DETERMINATION AND ANALYSIS OF THE VARIATION OF SOIL MOISTURE AT VARIOUS DEPTHS BY Ra-Be NEUTRON SCATTERING PROBE

KIRAN SHANKAR, BHISHM KUMAR *and* B. P. SINGH

Department of Physics, University of Roorkee, Roorkee-247 672

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The experiment consists of the recording of the changes in the neutron counting rate in the initial soil moisture conditions at various depths and then observing neutron counting rate under ponding conditions with respect to time until the initial moisture conditions are attained. This has been done using an instrument obtained from BARC moisture type probe no. DM655. The calibration of the neutron probe has been done by observing the soil moisture content, percentage by volume by collecting the samples at various depths and using the conventional method known as gravimetric method.

The variation of soil moisture as determined by this probe has been analysed for the ponding. Various graphs are given in order to understand the variation of soil moisture in a column and to understand the contribution of the ponded water to water table. A model has been proposed for the analysis of this data. A response function for the ponded water similar to that of flood hydrograph has been obtained. It is observed that 85 per cent of the water goes down to raise the water table in 47hrs 41min in a typical situation. The remaining percentage of water remains in the column and part of it is lost due to many other factors.

INTRODUCTION

WATER in unsaturated zone which is above the water table is called soil moisture. It is the term applied to the water held in the soil by means of molecular attraction. It forms a film around the soil particles, fills the small wedge-like spaces between soil particles, and may completely fill the smaller interstitial spaces.

There are several conventional methods to determine soil moisture. They are : (1) Gravimetric method; (2) Porous Sorption Blocks; (3) Tensiometric Measurement; (4) Thermal Conductivity Method; and (5) Electrical Resistivity Method.

Gravimetric method is the most common and direct way to determine moisture contents in a soil sample. In this method, the soil sample is weighed before and after oven-drying for 24hours at 105 °C. The volume of moisture removed by the oven-drying, divided by the initial volume of the bulk soil, and multiplied by 100, gives the moisture percentage by volume. It is generally assumed that the soil does not significantly swell and shrink with moisture changes *in situ*. By this method, a continuous record of moisture profile movement cannot be obtained as the samples have to be removed from various depths each time for the laboratory testing. But still this method can usefully be employed for calibration.

In case of the porous sorption blocks, the moisture is readily removed by the blocks when they are in close contact with the soil, the moisture removed, can be determined by weighing the block. In the tensiometric method, a porous cup is inserted in the soil and connected by a water-filled tube to a manometer to measure the capillary potential or tension between the water and the soil. The soil tension is related to the moisture content for any particular soil.

Thermal conductivity method is based on the relation between thermal conductivity of the soil and the soil moisture content. The basis of the Electrical resistivity method is the relation between the electrical resistance of porous dielectric materials (plaster of paris, nylon, fiberglass, gypsum) and their moisture content. The resistance between the electrodes, embedded in the dielectric material and buried in the soil varies with the moisture content of the material which maintains a moisture equilibrium with the soil.

In search of simpler and more efficient method of determining soil moisture content, neutron moisture gauges have been developed and used by McVulloch and Feronsky (1968), Bell and MuCullogh (1966), Van Bavel and Stirk (1967) etc. It provides non-destructive, rapid and repeated measurements *in situ*, representing a large volume (25–75 cm) of the medium under study. It is suitable for the routine field use. A single calibration serves for a wide range of mineral soils. The neutron-scattering soil moisture meter also gives the moisture percentage on a volume basis, which is often the most useful result in hydrological work. One neutron meter measurement is as good as several conventional oven-drying measurements, being the statistical average over the period of measurements.

When 1 gm of 1 curie of radium is mixed with several gms of powdered beryllium about 10^7 fast neutrons are emitted per second as a result of the following reaction:—

$$_4Be^9 + {_2He^4} \rightarrow {_6C^{12}} + {_0n^1} + 5.71 \text{ Mev.} \qquad \ldots(1)$$

This mixture provides a convenient source of neutrons. Ra and its decay products emit alpha particles. Ra-Be mixture provides neutrons at a sufficiently steady rate to be used as a standard source for neutron emission.

