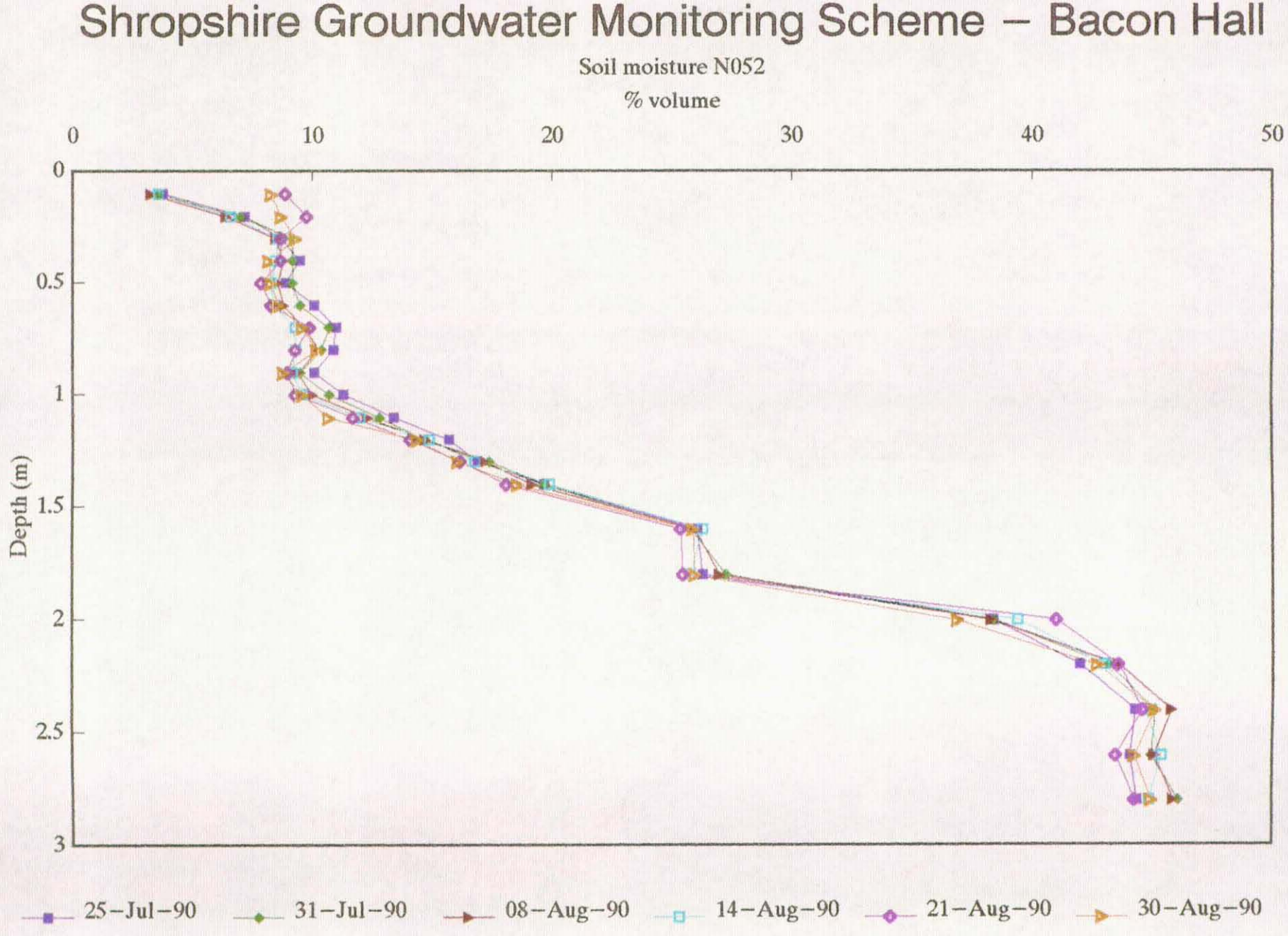


Figure 4f **N052 soil moisture content profiles 1989-90, Bacon Hall site**



