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Sediment Moisture Relations: Lysimeter Project 1976 - 1977 Water Year

T. L. Jones

June 1978

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Rockwell International

Atomics International Division
Rockwell Hanford Operations
Richland, WA 99352

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Rockwell Hanford Operations
Richland, WA 99352

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SEDIMENT MOISTURE RELATIONS: LYSIMETER PROJECT 1976-1977 WATER YEAR

T. L. JONES

RESEARCH DEPARTMENT
RESEARCH AND ENGINEERING

JUNE 1978

Rockwell International
Rockwell Hanford Operations
Energy Systems Group
Richland, Washington 99352

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SEDIMENT MOISTURE RELATIONS: LYSIMETER PROJECT 1976-1977 WATER YEAR

INTRODUCTION

Throughout the history of the Hanford Project, low-level radioactive wastes have been released into the unsaturated Hanford sediments through several disposal methods. These methods have used the sorptive capacities as well as the arid nature of these sediments to isolate the waste material within this unsaturated zone. Moisture movement within the unsaturated sediments may be capable of transporting these waste materials away from their initial storage site. For this reason, research to characterize moisture movement above the water table was initiated as part of the long-term management of low-level waste project.

Two large field lysimeters were constructed in 1971 to evaluate the possible vertical movement of naturally occurring sediment moisture. These lysimeters are located approximately one mile south of the 200 East Area. This report presents and evaluates sediment moisture data collected at the lysimeter site from September 1976 through August 1977, which is the 1976-1977 water year.

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SUMMARY

In 1971, two large lysimeters were installed one mile south of the 200 East Area. These lysimeters measure approximately 3 meters in diameter and 17 meters deep. Both were equipped with instruments for evaluating possible vertical movement of sediment moisture. One lysimeter was left open at the bottom while the other was sealed off at approximately 17 meters. Any large amound of downward moisture movement

was expected to result in an accumulation of moisture in the lower portion of the closed bottomed lysimeter. Three access tubes, for a 1.5-inch neutron moisture probe, were installed in each lysimeter to permit measurement of the moisture content at various depths.

During the 1976-1977 water year, sediment moisture content of the open and closed bottomed lysimeter was measured 11 times. The data collected during this water year are tabulated in Tables I through XI in Appendix IV and shown graphically in Figures 1 through 22 in Appendix V. These graphs illustrate how the top 1 to 2 meters show the greatest amount of seasonal variation, while this effect is reduced as the deeper portions of the profile are approached.

Early rains in August 1976 left the upper portions of the two lysimeters at about 5 to 8 percent moisture content. The lower-than-normal precipitation that followed until December 1976 resulted in the moisture content of the top 1 to 2 meters decreasing to about 5 to 6 percent. This zone gained moisture from winter rains and snow from December until March 1977. During March, increased air temperatures and solar radiation initiated drying which continued throughout the summer. Spring rains in May and June 1977 added some moisture to the profile; however, these rains were not sufficient to prevent severe desiccation to take place in July and August 1977. The primary evidence of wetting and drying was limited to the top 1 to 2 meters where fluctuations in moisture content of more than 2 to 3 percent were observed. Minor fluctuations of 1 percent or less were observed in the zone between 2 and 12 meters.

The zone between 12 and 16 meters maintained a uniform moisture distribution (approximately 6 percent) showing no variations with regard to depth or time that were significant in relation to the precision of the neutron probe (approximately

0.5 percent). This uniformity reduced the matric potential gradient to negligible levels (0.1 cm/cm maximum), resulting in a situation where the dominant driving force acting on the liquid moisture is due to gravity. The steady-state nature of the entire 12 to 18-meter zone (variations of <0.25 percent) implies that the moisture flux was also uniform at these depths.

A moisture flux equation, which may be used to calculate liquid phase drainage resulting from gravitational forces, estimates that a downward flux on the order of millimeters per year will occur in both lysimeters. There is uncertainty in this estimation resulting from the level of precision obtainable with the neutron moisture probe and incomplete data concerning hydraulic conductivity. Nevertheless, this information represents the best estimate of liquid flux currently available.

Moisture not accumulating in the bottom portion of the closed bottomed lysimeter is not necessarily inconsistent with a downward flux of liquid moisture. Precision limitations and spatial resolution associated with the neutron moisture probe make it difficult to detect small increases in moisture content. Also, thermally induced, upward, vapor phase flow may reduce the net moisture flux to near zero.

The precision of the neutron moisture probe prevents detection of an increase in volumetric moisture content of less than 0.5 percent. Taking into account the spatial resolution of the neutron moisture probe (a sphere approximately 0.6 to 1 m diameter sphere) and the dimensions of the lysimeters, a moisture flux of approximately 0.5 centimeters per year would be needed to cause a detectable increase in moisture near the bottom of the closed bottomed lysimeter. Present estimates of the hydraulic conductivity, at a moisture content of 6 percent by volume, range from 1.5×10^{-5} cm/min to

1×10^{-7} cm/min. The lack of a detectable moisture content increase in the closed bottomed lysimeter indicates that a hydraulic conductivity estimate of greater than 1×10^{-6} cm/min may be too high since it should produce a downward flux of greater than 0.5 cm/year. Any return vapor flow would reduce the net vapor-liquid flow and, therefore, higher conductivities may be reasonable.

