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INFILTRATION BENEATH A FOREST FLOOR

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Technical Report No. 21
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ABSTRACT

Using a tension lysimeter system, tensiometers and a soil moisture neutron probe, moisture characteristics of a glacial outwash soil were determined during periods of soil moisture flow resulting from rainfall. In the flow range from zero, with the soil at field moisture capacity, to 0.2 inches per hour a change of three percent was observed in the soil moisture, and a change of 25 centimeters in tension. At a depth of 16 inches lateral flow was found during periods of rapid soil moisture flow, in spite of the coarseness of the soil texture. It is presumed that this lateral flow was due to the gradual increase in coarseness with depth in the top two feet of this soil. Hysteresis characteristics of the soil were determined at depths of 16 and 74 inches. The increase in coarseness in the surface two feet partially inhibited unsaturated water percolation, causing a wetter-when-wetting moisture-tension hysteresis at the 16 inch depth. A textural boundary at the 74 inch depth of coarse over finer material caused no distinct hysteresis effect.

Key words: hydrology, *infiltration, percolation, *soil moisture

INTRODUCTION

Large areas of the Puget Sound Basin are involved in the production of two natural resources: timber and water. The soil cover over portions of these areas is of continental glacial origin. Successful land and resource management in the basin requires a knowledge of the physical and chemical properties of these glacial soils.

Knutsen (6) at a test site on a Barneston glacial outwash soil has studied the redistribution of moisture after it fell into a forested area. He presented data showing significant vertical soil moisture flow variability both beneath the tree canopy and also in a clearcut plot.

It was the main purpose of this study to delve further into the soil moisture properties of the Barneston series soil, clearcut of vegetation.

The specific objectives were:

a. Determine the variability of soil moisture flow and of moisture percent by volume attributable to a Barneston soil.
b. To determine the water budget of the soil if this variability were not too great.
c. To determine the soil moisture tension at specific depths.

STUDY AREA

"The experimental area is on the lower reaches of the Cedar River watershed, at an elevation of 700 feet near Landsberg, Washington, about 30 miles from Seattle. The area was chosen because of ideal experimental soil and forest conditions. The forest consists of a 35-year-old Douglas fir plantation established after repeated fires, and is quite uniform in species composition, size and spacing. Trees had been planted at a spacing of six feet by eight feet. Little ingrowth and mortality has occured, so the density has remained about the same. There are about 900 trees per acre with a basal area of 163 square feet per acre and a 90 per cent crown density. A few understory species are found. The most prevalent among these are salal, Oregon grape, and mosses. Generally, these plants form only a sporadic cover.

Climate records for a long period of time are available at Landsberg, Washington which is about 2 miles from the experimental site. The climate is a mild maritime type, characteristic of the Cascade foothills. Temperatures range from 0° to 100°F, and total annual precipitation is 54 inches. About 70 per cent of this falls during the period of October-March. Snow is infrequent, generally scanty, and does not remain on the ground long. Fog and mist is frequent, and 90 per cent of the rain falls at a rate of less than 0.1 inch per hour. Soils are not frozen except for occasional brief periods.

The soil is a Barneston gravelly loamy sand originating from glacial outwash laid down at the end of the Vashon glacial period. It is excessively drained throughout the profile and has only a small element- and water-holding capacity. Inorganic colloidal material is not abundant, so organic matter in the surface is important in modifying soil properties."(5)

The test plot consisted of an area approximately 40 feet by 40 feet near the center of a clearcut area measuring 100 feet by 150 feet. A micro relief of rolling hummocks one to three feet high exists on the site.

Details on physical properties of the soil are given in Table I. It can be seen by this table that in the upper 19 inches of the soil profile, the soil texture tends to get coarser with depth which is a relative condition since the entire profile is composed of coarse material. About half of the test plot is underlain by a well graded D horizon composed entirely of sand. Figure I(6) illustrates the moisture release properties of the upper 24 inches of the profile. At a given tension less moisture is held by the deeper depths. These and other study area conditions are discussed in detail in other publications (1,4,7).

MATERIALS AND METHODS

Precipitation Measurement

Precipitation was measured by two methods. About 100 feet north and south of the clearcut in which the study plot was located, a recording rain gage, mounted on a tower higher than the tree canopy, monitored the rainfall rate. Within the clearcut, ten one-quart cans were distributed around and in the plot to determine total storm amounts and distribution over the plot. The relative location of the cans is shown in the plan view in Figure II.

Flow Measurement

Vertical soil moisture flow rates were monitored with a suction lysimeter system described in detail elsewhere (1)(2)(3)(5). However, a diagram of the system is shown in Figure III. The plan view of the 11-inch diameter lysimeter plate installation is shown in Figure II. Three plates were emplaced flush with the surface of the mineral soil. Three were located at the bottom of the B horizon at 16 inches depth, and six more were at 74 inches depth at the bottom of the C horizon. The suction of all plates was adjusted to 0.1 atmospheres, to approximate the field moisture capacity value for this coarse soil. The flexible plastic tubing between the lysimeter plate and the flow cell in the collection bottle was full of leachate solution. The suction on each plate was adjusted individually by raising or lowering the collection bottles and therefore controlling the hydraulic head of the plate. The three legged pit used to emplace the

74 inch deep plates was shored and maintained for the purpose of adjusting the height of and the emptying of the deep plate collection bottles.

The lysimeter system was fully automatic and operated on a 24 hour per day basis.

Tension Measurement

Four Soilmoisture Company remote bulb tensiometers were located within six inches horizontally from two of the 16 inch deep plates and two of the 74 inch deep plates as shown in Figure II. The tensiometers were read daily just before and just after the soil moisture measurements.

Percent Moisture Measurement

Soil moisture content in percent by volume was measured with a Troxler neutron probe model 105A (50 milicurie americium-berrilium source; 1.48 X 10^5 neutrons per second emission rate), Shield and standard model S-6A and scaler model #200-B293-C.(9) Five 1-5/8 inch aluminum access tubes were installed in the plot as shown in Figure II. These penetrated to depths of 7 feet, 8 feet, 8 feet, 10 feet and 10 feet.

Because of the coarse cobbly nature of the soil the access tubes were installed by first removing a 12 foot by 12 foot square patch of forest floor in one piece. Next the hole was excavated to the desired depth with an 8 inch diameter bucket auger and the diggings were kept in large cans. The resulting hole diameter actually approached 20 inches in some holes because of large cobbles encountered. The tube was then placed in the hole up against one wall and the hole backfilled from the cans in reverse order. The tubes protruded from the surface about 4 inches. The final step was replacing the patch of forest floor. Since the tubes were against the wall of the holes, the probe sampled about half disturbed and half undisturbed material.

The installation of tubes 4 and 5 varied from the above procedure in that upon reaching the sandy D horizon at 74 inches, the tubes were driven to a depth of 12 feet. A 1-1/2 inch drill auger was then used to dig out the material in the tubes. The tubes could only be excavated to 10 feet because the sand became coarser with depth and eventually would fall through the auger and would not lift out.

Installing access tubes in such a coarse cobbly soil is hard work at best unless one has access to heavy drilling equipment. It took between 5 and 15 hours per tube installation by the method described.