Slow neutrons are obtained from high energy neutrons by allowing the latter to move through a material in which they can lose their energy in collisions. If slow neutrons are needed, the Ra-Be source can be used in water, paraffin, or some other hydrogen-containing material. The neutrons will quickly slow down to thermal energies by elastic collisions with protons. Neutron in thermal equilibrium with matter at a particular temperature are called thermal neutrons. Such material, as water is called a moderator in which neutrons are said to be "slowed down" or "moderated" to thermal energies.

In soil, hydrogen is present mainly in the form of moisture. Hence, fast neutrons when projected into the soil, will be scattered by the hydrogen nuclei and will be slowed down. The number of neutrons slowed down thus is proportional to the hydrogen concentration in the soil and hence, to the moisture content of the soil. These slowed down neutrons are detected by a thermal neutron counter. The number of counts per second gives the measure of the soil moisture content.

It is to be noted that the neutron probe technique provides a measure of soil moisture content averaged over a zone of importance or influence, the diameter of which varies with moisture content from about 25 to 75 cms. Thus, the measurement is considered as averaged over the volume. Although the probe is centered at a given depth, the indicated measurement of soil moisture cannot be regarded as a point measurement for that depth. (Bell & McCulloch, 1966).

INSTRUMENTATION

Depth Moisture Probe-Type DM 655 from Trombay Electronics Instruments, Atomic Energy Establishment, now known as BARC, Trombay, Bombay (India) has been used for the present study. It was cylindrical in shape, employing a 5 millicurie Ra-Be source in lower part and BF_3 detector in the upper half. Signal cable and extra high tension cable, each 25 fts. long, were connected to the probe with the Electronic Indicating Unit. This unit consists of pulse amplifier, discriminator, count rate meter and extra high tension unit.

The pulse amplifier was a 3-stages amplifier giving an adjustable gain of 8000 and a rise time of 0.8 micro second. The extra high tension unit was provided (2500 volts) for moisture probe. The output signals from measuring probe were fed to the Electronic Indicating unit which counted them directly or after amplification. From the dial reading, referring to the calibration curve, the actual moisture content of the

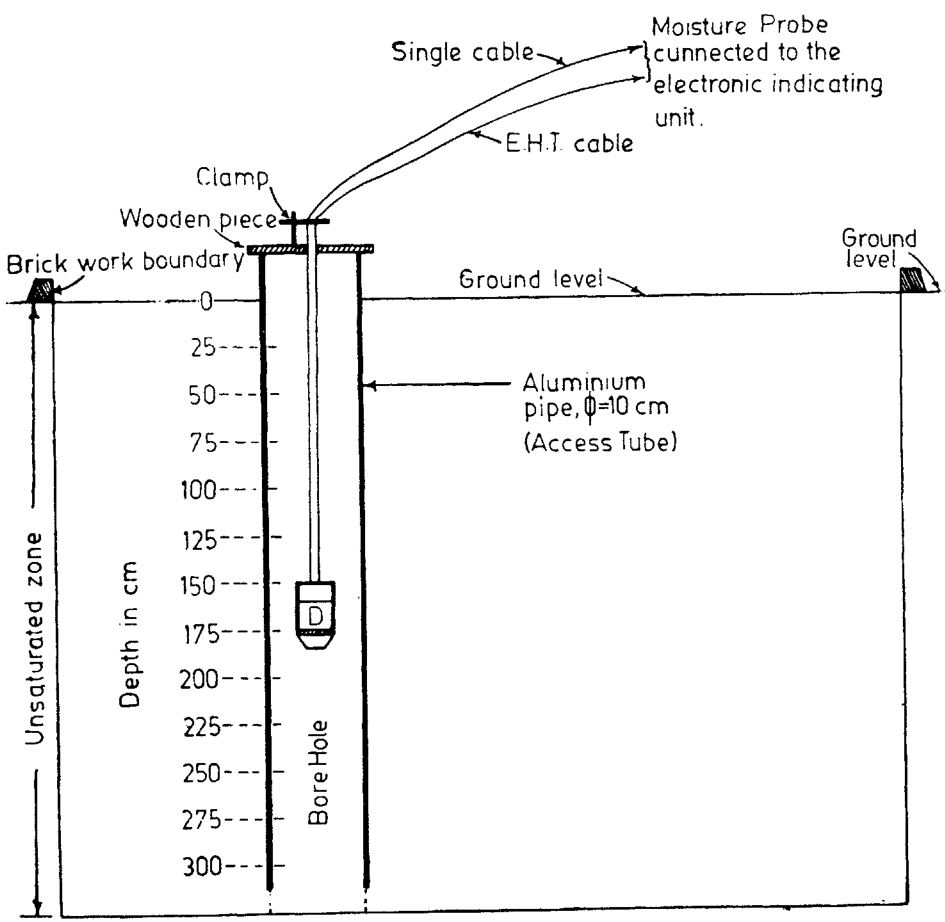

Fig. 1. Experiment site and neutron moisture probe.

soil can be found out. The system can detect moisture from 1.60 to 51.25 per cent by volume. The layout diagram of the experimental studies is shown in Fig. 1.