Measurements of sediment temperature taken near the lysimeters indicate the presence of a temperature gradient located deep within the lysimeter which will cause a moisture vapor flux toward the surface. The magnitude of this flux is unknown. However, a review of pertinent literature indicates that the flux is unlikely to exceed the liquid flux moving down, but may approach it in magnitude. Temperature measurements within the lysimeters and further laboratory characterization of lysimeter sediment will be needed before an accurate estimation will be available. Because of this return vapor flow, the net liquid plus vapor flux of moisture occurring in the lysimeters may be significantly lower than the liquid flux alone. This reduced net flux may result in moisture content increases below the limits of detection using the neutron probe. However, the flow of most importance to the movement of radionuclides will be the flow in the liquid phase. Complete characterization of the moisture movement in the Hanford sediments will require the separation of flux terms into vapor and liquid components. This is not possible at this time.

In order to resolve the problems and questions presented by the lysimeter project and to further refine our knowledge of moisture movement on the Hanford Reservation, work is continuing in the following areas:

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- neutron probe calibration to improve measurement accuracy
- characterization of sediment hydraulic and thermal properties to provide better estimates of liquid and vapor phase flow
- field instrumentation designed to expand data collection to allow more sophisticated analysis and expand the study area
- moisture transport modeling to allow application of lysimeter data to waste disposal sites.

Progress in these areas will be reported in the 1977-1978 water year report.

BACKGROUND

Two large, instrumented lysimeters (approximately 3 x 17 meters), which were designed to provide data relating to moisture transport within the unsaturated Hanford sediments, were installed one mile south of the 200 East Area during late 1971 and the early months of 1972.[1,2] One of these lysimeters was left open at the bottom while the other was sealed off at approximately 17 meters. The original design called for the lysimeters to be 18 meters deep, however, during installation 122 and 81 centimeters of sediment were removed from the closed and open bottomed lysimeters, respectively, to allow the instrument cables to reach the surface.[2] Details of the actual construction of the lysimeters, including schematic diagrams of the instrument locations, and the procedure used for preparing the fill material may be found in references 2 and 3.

Several parameters relating to moisture transport were to be studied. These were sediment matric potential,

temperature, pore air pressure, and volumetric moisture content. Evaluation of these parameters was to aid in: (1) obtaining estimates of deep percolation, (2) evaluating the impact of natural precipitation on the sediment moisture distribution, and (3) collecting field data needed for verification of numerical models.

The lysimeters were instrumented with sediment moisture access tubes, thermocouple psychrometers, thermocouple temperature sensors, and hollow steel tubes to be used for pore air pressure measurements. Because of a delay in construction of a sheltered instrument room, temporary shelters were used, forcing instrument reading devices to be exposed to the environment. The psychrometer and thermocouple measurements were discontinued as a result of erroneous readings produced under these conditions.[2] To date, pore air pressure instrumentation has not been installed, leaving sediment moisture content as the only parameter regularly measured. Volumetric moisture content measurements have been obtained using a commercial neutron moisture probe.

Difficulty in obtaining the steel tubes installed for pore air pressure measurements delayed filling the open bottomed lysimeter. The sediment used to fill the lysimeter was stored near the caisson, exposed to the weather. Delays in filling the lysimeter allowed the sediments to absorb additional moisture from rain and snow that fell in December 1971 and January 1972. This additional moisture accumulation resulted in the upper 6 meters of the open-bottomed lysimeter having a higher moisture content than the closed-bottomed lysimeter. The residual effect of this extraneous moisture is reflected in the neutron-probe readings by a zone of higher moisture content, located between 4 and 7 meters in the profile of the open bottomed lysimeter (Figures 1 through 11 in Appendix V). Data collected at the lysimeter location have been periodically

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reported by several investigators.[1-3] This report is the latest in the series of water year reports.

METHOD

The sediment moisture profile of each lysimeter was measured 11 times from September 1976 through August, 1977 (i.e., monthly measurements excluding December). The measurements were taken with a 1.5-inch diameter Model 503 neutron moisture probe manufactured by Campbell Pacific Nuclear Corporation.* This neutron moisture probe is equipped with a 50 millicurie americium/beryllium source of fast neutrons. Standard counts (N_{std}) of two minutes, as well as moisture counts (N) of two minutes, were used to form the ratio of N/N_{std}. This ratio was used in conjunction with a calibration curve to obtain percent moisture on a volume basis, i.e., cm^3 water/cm^3 sediment. Calibration of this instrument consisted of matching the readings taken in the field by the CPN probe with readings taken by a 1.5-inch neutron probe produced by Nuclear Chicago. The Nuclear Chicago probe had previously been calibrated using large steel drums filled with lysimeter-type sediments preconditioned to known moisture contents. The scatter diagram produced by the field comparison of the two probes is shown in Appendix II, along with a discussion of neutron probe precision and accuracy.