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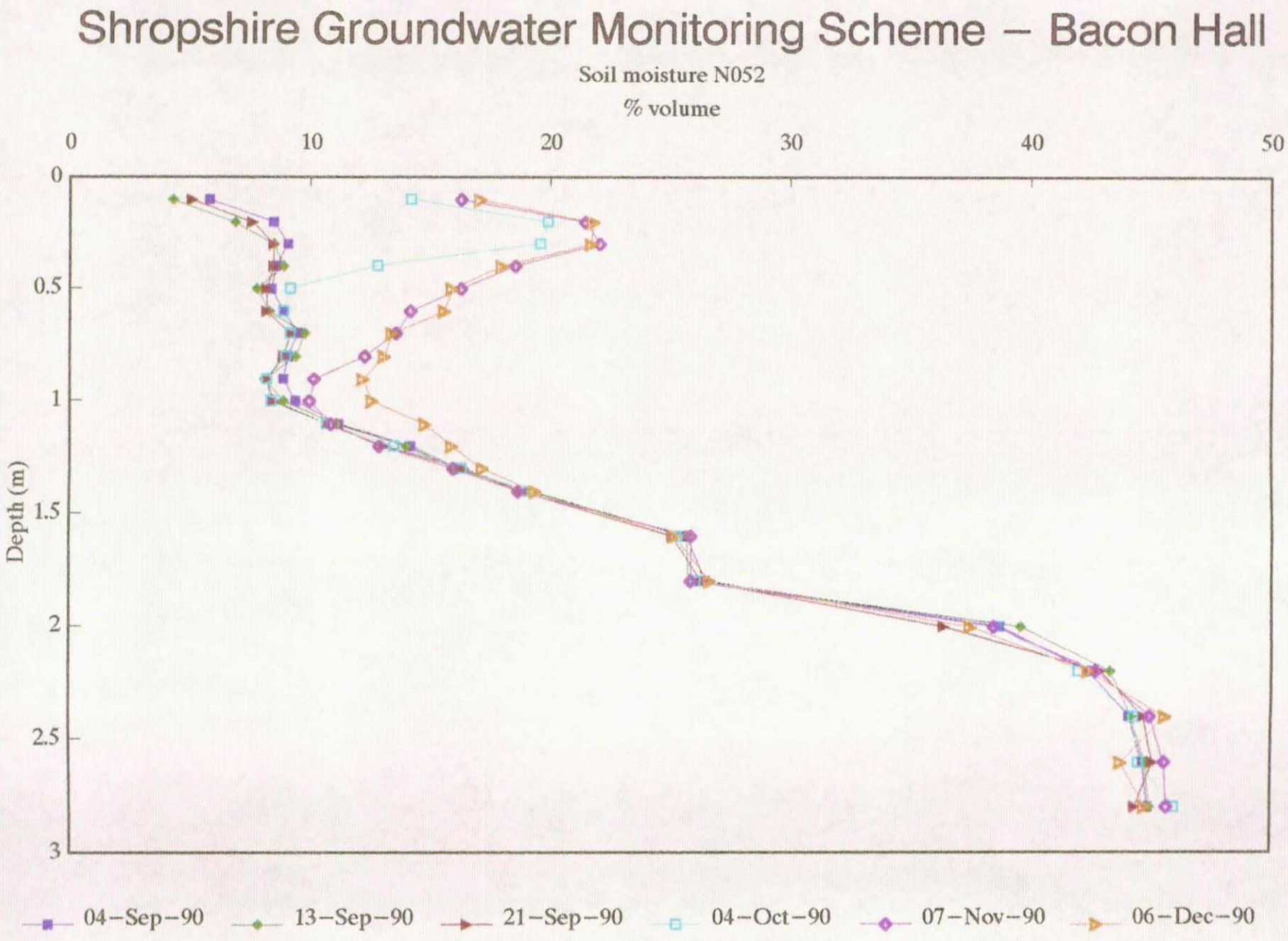


Figure 4h **N052 soil moisture content profiles 1989-90, Bacon Hall site**