Calibration Curve for The Neutron-Moisture Gauge

The neutron moisture counts were taken at various depths and corresponding soil samples were also taken by using hand auger. The moisture of the soil samples were determined in percentage by volume using gravimetric method. In order to find the relation between neutron-moisture counting reading with moisture of soil sample, many readings were required which has been done. A graph was plotted in between neutron counting rate and soil sample moisture content. The least square curve fitting gave the following relationship:

$$M = 0.212 \ Mc - 16.758,$$

where '*M*' stands for moiature content in percentage by volume and '*Mc*' for neutron counts per-second (dial reading of the neutron-moisture-gauge).

This linear relationship is quite useful. This is true for the moisture range which was generally obtained in various soil strata in unsaturated soil zone. This relationship i.e., calibration equation is to be determined before this gauge is to be used *in situ*. This relationship is not unique as it varies from soil to soil and depends upon bulk density of soil, and presence of certain elements like Bi, Cd, Cl, etc., which absorb neutrons. But for a particular borehole such effects will be relatively constant. Working with the statistics of the data, it is found that there is quite good correlation between the 'moisture percentage' and neutron counting reading. The correlation-coefficient was of the order of 76 per cent.

The instrument had two ranges '250 scale range' and '500 scale range.' The calibration in scale ranges was found to be different. In order to use the ranges together, a relationship was worked out between 'two scale ranges' by taking the reading on both the scales. This relationship was used whenever readings crossed '250 scale range' and '500 scale range'. The relationship was found to be $Y=0.989\ X+28.984$, where Y is the reading on '250 scale range' and X is on '500 scale range'.

Experimental Result and Discussion

Experiment was carried on a test plot on the northern side of the Physics Department Building, University of Roorkee where a few bore holes were made. One of them with an aluminium casing was used for this study.

Knowledge of initial moisture content is very important as it greatly affects the infiltration capacity during the initial stages of infiltration. Therefore, counting rates for initial moisture were observed by neutron scattering probe at depths of 25, 50, 75, etc., up to 300 cms.

The water was supplied at the rate of 81 CC/sec., from the tap till an equivalent ponding height of 21.67 cms was attained over the ponded area. Sixteen sets of observations were taken at the interval of 30 minutes for the first few sets, and then interval was increased from 1 to 4 or 5 hours for the rest. Observations were thus taken repeatedly until the initial counting rates were approximately arrived at. The last