Meteorological data including incoming solar radiation (Figure 23), temperature (Figure 24), and precipitation (Figure 25) were collected by the Battelle-Northwest Meteorological Group at the Hanford Meteorological Station located approximately 5.5 miles from the location of the lysimeters. See Appendix V for Figures 23-25.

*Measurements taken on November 5, 1976, and November 8, 1976, were taken with a 1.5-inch Nuclear Chicago probe.

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RESULTS AND DISCUSSION

The results of the neutron probe measurements are tabulated in Tables I through XI and shown graphically in Figures 1 through 22. A qualitative examination of the data reveals that the upper 12 meters of the profile formed a zone consisting of nonuniform, transient moisture contents which varied with the seasonal fluctuations in precipitation, air temperature, and solar radiation. The remaining 6 meters comprised a zone of uniform moisture content that showed no significant fluctuations in response to surface precipitation or climatological conditions.

ZONE OF SEASONAL VARIATION

In comparing the normal precipitation rate with the precipitation rate during the 1976-1977 water year (Figure 25), monthly precipitation was found to be considerably below normal throughout the fall of 1976 and most of the spring and summer of 1977. The dry fall in 1976 resulted in decreasing moisture content until December for the top 1 to 2 meters of the lysimeters. December precipitation, combined with cooler days (Figure 24) and reduced solar radiation (Figure 23), allowed the top portion of the profile to rewet. The surface moisture content continued to increase until March 1977 when large increases in solar radiation and air temperature, coupled with limited spring rains, initiated drying. Spring rains in May and June added some moisture to the upper profile; however, severe desiccation followed in July and August. This dynamic situation of shallow wetting and drying did have an impact on the remaining profile; however, the impact decreased rapidly with depth. Comparisons of Figures 1 to 22 indicate that the major moisture fluctuations (>2-3 percent) were limited to the top 1 to 2 meters with only minor changes (<1 percent) being recorded below this depth. It is difficult to

separate seasonal fluctuations of <1 percent from artificial fluctuations produced by neutron probe instability (see Appendix II).

ZONE OF NO SEASONAL VARIATION

The moisture contents found at depths below 12 meters remained essentially constant throughout the 1976-1977 water year (Figures 1 to 22).* The zone between 12 and 16 meters had a uniform moisture distribution of approximately 6 percent by volume. This zone showed variations of less than 0.25 percent over the entire year (Tables XII and XIII).

Tables XII and XIII in Appendix IV contain the monthly moisture contents for the 12 to 16-meter zone. The average moisture content for these depths was 6 percent by volume for both lysimeters. If the moisture content data for any given month is taken, the variation with depth below 12 meters is generally less than 0.3 percent. Comparing all the readings taken last year below 12 meters, excluding November and December, one finds a standard deviation of 0.18 percent, by volume. Some of this variation of 0.18 percent may be accounted for by the random neutron emission pattern produced by the probe itself, variations of 0.08 (see Appendix II). The results of Appendix II imply that one may not depend on the neutron moisture probe data to distinguish between two moisture contents which are less than about 0.5 percent apart. This leads one to discount the variations recorded below 12 meters and to assume a uniform moisture content of 6 percent between 12 and 16 meters.

*Neutron probe trouble was reported during the October 21, 1976 reading. The probe was sent for repair resulting in the November readings being taken with the 1.5-inch Nuclear Chicago probe. For this reason, the October and November readings are omitted when reporting annual variations in Tables XII and XIII.

Under conditions of near uniform vertical moisture content, the matric potential gradients become negligible. In the case of the lysimeters, the maximum matric potential gradient possible, taking into account the uncertainty in neutron probe measurements, is less than 0.1 cm/cm. In this same zone, the gravitational gradient is equal to 1 cm/cm (see Appendix I). This gravitational gradient produces the dominant force responsible for the downward flux of liquid moisture. Under these special circumstances, the liquid phase moisture flux may be described by:

$$J_w = -k(\Theta) \qquad (1)$$

where: J_w = liquid moisture flux ($cm^3\ cm^2\ mm^{-1}$)

$k(\Theta)$ = hydraulic conductivity ($cm\ min^{-1}$)

(See equation I-18, Appendix I)

The moisture content between 12 and 16 meters varies from 5.8 to 6.1 percent with an average of 6.0 percent (Tables XII and XIII). To compute the flux from equation 1, it is necessary to know $k(\Theta)$ when Θ = 6.0 percent; however, only one published source of data is available on the hydraulic conductivity of the lysimeter sediments. This report by Reisenauer[4] discusses a Millington-Quirk-type analysis, which was performed on the lysimeter, sediment-desorption curve. This type of analysis has been used successfully by previous investigators[5,6,7]; however, two limiting factors exist: (1) at least five alternative equations are referred to in the literature as Millington-Quirk equations; and (2) no one other than Reisenauer has attempted to entend this type of model to moisture contents below approximately 20 percent. To date, the applicability of Millington-Quirk-type analyses to Hanford

sediments has not been confirmed or rejected by experimental data. The limitations listed above and a lack of experimental verification of the Millington-Quirk method for the lysimeter sediment system would suggest a cautious use of these results. However, Reisenauer's hydraulic conductivity data (1972) combined with equation 1 may be used to make first approximations of the deep drainage taking place in the 12 to 16-meter zone.