The neutron probe apparatus was operated in the following manner: The probe-in-standard was hung by cable in mid air. Three one minute readings were taken with the scaler to calibrate the probe. The probe was placed on hole #1 and readings taken at depths of 1/2 foot, 1 foot, 1-1/2 foot, 2 foot and then at one foot intervals to the bottom of the tube, as measured by markings on the cable. These were actually the depths of the source below the soil surface. For accuracy, a minimum reading of 17,000 counts was taken as being practical timewise. A minimum of two readings at each depth were taken to check consistency. Similar readings were taken in holes #2 through #5. Additional calibrations were made before #2, before #4 and after #5. Readings were taken once per day just after a storm and tapered off to once every 2 to 3 days as the soil moisture rate of change decreased.

RESULTS AND DISCUSSION

The test equipment in whole or in part was operated from August 4 to December 7, 1965. The most fruitful portion of this period was August 25 to October 25, during which all of the instrumentation was represented. Fortunately, four storms occured during this period that provided the necessary distinct waves of moisture passing through the profile. The two month period was about 25% drier than the average for the area.

Precipitation

Rainfall over the test plot was very uniform. The volumes in the quart cans were measured out in graduated cylinders. Volumes between cans seldom varied more than 2 milliliters or 0.00098 inches of water at the factor of 0.0049 inches per milliliter. The total storm volumes measured in the plot agreed with the quantities measured by the recording gages over the canopy.

Moisture Flow

Figure IV shows a typical set of hydrographs of soil moisture flow at three levels in the profile along with the precipitation that caused the flow. The graphs, with one exception, were as expected. Starting and peaking lags increased with depth. Peak flow decreased with depth and recession lengthened with depth. Individual plates rather than the average of all plates at each level are used in this illustration due to some thermal problems encountered with the flow cells that caused intermittant flow records at times. The self siphoning flow cells, when siphoning, cool a positive temperature coefficient resistor (PTC) which sends a pulse of current to the data logger. It was difficult to adjust the electrical back up properly to the PTC resistors so as to tolerate the warm midday summer temperatures and the cold night temperatures.

An exception is seen for the 16 inch deep plate. It peaked much higher than the surface plate and collected more total water than the rainfall. Upon noting the high flow volumes at the 16 inch depth, the tensiometers readings were checked to determine the difference between the plate suction of 100 centimeters of water and the actual soil tension. The tension at plate #4 ranged from 64 centimeters down to 33 centimeters. At plate #5 the range was 38 to 4 centimeters. The plate tension at the 16 inch depth was then reduced to 60 centimeters in an effort to more closely approximate the soil condition. However, plates 4, 5 and 6 continued to gather more moisture than fell as precipitation, with plate 5 taking in the most. This would be expected since it had the greatest tension differential. At the 74 inch depth, tensions ranged from 86 and 79 centimeters to 72 and 64 centimeters. The differential between these tensions and the plate setting of 100 centimeters did not result in excessive flow volumes at this depth.

A water budget within the soil profile was not possible due to the high variability at each plate installation depth. For example, on August 23, 1965, 1.994 inches of rain fell. At the 74 inch depth, total storm flow ranged from 0.36 to 2.72 inches for a mean of 1.48 inches and a standard deviation of 0.85 inches. Based on having 90% confidence that the sampled average flow at the surface was within 10% of the mean, as many as 34 plates would be needed depending on which storm the computation was based on; at the 16 inch depth, up to 64; at the 74 inch depth up to 86 plates.

Percent Moisture

The percent moisture vs depth curves for the 5 access tubes as shown in Figure V are approximations of the field moisture capacity profiles for the holes. Actually, since the probe was not calibrated for this soil and some organic matter was present, it might be appropriate to relabel the curves "percent hydrogen present."

The points on the curves are plotted at the calculated center of measurement of the probe which for the range of moistures present approximated 6 inches above the source. The formula used was: height of measurement center above source equals $2.95\left[\frac{100}{\text{Vol \% } H_2O}\right]^{1/3}$

In Figure V the curves resemble each other down to 5-1/2 feet except for hole #4 which was bored through a large decayed and buried cedar log. The 6-1/2 foot readings show the presence and absence of sandy D horizon. The higher retention storage of the sand over the cobbly gravel is evident (tubes 1, 4 and 5).

The uppermost points on the curves are those of the one-half foot deep center of measurement which correspond to the one-foot source depth. This measurement was considered accurate because of the work of Van Baval and others (8) with a probe of similar dimensions and neutron density but with a 10 milicurie Ra-Be source. In a four-foot cube of soil at 17.6% moisture they first experienced surface effects at 11.8 inches source depth. The minimum percent hydrogen experienced at the one foot source depth in this study was 17.0% in hole 2 with most holes indicating 18% and higher, 95% of the time.

Figure VI shows the storm of September 14, 1965 and the wave pattern flow through the profile near hole #1. These curves were obtained by subtracting the field moisture capacity values from the moisture readings. Note the apparent moisture left near the surface on October first. This is the result of using the lowest moisture reading, or the average lowest, at each level to determine the field moisture capacity. Obviously, between storms some evaporation occured. This error was left in the figure to illustrate the depth of penetration of evaporation; at least deep enough to effect the one-foot center of measurement or the one and one half foot source depth reading.

Figure VII illustrates the variability possible in the total moisture around individual access tubes. Hole #1 approximates the rain input, hole #3 has less and hole #4 has more. The moisture would appear to be redistributed within the soil. This redistribution, and the resulting variability from place to place, prevented any reliable water budgeting within the profile.

Again, budgeting the soil water was not possible with the number of access tubes used. For example, on October 13, 1965, 0.50 inches of rain fell. The 5 access tubes showed an increase of from 0.36 to 0.76 inches of soil moisture for an average of 0.58 inches and a standard deviation of 0.17 inches. Based on this variability and on having 90% confidence that the sampled average soil water increase was within 10% of the mean, 23 tubes would be necessary. During the storm of October 5, 1965, variability was such that 61 tubes would be necessary.

Hysteresis

Figures VIII and IX show typical moisture tension relationships at the 16 and 74 inch depths. At 16 inches it is apparent that the relationship loops with the wetting and drying cycles. Note that the loops show the soil to be wetter when wetting. It is postulated that the cause of this is the textural soil distribution of finer material over coarser at this level as indicated in Table I and Figure II. Water percolating downward in this zone must pause at each micro level until enough collects to lower the tension of the water to that of the larger pores below. It is interesting that the loops are formed within a moisture difference of only 3 to 4 percent and a tension differential of 30 to 40 centimeters of water. The loops are truncated, of course, because only one moisture and tension reading was taken daily.

At the 74 inch depth, only the hint of loops can be seen. At this level, two conditions exist: The water crosses a textural boundary at the C-D horizon interface of gravel to sand and also, as shown in Figure V by the moisture retention curve in the upper D, the D horizon grades coarser with depth (as was verified visually when augering out the access tubes. This was mentioned earlier). The probe being a low resolution instrument integrates both these conditions.