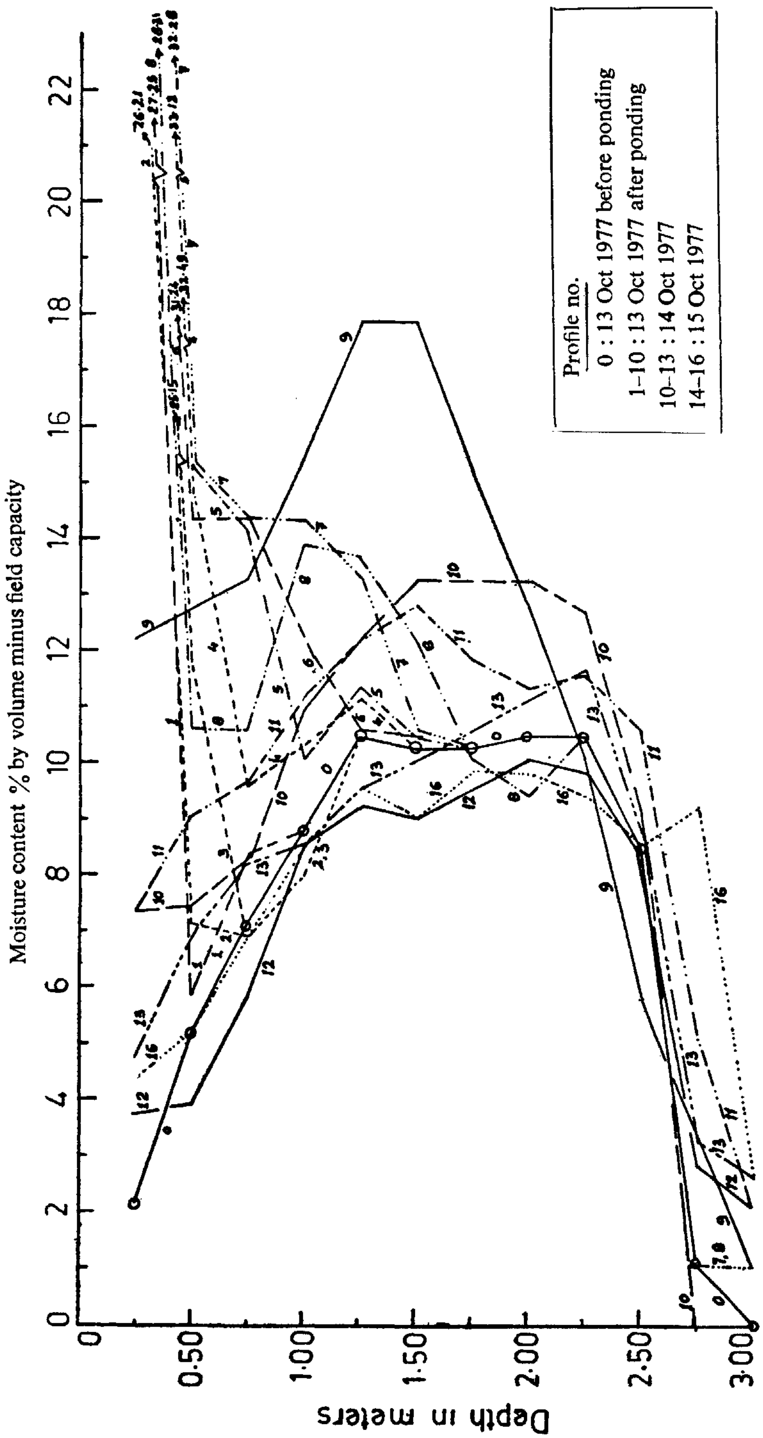

FIG. 2. Moisture profiles for bore hole no. 2.

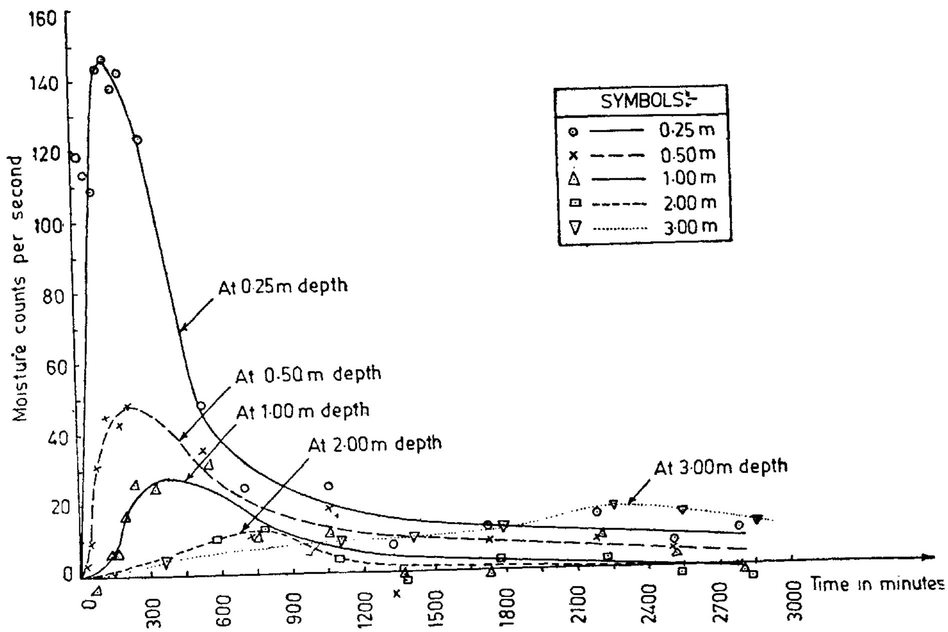

FIG. 3. Soil moisture variation with time at different depth (due to ponding).

observation ended after 47 hrs and 41 min from the beginning of the ponding. The moisture at various depths is shown in Fig. 2.