The moisture contents found at the 17 and 18-meter depths are different from those in the 4 meters immediately above, and they show generally less variation throughout the year (i.e., standard deviation of from 0.05 percent and 0.13 percent [Tables XII and XIII]). Such a variation is likely accounted for by instrument instability (see Appendix II); therefore, one may conclude that the moisture content and hence the moisture flux from 12 to 18 meters may be said to have attained steady state. The flux calculations made within the 12 to 16-meter zone, using equation 1, are therefore valid for the nonuniform zone at 17 to 18 meters.* From Reisenauer's hydraulic conductivity curves, $k(\Theta)$ when $\Theta = 6$ percent is approximately 1×10^{-5} cm/min. The neutron probe calibration line used to compute moisture contents predicts $\Theta \pm 1.2$ percent, i.e., $3\sigma_{yx}$ (see Appendix II). This variation in Θ translates into $k(\Theta)$ values ranging from 1.5×10^{-5} to 1×10^{-7} cm/min. If these values for $k(\Theta)$ are used, equation 1 estimates a downward flux of liquid moisture of from 0.05 cm/year to 7.9 cm/year.

*As stated earlier, the 17.4 and 18.4-meter readings are outside each of the lysimeter caissons. The closed bottomed lysimeter has a layer of concrete sealing it off. The 17.4 meter readings may be in the concrete layer. It is not known if the 17.4 and 18.4-meter readings are in media, which are hydraulically connected. The discussion relating to the 17 and 18-meter depths applies mainly to the open bottomed lysimeter.

RELIABILITY OF LIQUID PHASE FLUX ESTIMATION

The closed bottomed lysimeter was installed in order to detect any downward migration of moisture as indicated by a rise in moisture content at the bottom of the lysimeter. The moisture content profiles discussed above indicate that a positive downward flux of liquid moisture is taking place, yet no consistant increase in moisture content was detected during the past water year. The lack of agreement between theory and field observations may be explained by four factors: (1) the limited precision of the neutron probe measurements, (2) the lack of spatial resolutions of neutron probe measurements, (3) the failure of the Millington-Quirk method to predict accurately the hydraulic conductivity, and (4) the upward flow of moisture vapor by thermal gradients deep within the lysimeter.

The discussion in Appendix II of neutron probe precision and accuracy indicates an absolute accuracy of 1.2 percent with a reproducibility of approximately 0.5 percent, which affects the calculations in two ways. First, the absolute error leads to erroneous values for the water content used to compute the hydraulic conductivity, which could lead to either an over-estimation or under-estimation of moisture flux. Secondly, the precision level of 0.5 percent prevents the probe from detecting increases of 0.5 percent or less. Because such an increase may be real or machine error, the increase is not regarded as significant.

If the dimensions of the lysimeter, as well as the estimated spatial resolution of the neutron probe are taken into account, expected increases in moisture content from a given flux can be estimated. For moisture contents around 6 percent, such as those found in the lysimeter system, the probe has a sphere of influence greater than 0.6 meters in diameter* and

*Manufacturer figures show that for moisture contents between 0 and 8 percent, the radius of the sphere of influence varies from ∞ to 10 inches.

may be greater than 1 meter. Under this condition, a net moisture flux of approximately 0.5 cm/year may fail to increase the moisture content in the bottom of the closed bottom lysimeter by more than 0.5 percent and would go undetected. These flux rates correspond to a hydraulic conductivity [$k(\Theta)$] of approximately 5×10^{-6} cm/min.

Errors in the estimation of hydraulic conductivity appropriate for the low water contents found at Hanford introduce the greatest amount of uncertainty to the flux estimates. The lack of detectable increases in moisture content deep within the closed bottomed lysimeter may indicate that hydraulic conductivity estimates greater than 10^{-6} cm/min are too high. Actual laboratory measurements will be necessary before this may be determined. Another factor contributing to the apparent lack of moisture accumulation is the expected presence of a thermal gradient which acts as a driving force for the movement of moisture. In the lower portions of the lysimeters, this force acts in opposition to the forces produced by gravity. The error that neglecting this thermal gradient introduces into the use of equation is negligible since equation 1 applies only to the liquid phase. The effects of thermal gradients on moisture flow are primarily restricted to the vapor phase. In the case of the lysimeters, a return flow toward the surface through the vapor phase is expected near the bottom of the lysimeters. This moisture vapor flow may reduce the total net moisture flux to near zero. If this is the case, accumulation of moisture in the lower portions of the closed bottomed lysimeter will not be a reliable indicator of liquid moisture movement. Since nearly all radionuclide transport takes place in the liquid phase, the need exists to isolate this component from the net flux term.

For estimating liquid phase flux, the gravity flow approach seems adequate, provided that accurate hydraulic conductivity

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data are given. The precision and spatial resolution of the neutron moisture probe put definite limits on achievable sensitivity, however, they are not the limiting factors at present.

FUTURE WORK

The moisture transport analysis in this paper indicates several areas where more sophisticated data are required for a more quantitative approach to moisture flow modeling. These areas include: (1) characterization of sediment, hydraulic, and thermal parameters; (2) more reliable neutron probe calibration; and (3) improved field instrumentation designed to expand data collection.