Lateral Flow

On October 14, 1965, the entire instrumented plot was covered with polyethelene plastic to allow the plot to go to field moisture capacity, especially the surface foot or so that had previously been subjected to evaporation. On October 15 and 16, 0.05 inches of rain fell and on the 17th, 0.15 inches more. On the 18th, 0.72 inches fell as shown in Figure X. Plate #5 at the 16 inch depth was 5 feet from the edge of the plastic sheet. On the 18th the plate began to take in water, even though covered. It responded again on the 20th to only 0.05 inches of rain. The plastic cover was checked carefully for leaks and was found to be sound.

Also, the percent moisture values in the access tubes showed little sign of decreasing. This definite evidence of lateral flow and the necessity of vacuuming the water from each storm off the cover to prevent spillage caused the abandonment of the field moisture capacity attempt.

Covering the plot did lend further evidence that lateral flow and redistribution exists within the soil. It is thought that this is caused, at least partially, by the textural layering of finer over coarser material in the upper few feet of the soil. As was mentioned earlier, the moisture collects in the micro layers until the tension decreases to that of the lower horizon. In the meantime, it is free to respond to the gravity potential should these horizons be inclined. Inclination is probable since the area is covered with one to three feet high hummocks and the soil horizons tend to follow the surface contours. Once in motion the water could flow down into depressions in the horizons and percolate down from these points. This is perhaps the explanation for the high water intake of the 16 inch deep plates.

Water that would normally flow down the incline of the horizon occupied by the plate is sucked into the plate which is at a higher tension. The plate would then act as a sink. Actually, in the described condition, the plate would act as a sink even if the plate tension could be adjusted to exactly match the soil water tension. Plate 5 may be at the bottom of a depression or a trough, judging by the consistently higher intake of plate #5 over #4 and #6.

Lateral flow is born out by the total moisture variability from one access tube to another and by the total storm variability through plates at the same depth.

CONCLUSIONS

1. Uniform rainfall on this coarse soil is redistributed within the soil by lateral flow which causes significant variability in both percent moisture and vertical soil moisture flow from place to place at any particular depth.
2. A more extensive system of instrumentation would be required to obtain a water budget of this soil with reasonable precision.
3. A moisture tension relationship exists at the 16 inch depth in this soil such that the soil is wetter when wetting, probably caused by the increase in coarseness with depth.

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TABLE I

SOIL TEXTURE

HORIZON	COMPONENT PERCENTAGES							TEXTURE
	> 3"	2mm-3"	< 2mm	SAND	SILT	CLAY	ORGANIC	
A_0 3/4"	--	--	--	--	--	--	100.0	
A_1 0"- 2"	--	57.2	42.8	31.2	9.2	2.9	3.8	GRAVELLY SANDY LOAM
B_1 2"- 11"	8.9	62.5	28.6	23.0	3.4	1.1	0.5	GRAVELLY LOAMY SAND
B_3 11"-19"	5.8	66.7	27.5	24.1	1.9	0.5	--	GRAVELLY SAND
C 19"-74"	8.6	61.7	29.7	28.0	1.3	--	--	GRAVELLY SAND
D 74+"	--	--	100.0	100.0	--	--	--	SAND

ACKNOWLEDGEMENT

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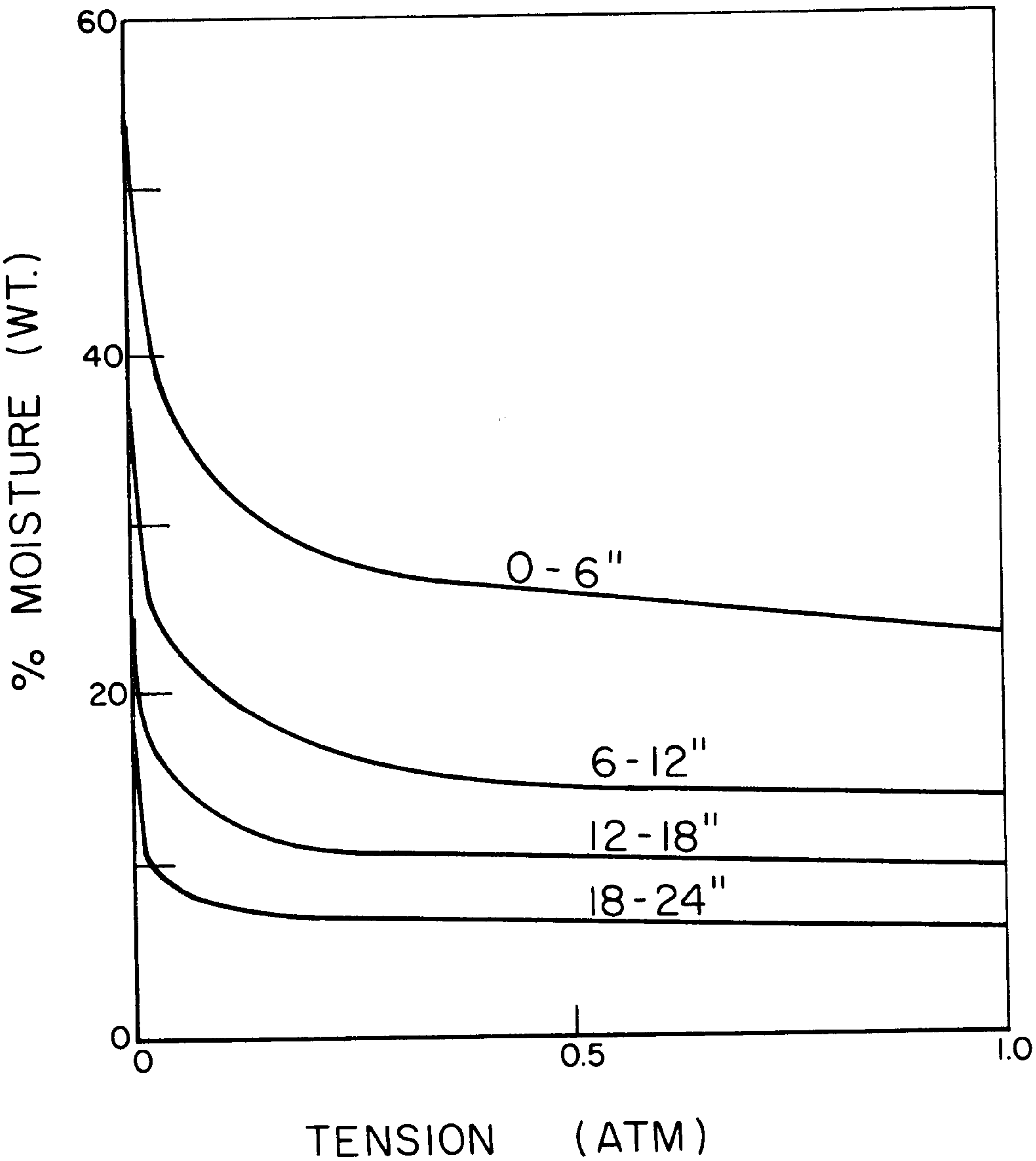

FIGURE I. MOISTURE RELEASE.