2. The variation of soil moisture contents with time at various depths (25, 50, 100, 200 and 300 cms) is given in the Fig. 3 for ponded water. This gives the travel of moisture (maxima) as time passes.

3. In order to understand the variation of moisture in a column under observation and further to understand the contribution of the ponded water to the water table, the following approach has been made use of :—

The integration of the soil moisture profile gives the total moisture content for a given soil column at a particular time. Initial soil moisture content has been subtracted in order to find the effects due to ponding only and the variation of moisture in the column for depths of 100, 150, 200, 250, and 300 cm with time is given in the Fig. 4. It is interesting to find that these graphs clearly indicate the "response function" but do not follow any systematic pattern.

4. In the calculations done above, the initial counting rate before ponding i. e., equivalent to initial moisture content, has been subtracted. This may be misleading, if we do not take care of the field capacity together with moisture present before ponding. These two factors play an important role in moisture flow. There is certain amount of water in the soil system which is trapped due to capillary forces and due to molecular binding forces etc., such that this much amount of water will be retained in the system at all time. The gravity forces will not allow such water to infiltrate and is better known as field capacity. But the water in excess to this will move in the system. The initial moisture is the water held at field capacity and also may be more than this. The excess water is useful in the conduction of the water to the system and will be

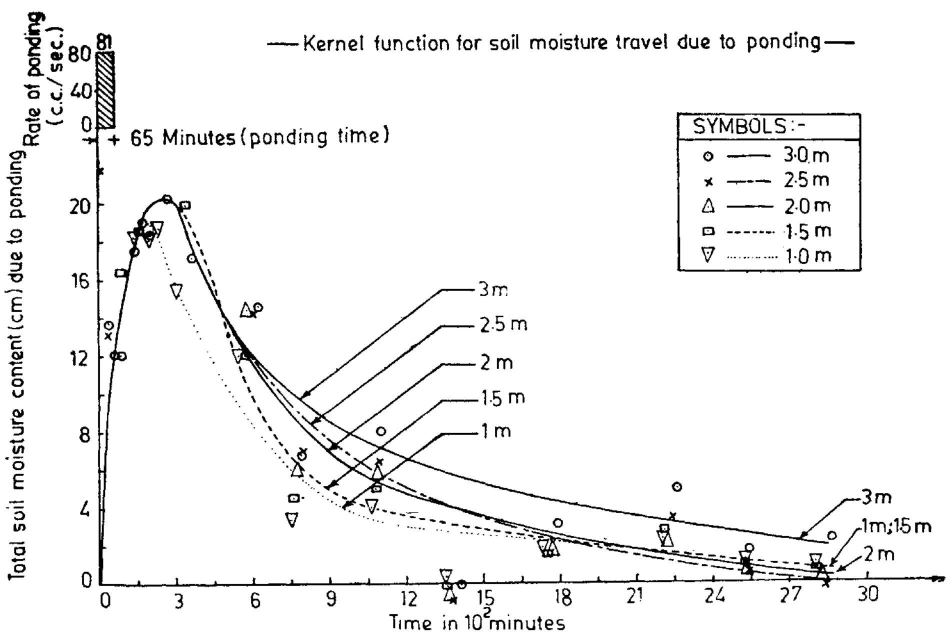

FIG. 4. Total soil moisture content derived from integrating soil moisture profiles over different depths indicated. Total ponded water was 21.67 cm (surface depth) over the area.