New and more appropriately designed neutron probe calibration facilities are being planned. These facilities will contain sites with the same access tubes as those in the lysimeters. Alternative methods of neutron probe calibration are also under consideration. A method which uses neutron absorption by graphite is being studied.[8] Field tests of instrument precision will be conducted to determine the level of agreement between the statistical prediction given in Appendix II and the actual measurements.

Projects have been planned that will include evaluation of sediment temperature with depth and laboratory determination of thermal transport coefficients. The diurnal, as well as annual and long-term, temperature fluctuations will be characterized in order to acquire sufficient field data to allow evaluation of nonisothermal moisture flow equations. Research has been planned to measure the hydraulic properties of the lysimeter's sediment. This research will include both the spatial variability and moisture content dependence of the hydraulic conductivity. A study is in progress for evaluating the appropriateness of Millington-Quirk-type analysis to the Hanford sediments.

Several instrument designs capable of measuring sediment moisture potential will be examined and determinations of their applicability will be made. These instruments will be used along with temperature sensors, sediment salinity analyses, and micrometeorological information to expand the data base available for flow characterization. Computer simulation models which will process this expanded data base are in the final stages of development. These models will use the non-isothermal equations more applicable to the general moisture flow problem than the equations presented here. The models will provide the mechanism to evaluate flow in the upper sediments where transient conditions dominate.

CONCLUSION

An examination of the data collected during the 1976-1977 water year reveals that the moisture content of the upper 12 meters of the lysimeters was nonuniform and did change from month to month throughout the year. These changes in moisture content were in response to monthly fluctuations in surface precipitation and solar radiation. Fluctuations of greater than 2 to 3 percent were recorded in the top 1 to 2 meters, while changes on the order of 1 percent or less were recorded below this depth. The nonuniformity and transitory nature of the moisture distribution above 12 meters made quantitative analysis of moisture flux difficult. Insufficient data have been gathered to properly characterize the moisture movement in upper sediments.

No significant changes in moisture content were recorded below the 12-meter depth throughout the year. The moisture content between 12 and 16 meters was also uniform with depth, at approximately 6 percent by volume. The uniform moisture distribution between 12 and 16 meters resulted in the matric potential gradient being reduced to near zero (<0.1 cm/cm)

and the gravitational potential gradient (1 cm/cm) becoming the dominant driving force for the downward flux of liquid moisture. Under such conditions, the liquid phase moisture flux may be estimated as being equal to the hydraulic conductivity. This approach leads to an estimated liquid moisture flux on the order of millimeters per year, moving downward in the lower portions of the lysimeter.

Liquid moisture moving downward in the closed bottomed lysimeter is not necessarily inconsistent with the lack of a detectable increase in the moisture content deep in the lysimeter. Taking into account the precision and spatial resolution of the neutron probe and also the dimensions of the lysimeter, a flux of <0.5 cm/year could go undetected under isothermal conditions. This annual flux corresponds to a hydraulic conductivity of approximately 5×10^{-6} cm/min. Under the nonisothermal conditions that do exist in the bottom of the lysimeter, liquid fluxes >0.5 cm/year could go undetected. The thermal gradient found deep within the lysimeters will cause some moisture vapor to flow upward. This return flow will in part balance the downward liquid flow, possibly resulting in a net moisture flux of <0.5 cm/year.

It would seem that the liquid phase flow would be of great interest. In the case of the lower portions of the lysimeters, an isothermal, steady state approach such as described above has merit. More work on the estimation of hydraulic conductivity and neutron moisture probe calibration needs to be done in order to gain more confidence in moisture flux estimations.

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APPENDIX I

MOISTURE FLOW THEORY

Previous reports[1,2,3,4,5,6] have presented lysimeter sediment moisture data as a function of depth, however, they have not attempted any quantitative description of deep percolation or moisture redistribution within the lysimeter system. One factor making quantification extremely difficult is the contradiction between the complexity of the mathematical models generally used to describe moisture flow and the sparcity of the data collected. The existence of this disparity between required model input and available data has limited analysis to qualitative descriptions of profile wetting and drying. This section presents a simplified model which is more compatible with available information. The many assumptions incorporated in the following development will reduce the model's applicability to the general flow problem encountered in the lysimeter, but this approach does have the advantage of allowing one to quantitatively analyze moisture transport in certain portions of the lysimeter system.

The following presentation consists of: (1) an explanation of the most fundamental concepts of moisture flow theory, (2) development of two general flow equations for unsaturated flow, and (3) a simplification of the cited equations to a form applicable to certain specific portions of the lysimeter profile.

The discussion of fundamental theory is purposely very basic and simplistic. In order to carefully outline the adaptation of saturated flow theory to an unsaturated system and to incorporate moisture content as the primary parameter through further manipulations, the discussion begins with Darcy's Law and concludes with the development of a diffusion-type equation based upon moisture "concentration" gradients.