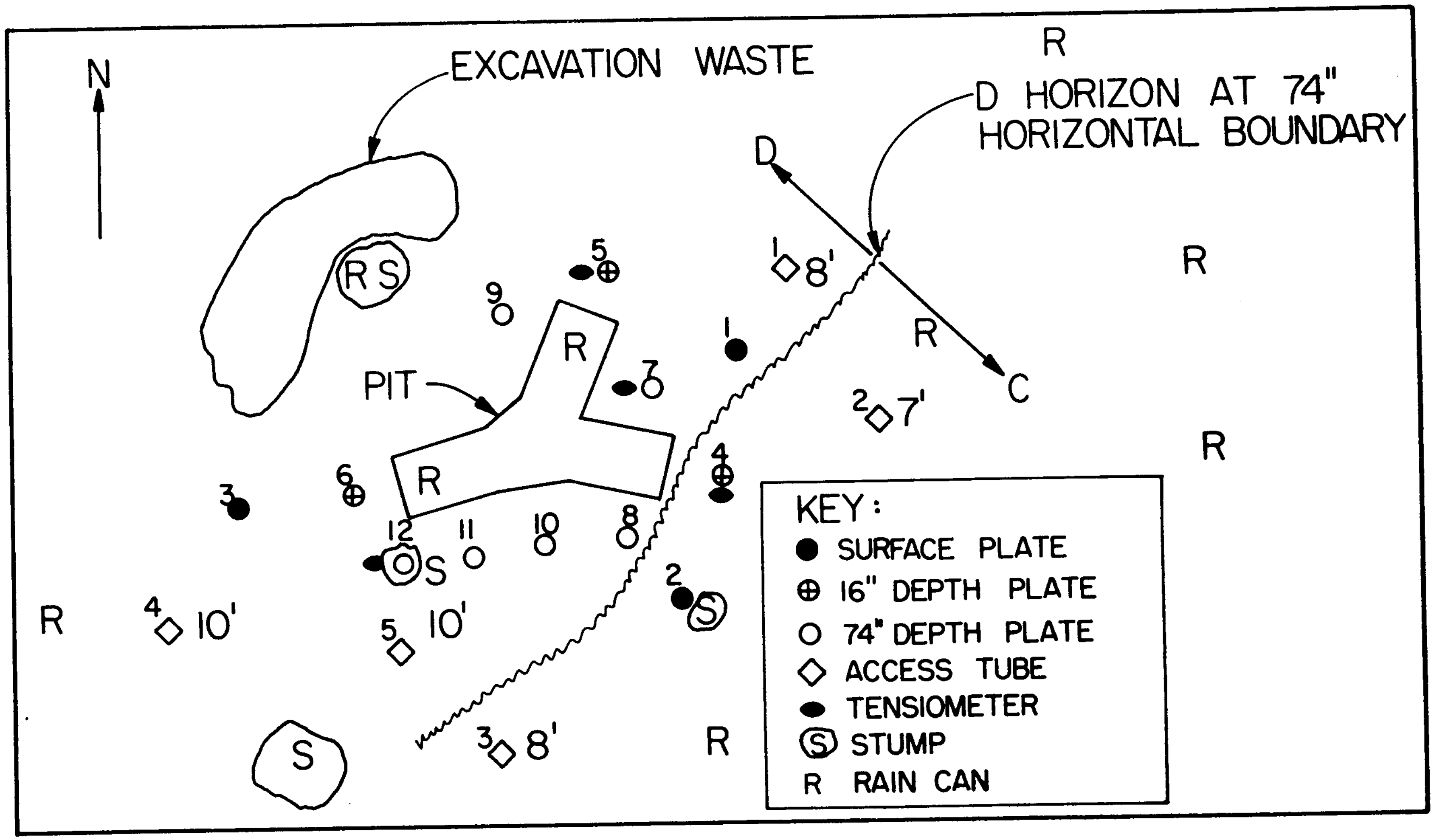

FIGURE II. TEST PLOT PLAN VIEW.

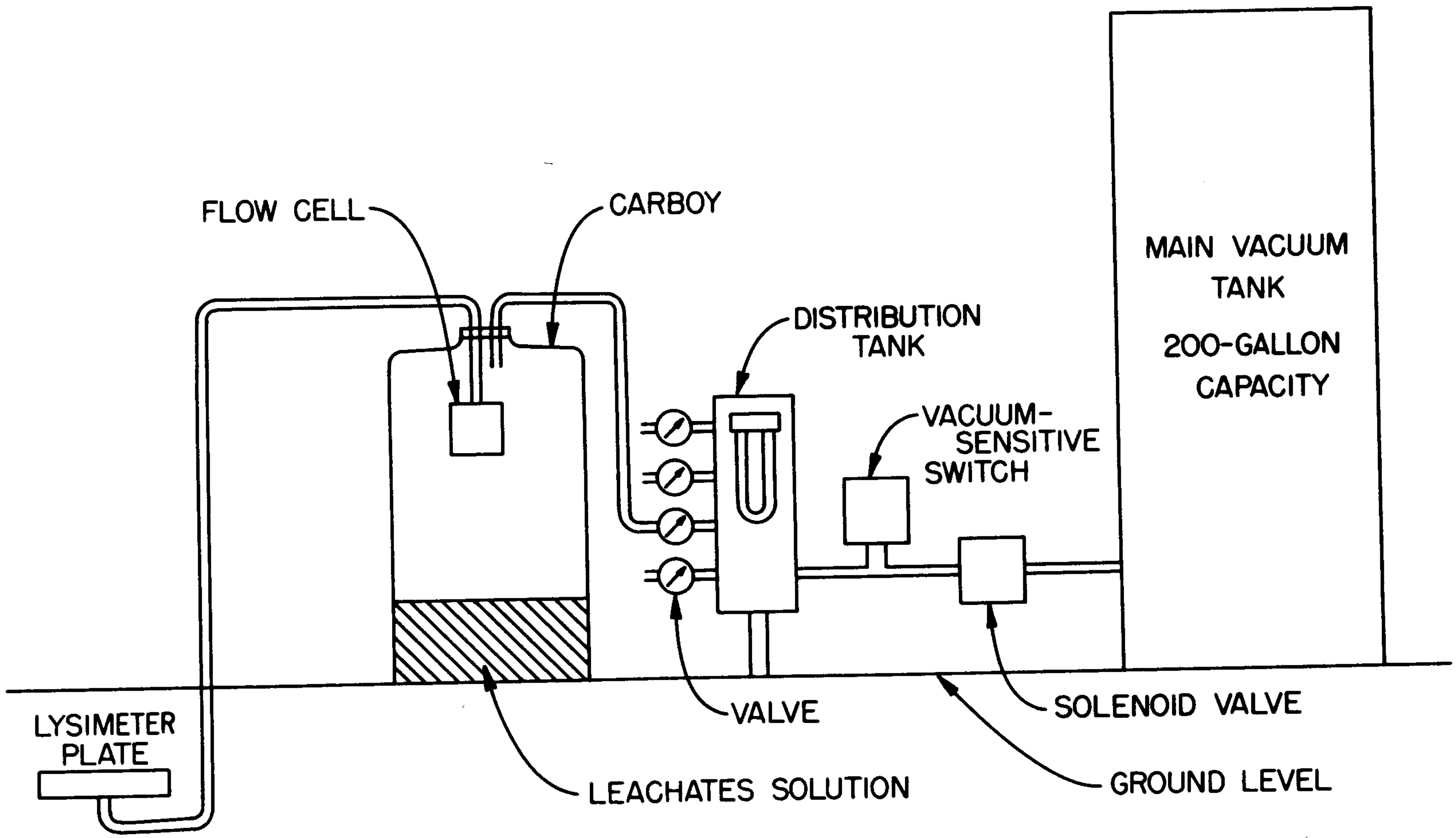

FIGURE III. LYSIMETER INSTALLATION INCLUDING COLLECTION & VACUUM CONTROL SYSTEMS.