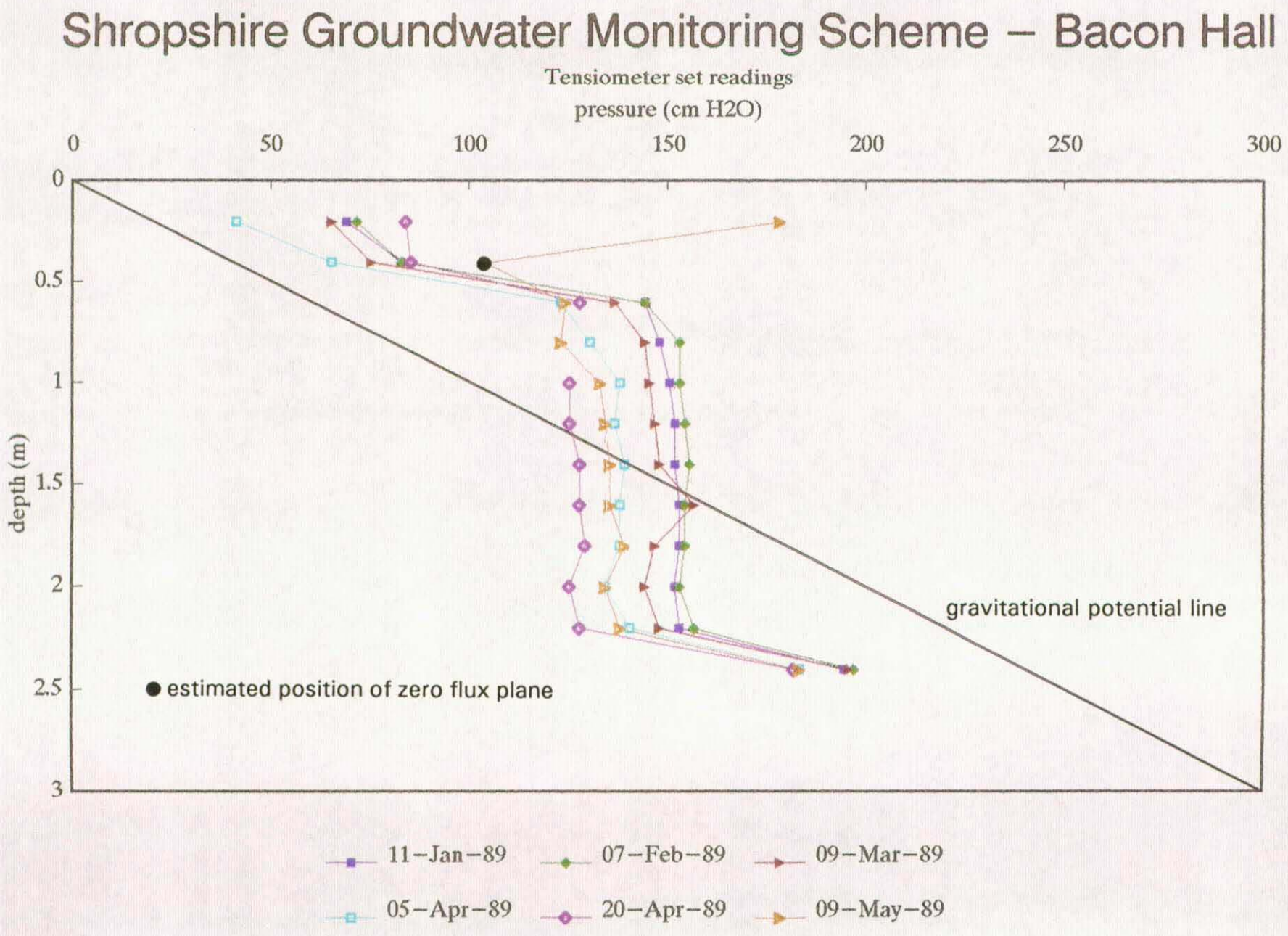


Figure 5a **Tensiometer set readings 1989-90, Bacon Hall site**