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SATURATED FLOW

Darcy observed experimentally that the steady state flux of water through a saturated sand system was proportional to the hydrostatic pressure gradient (i.e., how the pressure changes in space). Darcy's findings, known as Darcy's Law, are formalized as follows:

$$J_w = -k \nabla P \qquad \text{(I-1)}$$

where: J_w is a vector describing the rate and direction of flow

∇P represents a vector describing how the pressure changes in space

k is simply the proportionality constant relating the two vectors.

To give some physical meaning to the variables and to encourage an intuitive feeling for how the mathematical formulation applies, we should realize that:

- J_w describes how much moisture is moving and in what direction.
- ∇P is often referred to as the driving force causing the flow. Dimensionally, P is a force per unit volume.
- k is generally referred to as the hydraulic conductivity, although in engineering it is sometimes referred to as the permeability. k has to do with the porous media's ability to resist the flow of moisture generated by the hydrostatic driving force or push. Generally, the smaller the size of the pores in the flow media, the greater the resistance to flow and the lower the conductivity.

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In general, Darcy's Law is an equation that relates moisture flux to the hydrostatic pressure gradient and the hydraulic conductivity. The pressure gradient describes the energy state of the water in the porous media and the forces responsible for flow; the hydraulic conductivity characterizes the porous media and how it will restrict the fluid's ability to respond to the hydrostatic forces placed upon it. Darcy's Law or equation is often characterized as an isothermal, steady-state, saturated flow equation. Such a description implies certain restrictions that must be understood before proceeding.

A steady-state process is one which does not change with time. This is in contrast to a transient process which does vary with time. One weakness with applying the above terms to Darcy's Law is the implication that this "steady-state" equation will not describe the flux under transient conditions which is not entirely true.

Equation I-1 produces what are called discrete solutions that are valid for one point in time. If the pressure gradient or the hydraulic conductivity changes in time, then a separate solution will be needed to describe a new flux for each time change. While this continual updating and resolving has practical limitations, transient conditions do not prevent Darcy's Law from producing accurate discrete solutions.*

The important limitation of the Darcy equation is its requirement of saturated flow. Darcy's Law is fundamentally a simple proportionality between the moisture flux and the hydrostatic pressure gradient. Inherent in this relationship

*An exception to this occurs when the magnitude of the pressure changes are great enough that inertial forces must be accounted for. This is not the case in sediment moisture flow applications.

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is the assumption that the proportionality constant (k) is indeed a constant that is independent of the hydrostatic pressure. As long as the porous media is saturated, this holds true. Under unsaturated conditions, this assumption is no longer valid. This change in the nature of k produces rather dramatic mathematical and experimental consequences.

Another critical restriction is the assumption of isothermal conditions. Under nonisothermal conditions, the laws of potential equilibrium do not apply. Darcy's Law only includes potential energy gradients as driving forces and, therefore, is incomplete under conditions where thermal gradients exist.

What has been presented to describe saturated flow is an equation or model relating moisture flux to the hydrostatic pressure gradient that also includes the third term of hydraulic conductivity. The model is limited in a practical way to steady-state processes and in a fundamental way to saturated flow and isothermal conditions. Eliminating the hydraulic conductivity is not possible; however, with some additional manipulation, Darcy's Law can be extended to unsaturated flow. The pressure gradient term can be replaced with a moisture content term, and this new equation can be combined with an equation of continuity to form a model applicable to transient processes.

UNSATURATED FLOW

The portion of soil pores not filled with solution are filled with the sediment atmosphere. This results in a three-phase system of gas, liquid, and solid, as opposed to the original solid-liquid, two-phase, saturated system. With the introduction of a third phase, in this case air, an air-liquid interface is created. Under isothermal conditions, the energy distribution along this interface will determine the rate and direction for the movement of moisture.

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As the movement of fluid through unsaturated media was studied, it was found that a fundamental difference exists in the mechanism of flow. Under saturated conditions, the moisture is constantly being pushed from behind by more moisture. This results in a hydrostatic pressure gradient being built up within the media, which constitutes the driving force responsible for flow. Positive hydrostatic pressure is absent during unsaturated conditions, so other mechanisms and other driving forces must be found. Fundamental principles of physics and thermodynamics suggest that systems will move toward an equilibrium state in which the system's total energy is evenly distributed. If the energy distribution of a system could be completely characterized, how moisture movement would take place could be predicted. Over the years, just such a fundamental approach has been worked out to describe isothermal moisture movement through sediments. The change in the moisture's energy state from point to point (i.e., the energy gradient) will emerge as the driving force involved in unsaturated flow systems. This is simply a generalization of the hydrostatic pressure gradient described above as found in saturated flow.

The energy of a system can be broken down into the sum of kinetic energy term and a potential energy term. The kinetic energy of a system component is that energy realized by virtue of an object's motion, while the potential energy of a system component is due to its relative position in a force field. To know the distribution of the sediment moisture's total energy, both the kinetic and potential energy distributions must be known. Fortunately, conditions often exist that minimize the calculations which are required to accomplish this. The driving force causing flow is related to the energy gradient and not the absolute energy concentration at any one point. This implies that only those elements of the system's energy which show spatial or time variance

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need to be characterized. If the sediment is isothermal, that is, of equal temperature at all points of interest, then the kinetic energy distribution is uniform. In other words, the total energy gradient is equal to the potential energy gradient. Fluid motion does slightly disturb the kinetic energy distribution; however, because of the extremely slow fluxes (i.e., 1 cm/min or less), the kinetic energy gradient is of little practical importance. Such an assumption is verifiable by the success of the potential energy model under controlled isothermal conditions.