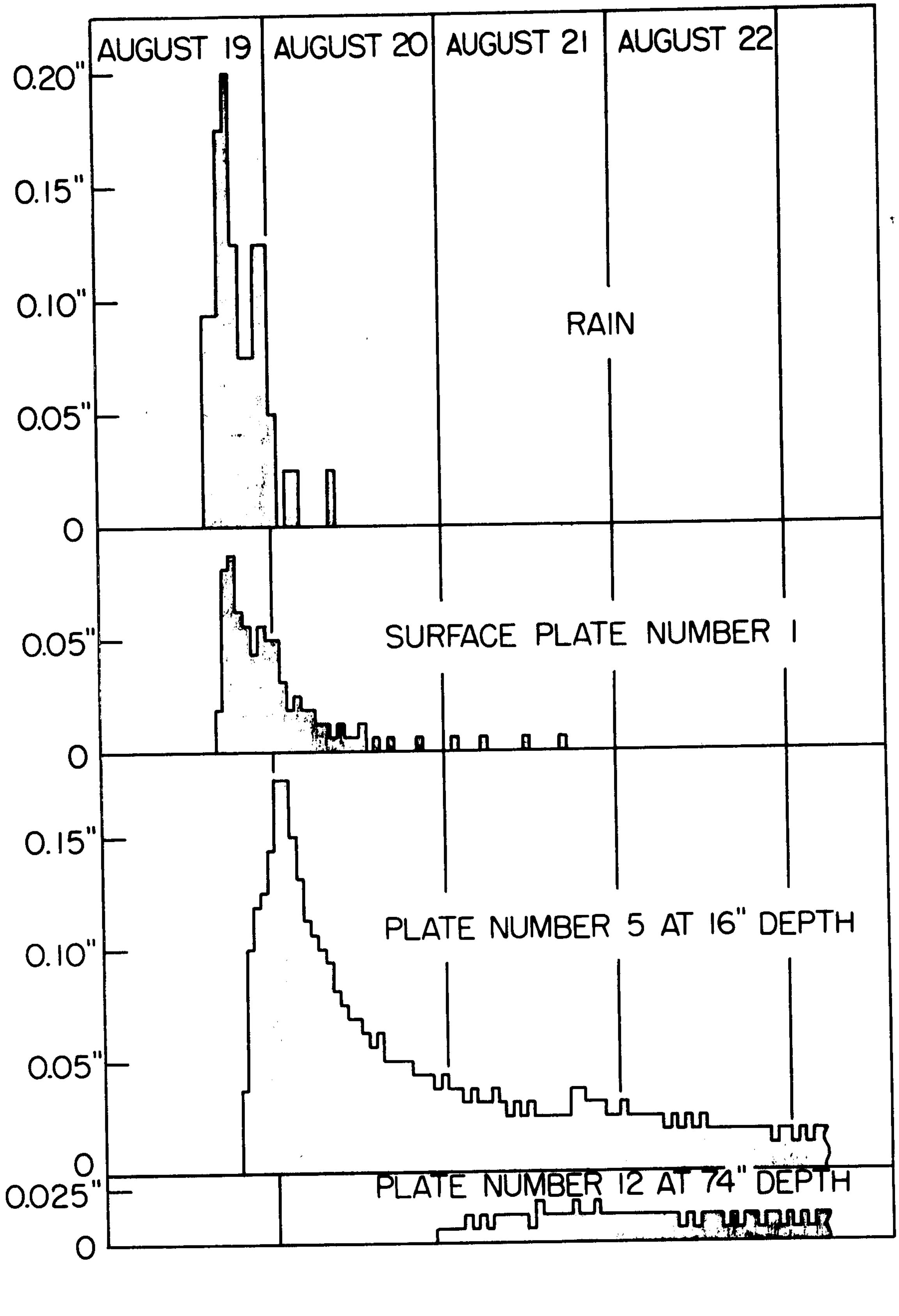

FIGURE IV. RAIN & SOIL MOISTURE FLOW PATTERNS.