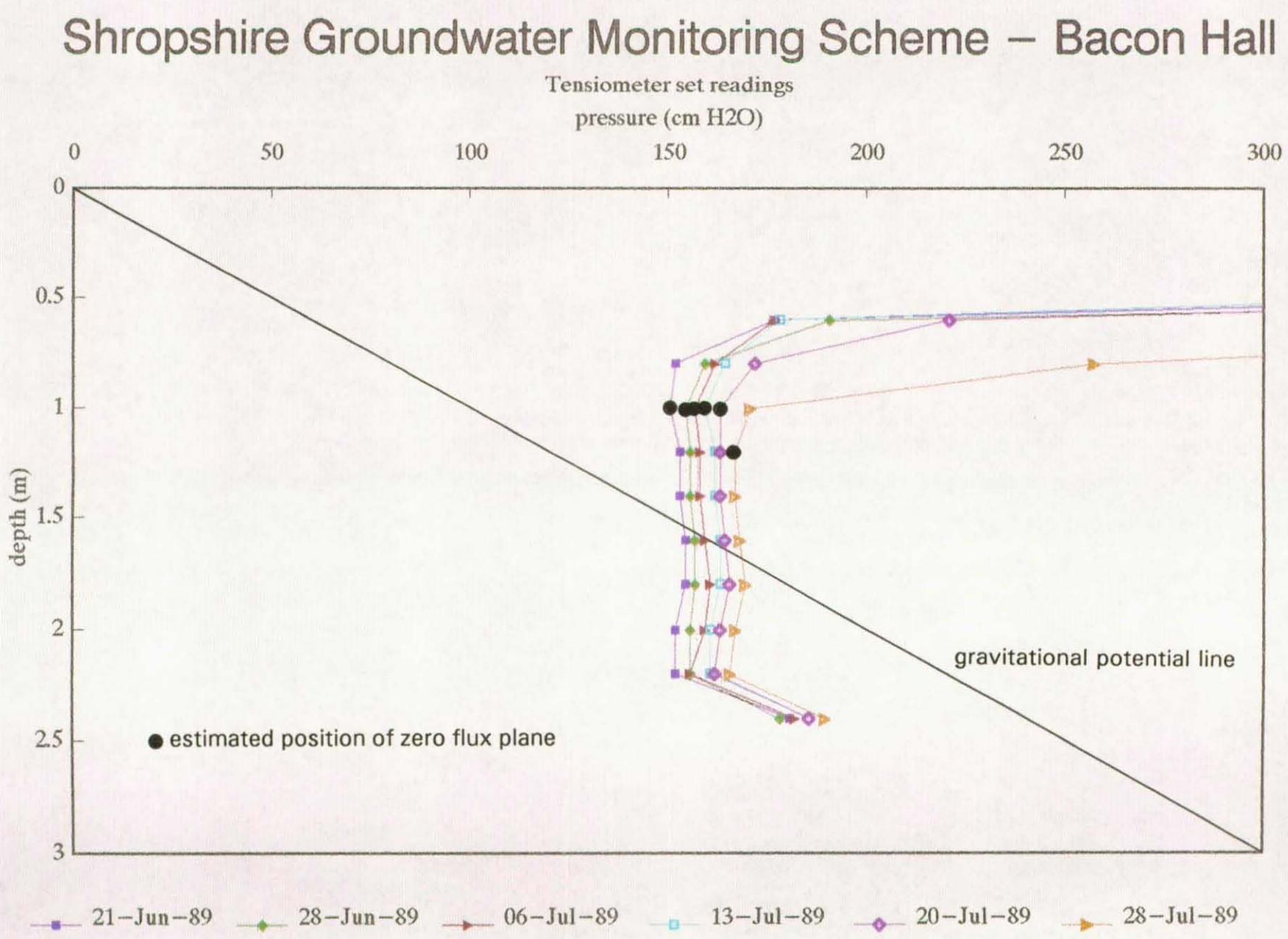
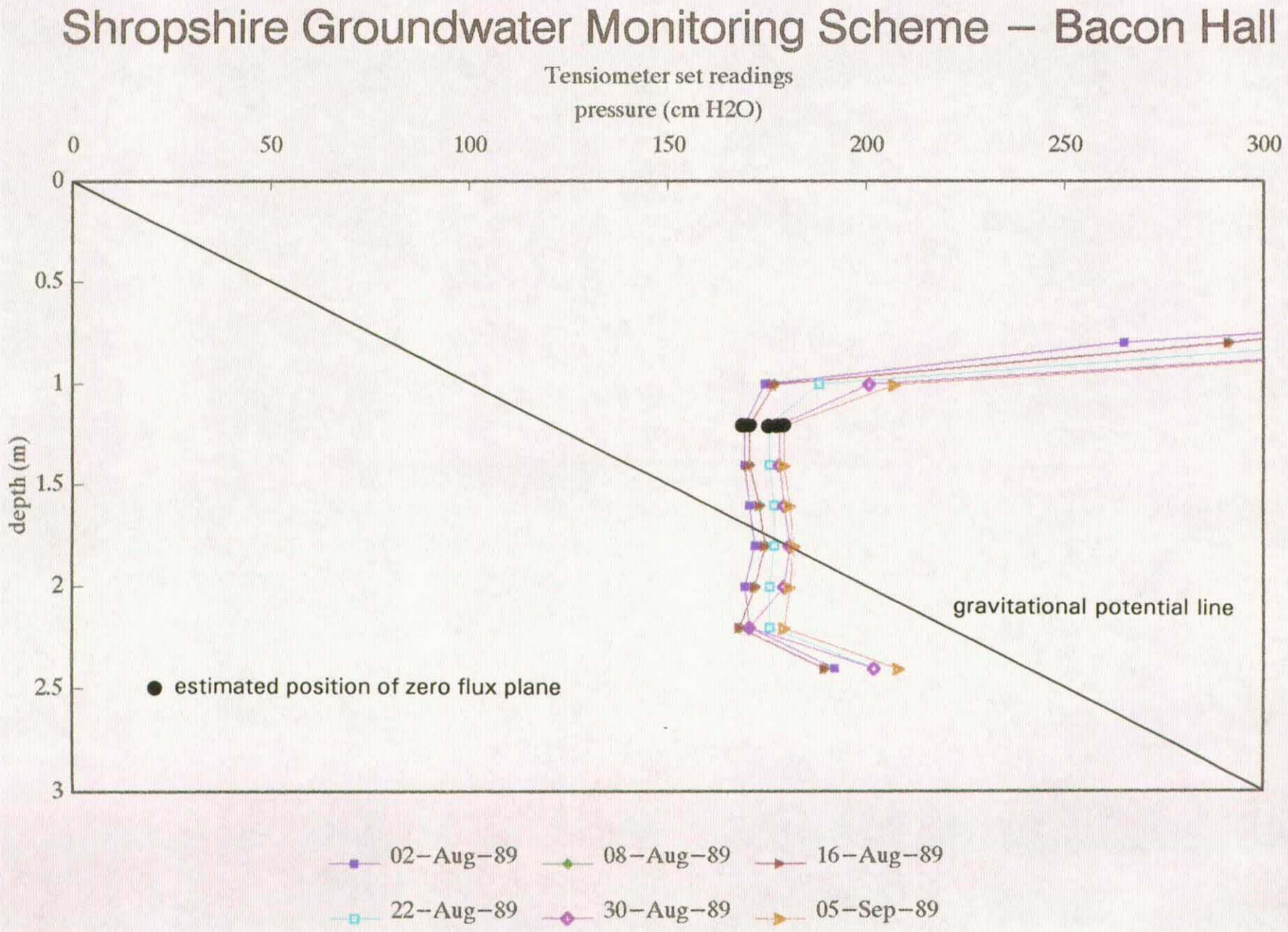


Figure 5b **Tensiometer set readings 1989-90, Bacon Hall site**