A real problem with such an approach based on potential measurements, however, is the isothermal restriction. Accounting for thermal gradients and their effect on flow is difficult to accomplish and is impossible with the data collected by the lysimeter project to date. The only estimates of flux possible must come from an isothermal model based upon sediment moisture content. Since thermal gradient effects must be ignored, the potential energy of the sediment's moisture is the only energy component which must be characterized. To do this, a term called moisture potential must be defined.*

Moisture potential is defined as the total potential energy per unit volume of sediment moisture. From this

*The concept of total potential for describing moisture movement under all conditions has not been accepted by all scientists. During the 1960's, a great discussion took place between P. F. Low[10] who favored the concept and A. T. Corey and W. D. Kemper who saw certain weaknesses when applying total potential to special cases. The problem occurs when one realizes that to apply a concept of total potential, one must also apply a single conductivity term. In the case of nonisothermal flow, separate conductivities coupled with their appropriate driving forces have generally been used and the concept of a total potential has been avoided. For the cases described here where only the matric potential (Ψ_m) and gravitational potential (Ψ_g) are considered important, the concept of total moisture potential (Φ) where $\Phi = \Psi_m + \Psi_g$ is normally used.

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definition and that of potential energy, it follows that all the force fields operating on the sediment moisture must be identified (see Baver, et al.,[7] or Taylor and Ashcroft[8] for detailed explanations of how force fields are identified and described). The approach found in Baver, et al.,[7] is derived from physical mechanics; in contrast, the approach of Taylor is thermodynamic. In Taylor's analysis, with the exception of the effect of gravity, the moisture potential is the chemical potential of the sediment moisture. The standard result of both points of view is to divide the sediment moisture potential into five major components: (1) a matric potential (Ψ_m), (2) an osmotic potential (Ψ_o), (3) a gravitational potential (Ψ_g), (4) a pressure potential (Ψ_p), and (5) an overburden potential (Ψ_Ω). The sediment moisture potential (Φ) is equal to the sum of its components.

The matric potential arises from the forces of attraction between the sediment moisture and the sediment particles, as well as the surface tension of the fluid. The osmotic potential results from the presence of dissolved ions in the sediment solution. The gravitational potential is due to the moisture's position in the earth's gravitational field. The pressure potential is due to either the air pressure in the pores or, in saturated systems, to the weight of the free-standing water. The overburden potential is due to the weight of soil particles in solution. Any sediment free to move with the moisture will exert a weight of overburden potential on the liquid phase. A more complete explanation of this, and also of which potential components are important for different flow applications, is given in Baver, et al.[7] During unsaturated flow conditions in coarse textured sediment (e.g., Hanford sediments), the components of moisture potential controlling flow will be the matric potential (Ψ_m) and gravitational potential (Ψ_g). Overburden potential (Ψ_Ω),

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pressure potential (Ψ_p), and osmotic potential gradients (Ψ_o) tend to be insignificant.

In order for the osmotic potential (Ψ_o) to play a direct role in moisture flow, the free movement of solutes must be restricted by a semipermeable membrane. Sediments do act as semipermeable membranes to a certain extent and this effect has been examined in agricultural soil materials. It has been found that for very fine textured soils, the osmotic potential gradient is about 10 percent as effective as the matric or gravitational potential in causing flow. For coarse textured sediments of soils, the effectiveness drops off sharply to perhaps 1 percent or less. This work, while not done on the Hanford sediments, directly supports the elimination of Ψ_o from the flow equation. Darcy's Law is appropriately written as: $J_w = -k \nabla(\Psi_m + \Psi_g)$[4] where $\Psi_m + \Psi_g$ has been substituted for the hydrostatic pressure term P.

The next term of the equation which must be modified is the hydraulic conductivity (k). This number is no longer constant under unsaturated conditions. This can be readily visualized if the sediment characteristics which determine the value of k are considered. Pore size is important to the extent that more fluid can be moved through a large pore than a smaller one. Since any porous medium contains many pores and many pore sizes, the pore size distribution is important. Samples with the same total porosity may show large differences in the "k" values simply because one medium consists of a few large pores and the other a great many small pores. As the sediment is desaturated, some of the pores are prevented from contributing to flow. As a result, the sediment becomes hydraulically equivalent to a porous body with a reduced total porosity with a new pore size distribution and exhibits a corresponding reduction in hydraulic conductivity. As more and more empty or partially filled pores appear, it becomes less likely that all water filled pores will be

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connected. This leads to the appearance of "dead end" pores, which further reduce the ability of the potential gradients to move the moisture. The presence of empty pores also increases the length and tortuosity of the flow path, causing still further reductions in conductivity. Desaturation produces many changes, all resulting in a reduction of hydraulic conductivity.