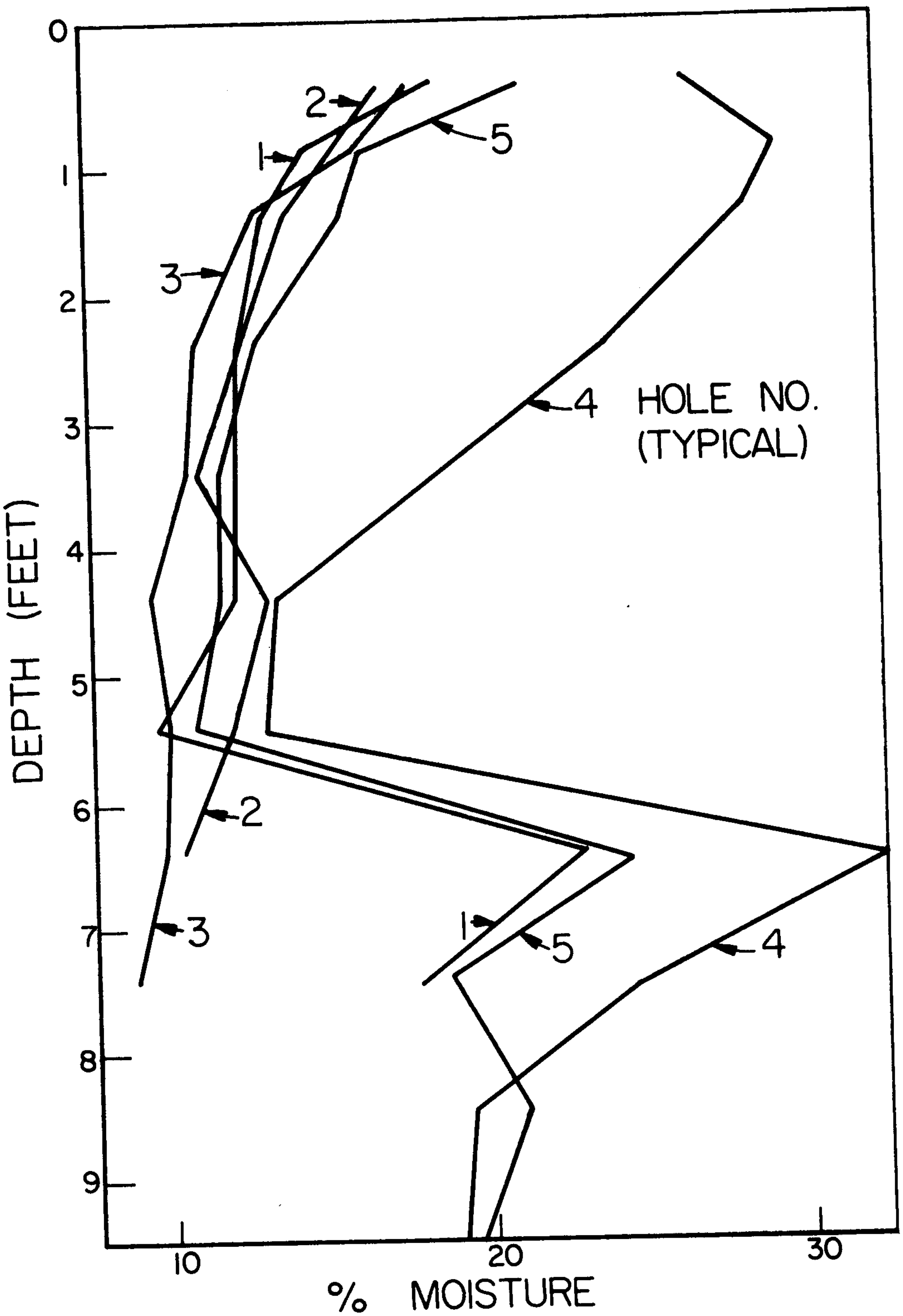

FIGURE V. FIELD MOISTURE CAPACITY PROFILES.

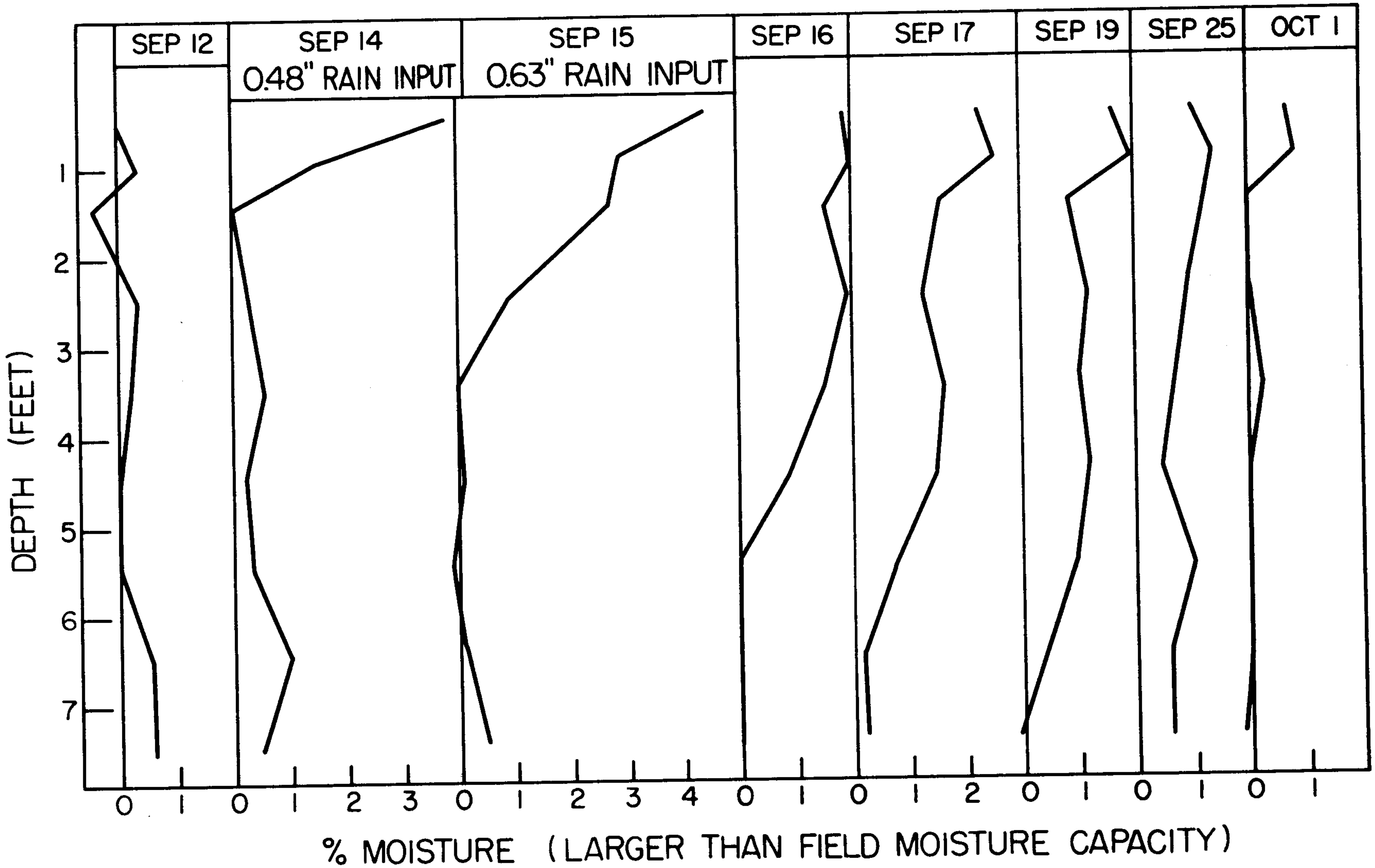

FIGURE VI. FIELD MOISTURE CAPACITY PROFILES.