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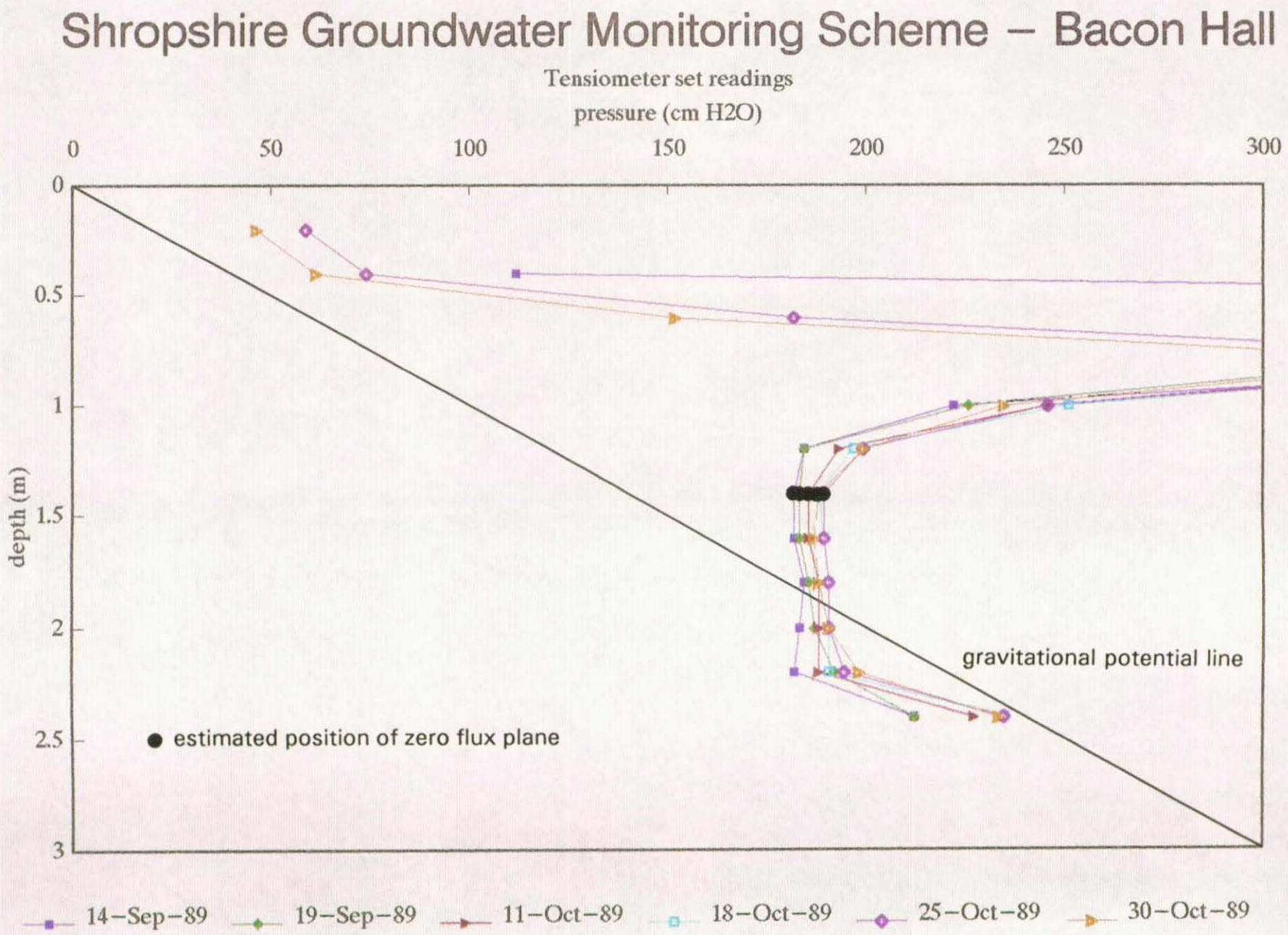
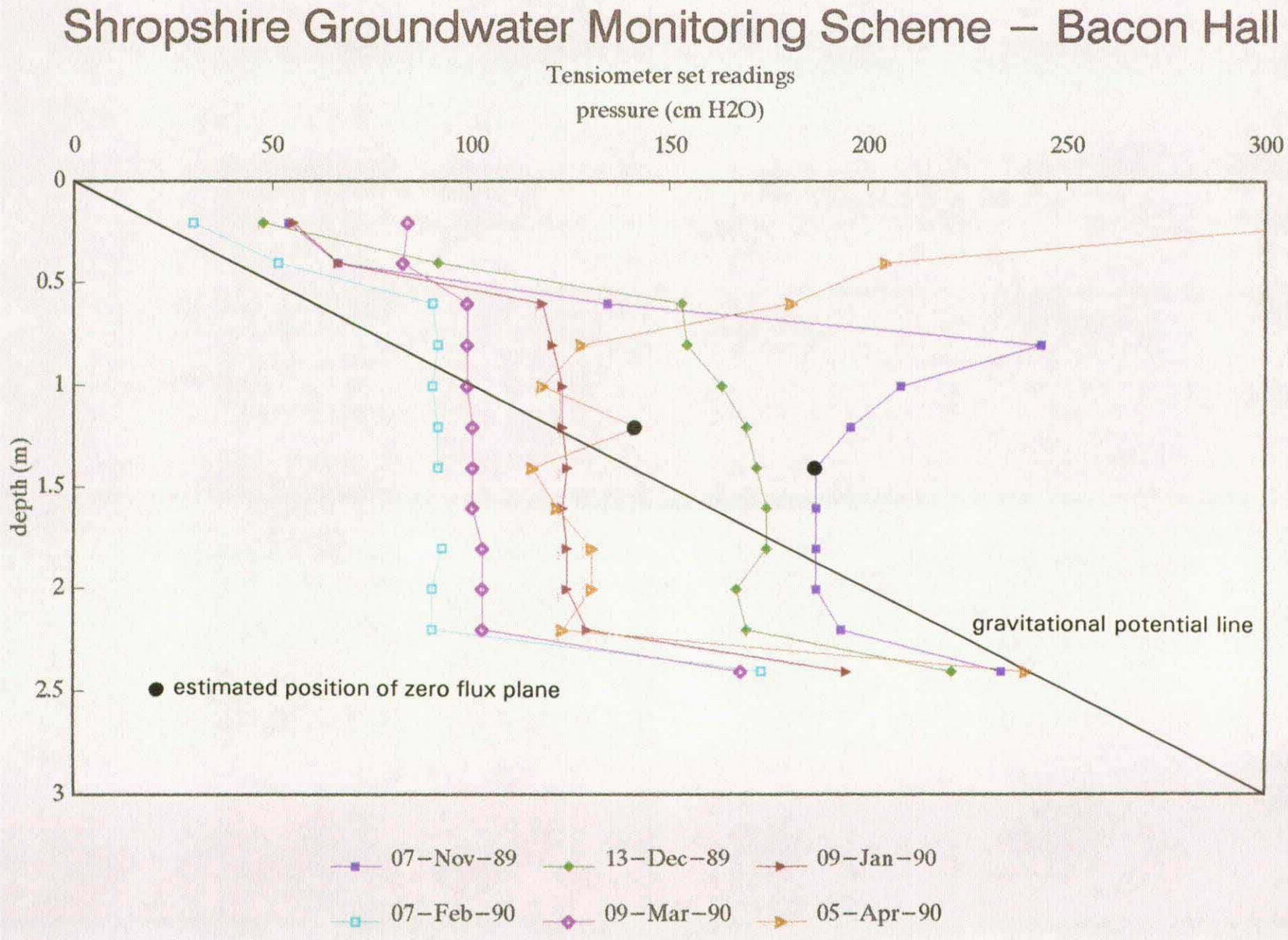