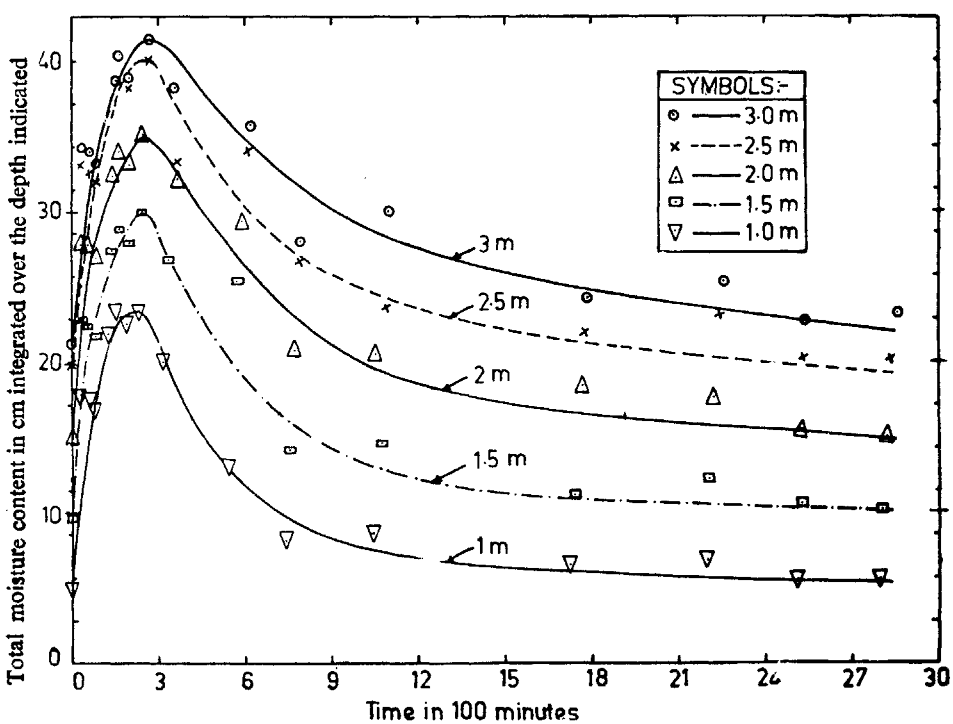

FIG. 5. Total soil moisture content derived from integrating soil moisture profiles over the depths indicated with field capacity subtracted.

added to the ponded water. Let us assume that the field capacity up to 3 meters of depth of the type of soil (mixed loam in the present area of study) with different compaction is same. Let us also assume that minimum moisture level present at any depth below 1 m is at field capacity, since above 1 m, the soil is subjected to heat etc. Now this moisture at this field capacity is subtracted and another graph is plotted as given in the Fig. 5 similar to the ones given in the Fig. 4. In this graph, the initial moisture content minus the field capacity is retained. The plots as given are more smooth. This also gives the consistency in results and method. The field capacity as calculated by the neutron probe was 17.50 per cent by volume. These curves can be taken as impulse curves or response curves of the type —

$$U = \frac{1}{k(z)\Gamma_n} e^{-t/k(z)} \left(\frac{t}{k(z)} \right)^{n-1}, \qquad \ldots(4)$$

where U is the cumulative moisture content in cm at any time t and k and n are the characteristic constants and can be determined by taking the first and second order moments of the curve. Γ_n is gamma function. Eqn. (4) is derived on the assumption that the data can be extended over roughly until its storage up to the field capacity.

5. In this typical experiment, let us consider the variation in the column of 300 cm depth where the ponding was done at the rate of 81 c.c/sec for 65 minutes (totalling equivalent to 21.67 cm of depth over the ponded area). It is found that soil moisture in the column equivalent to 20.32 cm of ponded height (93.8% of the ponded height) is occurring after 4hr 32min from the start of ponding. We further noticed that the moisture retained after 47hr 41min was 10.7 per cent of the total ponding. Therefore, 83.1 per cent of the total ponded water had gone below 300 cms depth. These results are shown in the following Table I :—

TABLE I

Sl. No.	Items	Moisture content in cm	%
1.	Input due to ponding	21.67	
2.	Initial moisture content minus field capacity	21.08	
3.	Total input	42.75	100
4.	Total moisture observed	41.38	96.8*
5.	Moisture lost	1.37	3.2
6.	Moisture remained	23.38	54.7**
7.	Moisture travelled below 3 m depth	18.00	42.1

*Observed in 4hrs 32min from the start of ponding.
**Observed in 47hrs 41min from the start of ponding.

(6) The analysis and method given above clearly indicate that 83 per cent of the ponded water has gone down below 300 cms. This has taken 47hrs 41min. Therefore, if water is stable at 3m, then this may give an increase in the table by 18.00 cm in 47hrs 41min for 21.67 cm of ponded water. Therefore, 18.00 cm of water had passed at 3

meters in 47hrs 41min. This rate of flow at 3 meter will not provide any appreciable amount of moisture present at any time for an observer. It has been told often that there is hardly any appreciable change in moisture after 2 to 3 meters at any time in unsaturated zone and even it is taken for granted that water is infiltrating and raising the water table. This experiment clearly provides an answer to this question that water travels at a slow rate.

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