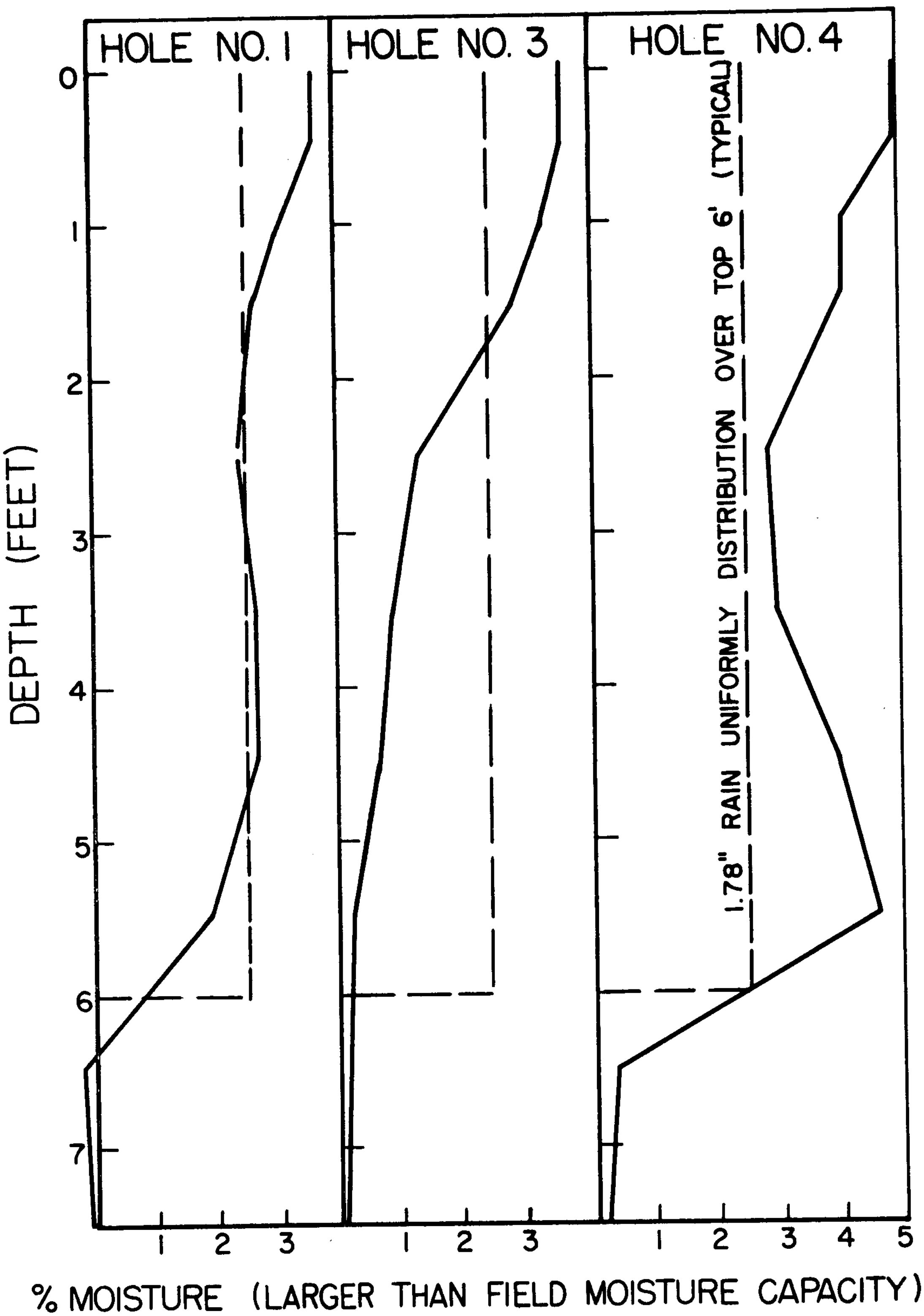

FIGURE VII. SOME MOISTURE GAIN AFTER 1.78" RAIN.

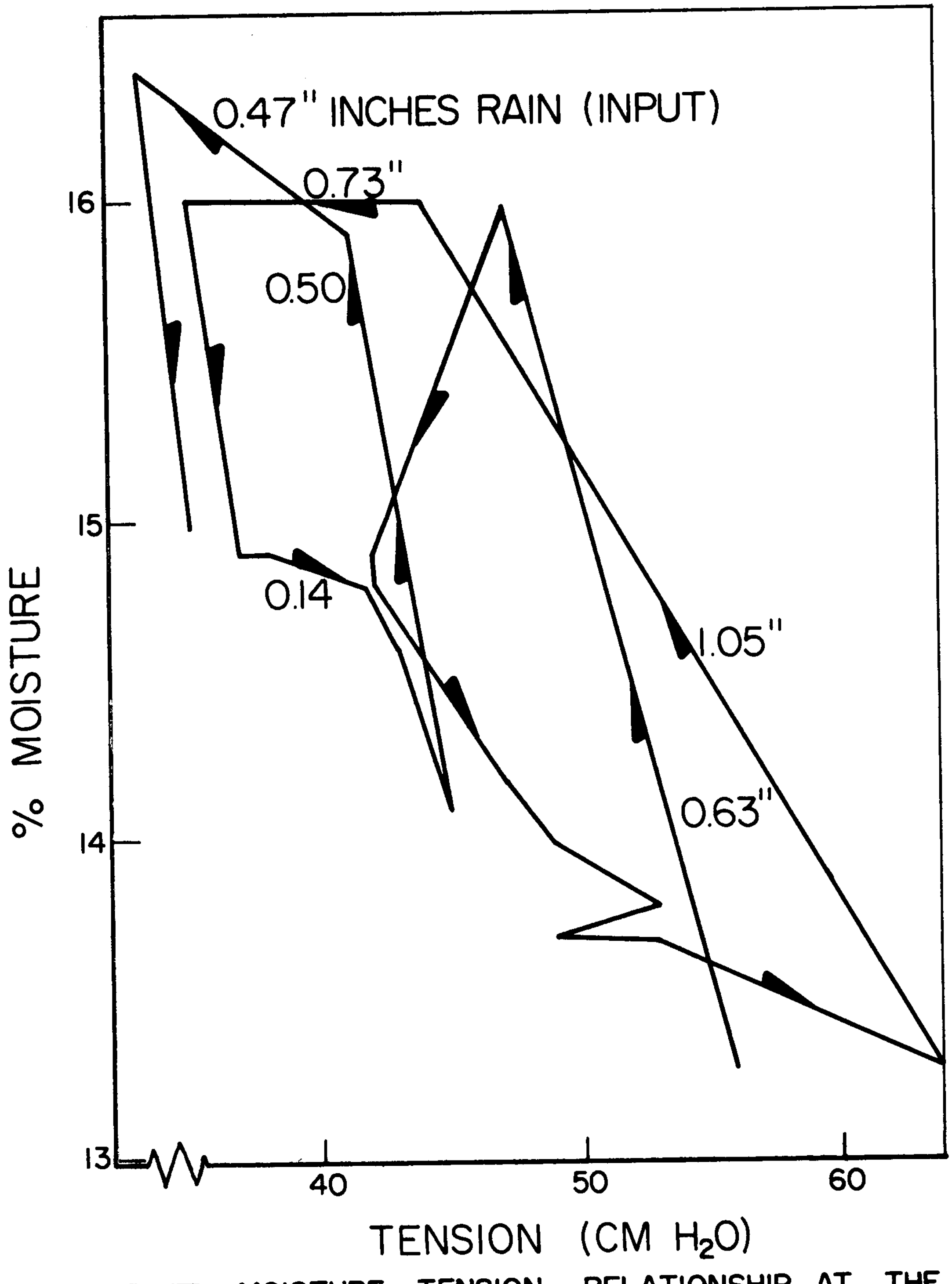

FIGURE VIII. MOISTURE - TENSION RELATIONSHIP AT THE 18" DEPTH.