Figure 5d **Tensiometer set readings 1989-90, Bacon Hall site**



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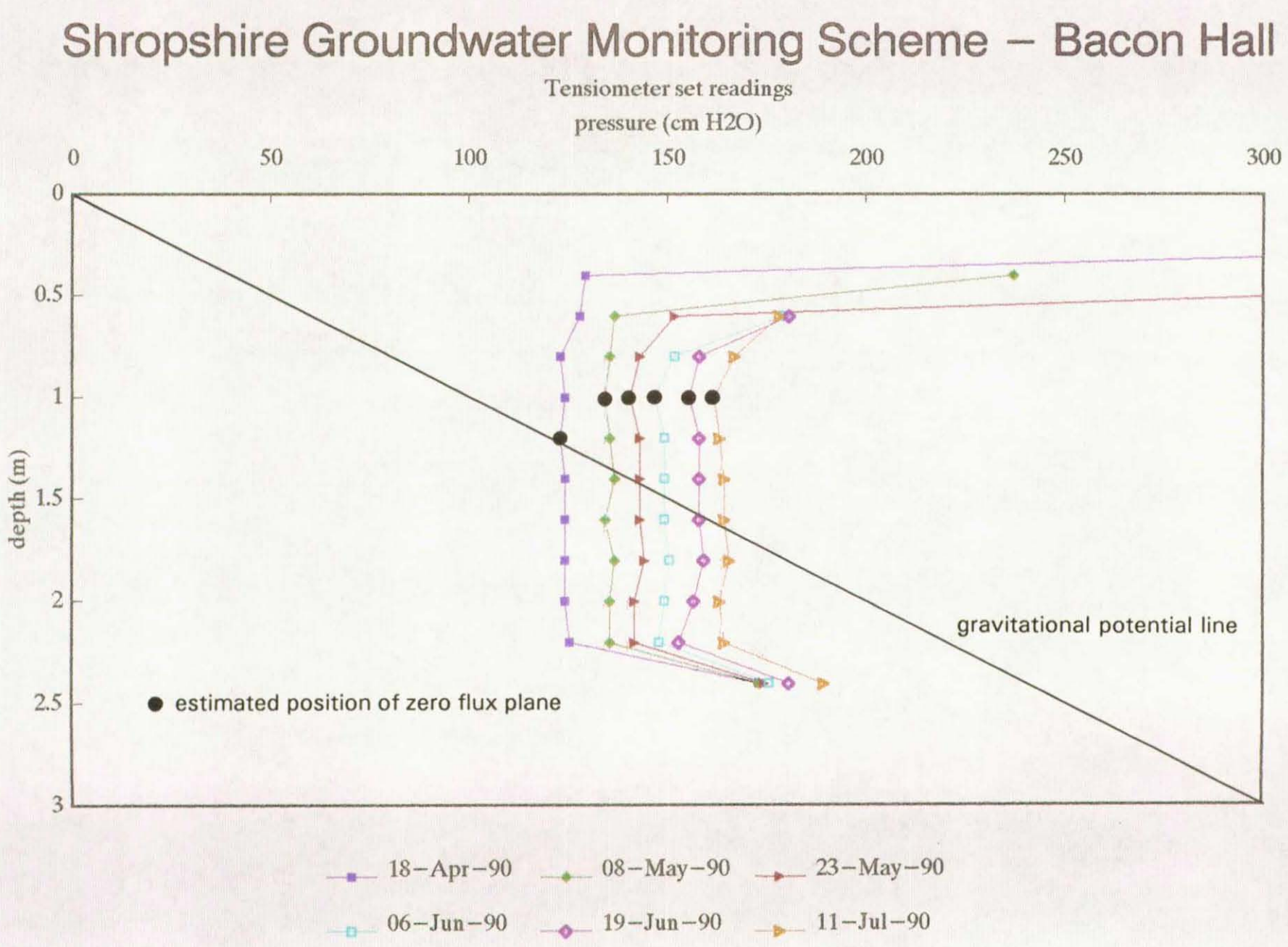

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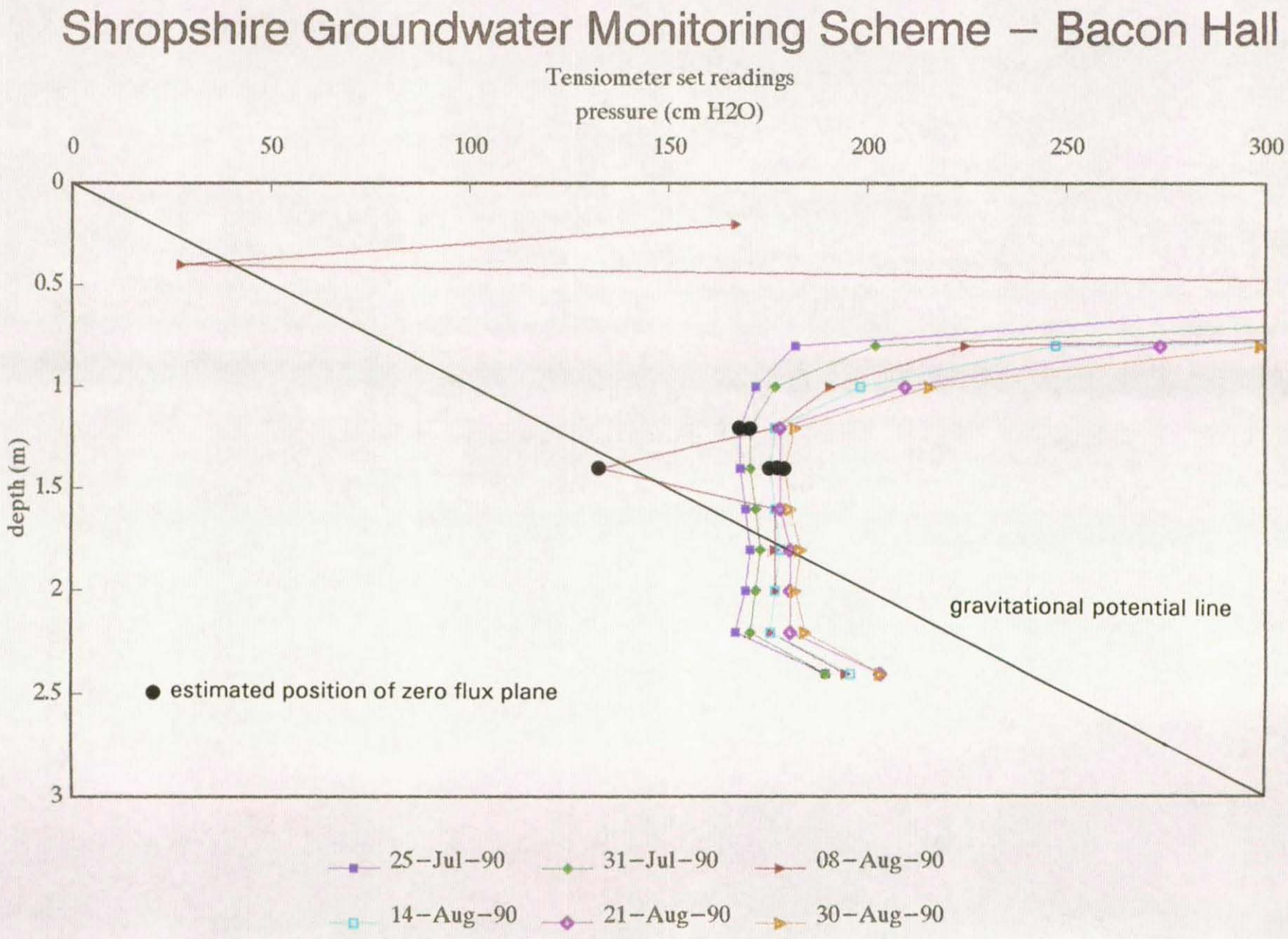

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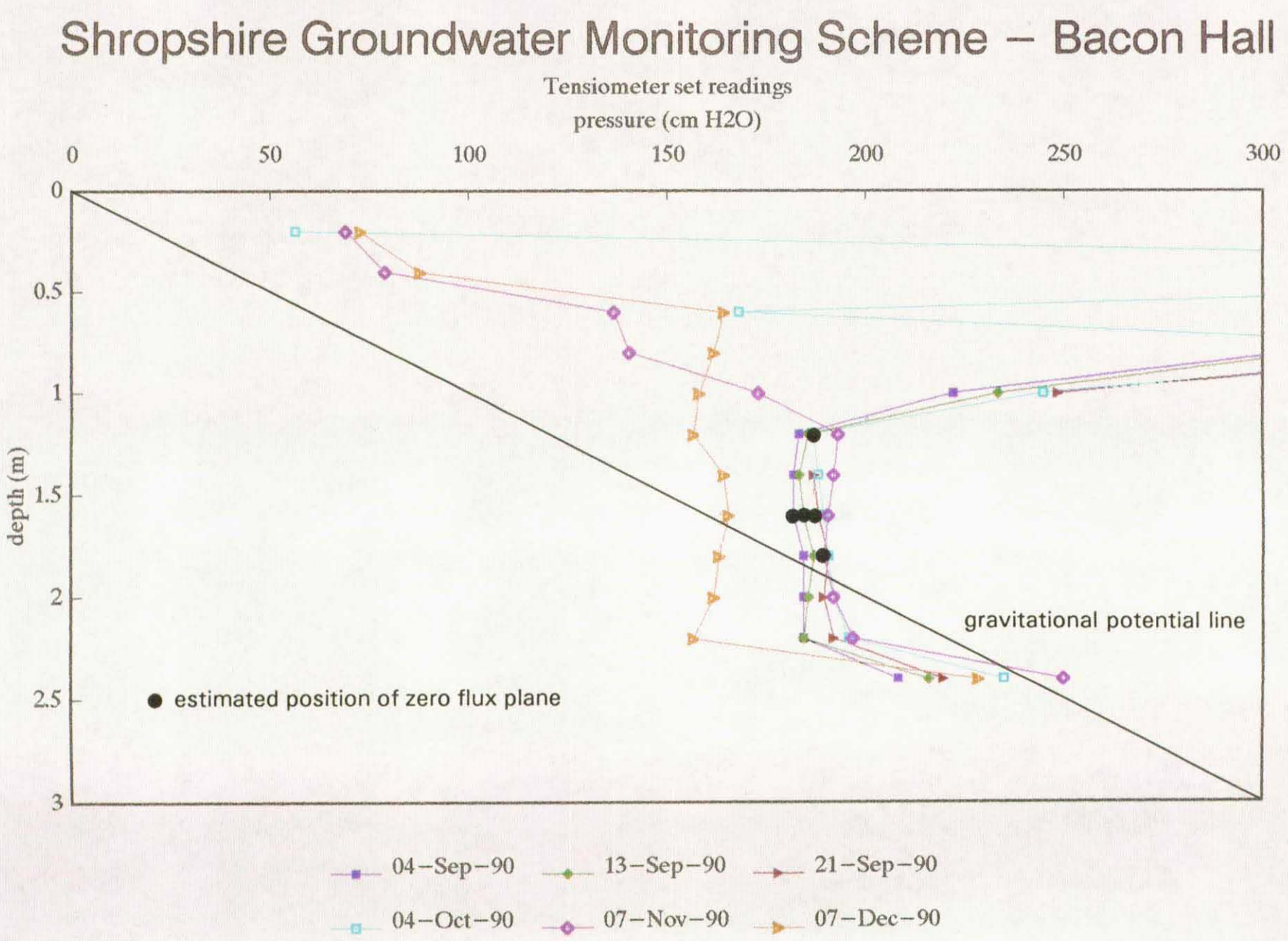

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