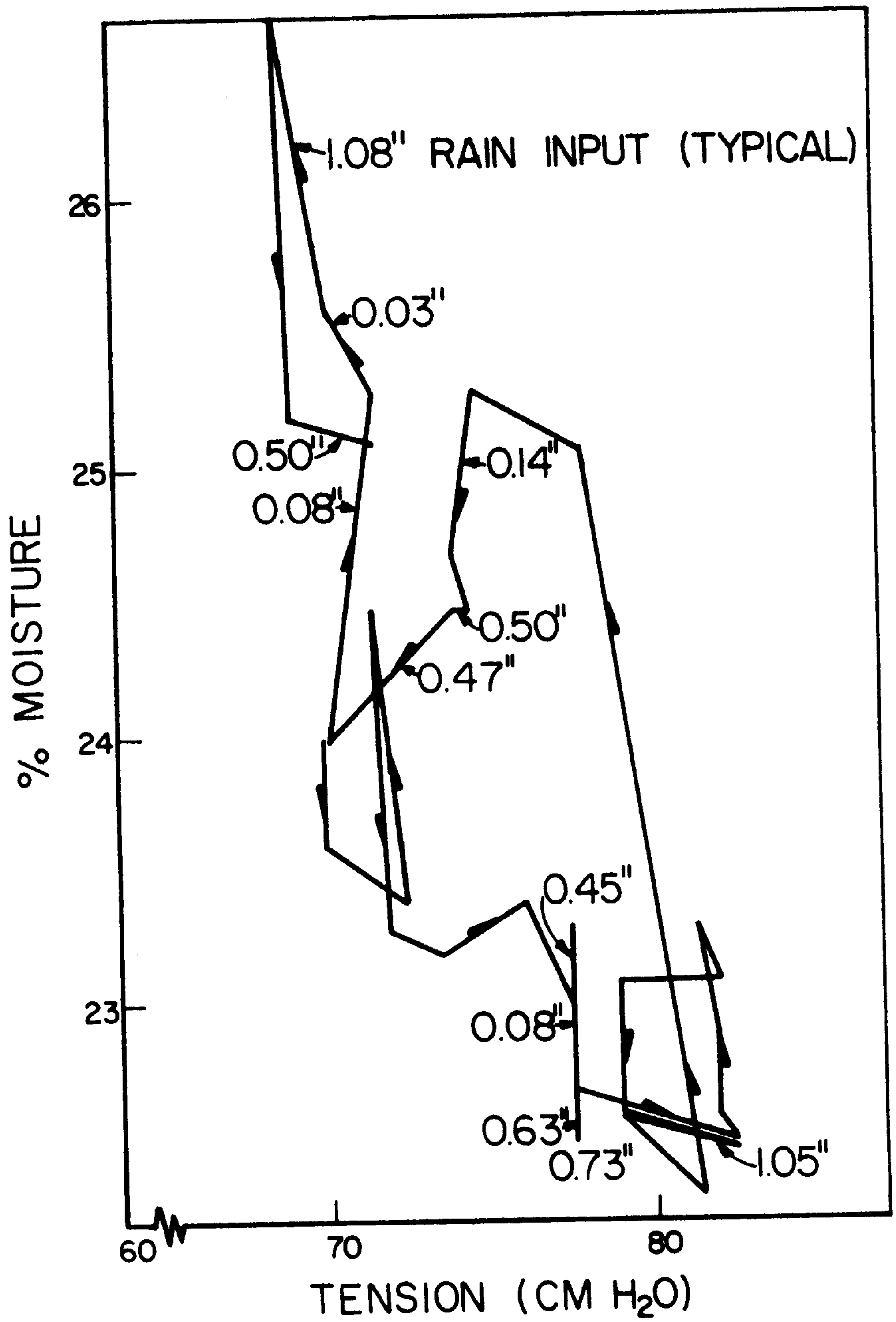

FIGURE IX. MOISTURE - TENSION RELATIONSHIP AT THE 74" DEPTH.

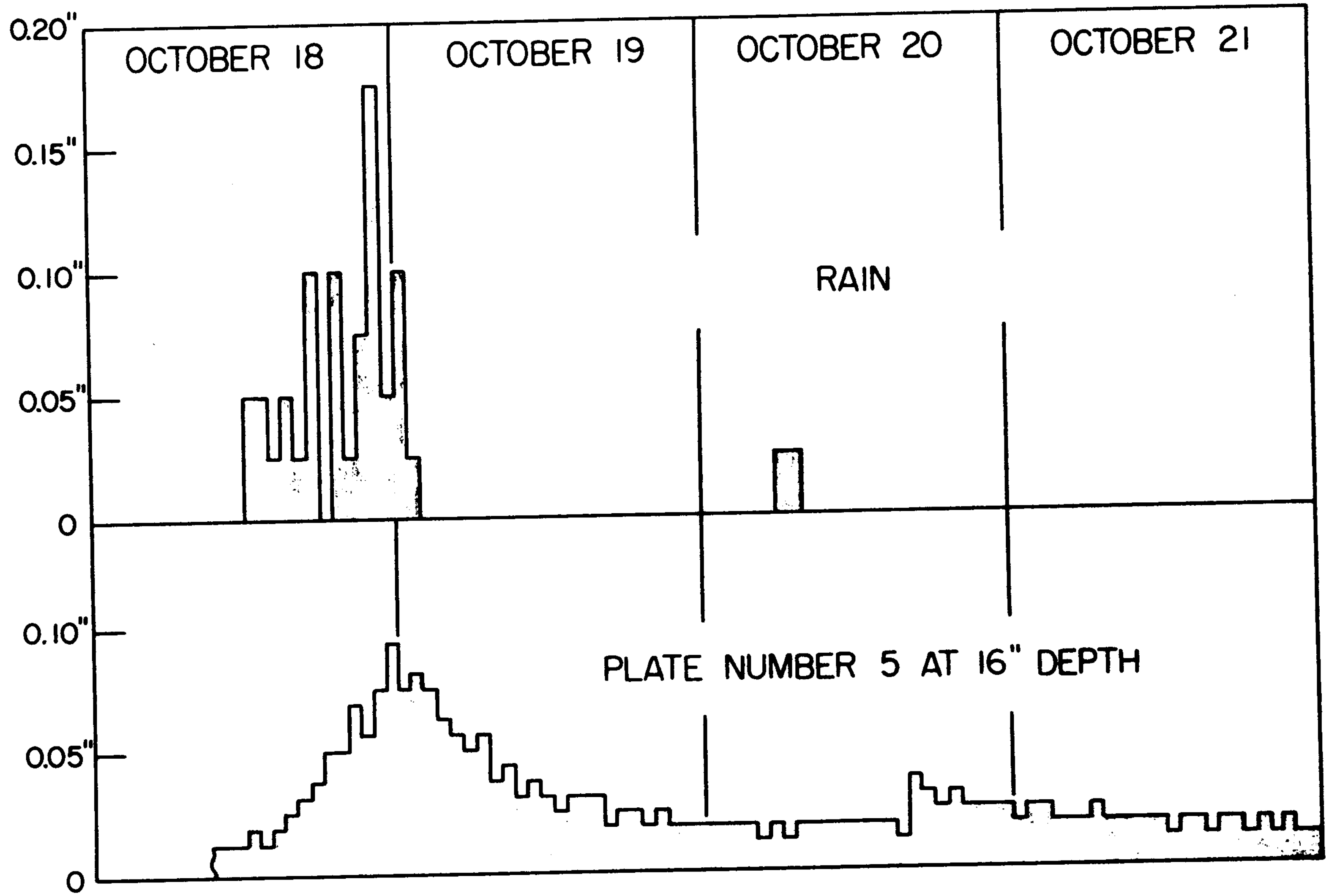

FIGURE X. SOIL MOISTURE FLOW UNDER COVERED PLOT.