L. A. Richards[12] is often given credit for extending Darcy's Law to unsaturated systems. He accomplished this by generalizing the hydrostatic pressure to moisture potential and also by introducing a hydraulic conductivity, which was a function of the matric potential. A modified or extended Darcy's Law appropriate for unsaturated flow may now be written as:

$$J_w = -k(\Psi_m)\ (\Psi_m + \Psi_g) \qquad \text{(I-2)}$$

The transformation of equation I-2 to a form more appropriate to transient flow is accomplished by combining a Darcy-type equation (e.g., I-2) with the equation of continuity. Derivations of the continuity equation are given in any text on soil physics or fluid mechanics, such as Baver, et al.,[7] Hillel,[13] and Bird, et al.[14] This equation is essentially a mathematical formulation of the law of conservation of mass and is stated in the following way:

$$\frac{\partial \rho}{\partial \tau} = \nabla \cdot (\rho J_w) \qquad \text{(I-3)}$$

This equation states that the change in density of a fluid is equal to the divergency of the mass flux. There is a subtle difference between how the equation of continuity is applied to porous systems and how it is applied to the more common flow systems such as pipes and canals. One of

the common assumptions involved in the application of equation I-3 is that the fluid in question is incompressible (i.e., the density is constant with time). When this is applied to equation I-3, the result is that $\nabla\cdot(J_w) = 0$. The divergence of a volume flux being equal to zero is a common consequence of fluid flow theory. In unsaturated porous media flow, one does not arrive at this conclusion. Normally, the density of water is equated with its mass in equation I-3 because a unit volume of liquid is used. In unsaturated flow, a unit volume of porous media is used so the density of water and the mass of water contained in a unit volume of porous material are not equal. The appropriate analysis for porous media is as follows.

The law of conservation of mass becomes:

$$\frac{\partial m}{\partial t} = \nabla\cdot(\rho J_w) \qquad \text{(I-4)}$$

but $m = \rho\Theta$ - where $m = \dfrac{\text{mass fluid}}{\text{unit volume of material}}$

ρ = density of fluid

$$\Theta = \frac{\text{volume of fluid}}{\text{volume of material}}$$

therefore

$$\frac{\partial \rho\Theta}{\partial t} = \nabla\cdot(\rho J_w) \qquad \text{(I-5)}$$

By setting ρ = const, it follows that:

$$\frac{\partial \Theta}{\partial t} = \nabla\cdot(J_w) \qquad \text{(I-6)}$$

Equation I-6 is the form of the continuity equation applied to moisture transport through sediment. The assumption of fluid incompressibility is still contained in the analysis.

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Combining equations I-2 and I-6 produces:

$$\frac{\partial \Theta}{\partial t} = \nabla \cdot [k(\Psi_m) \quad \nabla(\Psi_m + \Psi_g)] \qquad \text{(I-7)}$$

This equation will serve as the so-called transient model. Although it does not contain the Darcian flux as an explicit variable, it does produce solutions showing the change in water content with time. Any attempt to predict or explain moisture redistribution must address itself to equation I-7 or an alternative form of it. The final step in developing the model will be the transition from moisture potential as input parameter to moisture content. This is accomplished by realizing the existence of a functional relationship between matric potential and moisture content. This relationship between the sediments level of saturation and matric potential is discussed in Appendix II. Once this relationship is understood, a simple change of variable accomplishes the transition as follows:

Assume:

$$\Psi_m = \Psi_m(\Theta) \qquad \text{(I-8)}$$

then

$$\frac{\partial \Psi_m}{\partial x} = \frac{\partial \Psi_m}{\partial \Theta} \frac{\partial \Theta}{\partial x} \qquad \text{(I-9)}$$

Combining equations I-2 and I-9 and expanding them in terms of cartesian coordinates produces:

$$J_w = -k(\Theta)\frac{\partial \Psi_m}{\partial \Theta} \quad [\frac{\partial \Theta}{\partial x} + \frac{\partial \Theta}{\partial y} + \frac{\partial \Theta}{\partial z}] \; -k(\Theta)\frac{\partial \Psi_g}{\partial z} \qquad \text{(I-10)}$$

As a result $-k(\Theta) \frac{\partial \Psi_m}{\partial \Theta} = D(\Theta)$, which is called the sediment moisture diffusivity, is defined.

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This reduces equation I-10 to:

$$J_w = D(\Theta)\ \nabla\Theta - K(\Theta)\ \frac{\partial \Psi_m}{\partial z} \qquad \text{(I-11)}$$

which is known as the diffusion equation for vertical moisture flow. If restricted to horizontal flow, equation I-11 becomes:

$$J_w = D(\Theta)\ \nabla\Theta \qquad \text{(I-12)}$$

which is similar in form to Fick's law of diffusion and Fourier's law of heat transfer. Equation I-11 introduces one more assumption. This assumption is contained in equation I-9. In order for this differentiation to be meaningful, it must be assumed that Θ is a single valued function of Ψ_m. The phenomenon of hysteresis, discussed in Appendix II, introduces some error in this assumption. Another profile characteristic complicating the use of the diffusion-type equation is stratification. Layers of different textural composition will have different desorption (i.e., Θ versus Ψ_m) relationships and, therefore, will prohibit the use of the same values for the term $\frac{\partial \Psi_m}{\partial \Theta}$. The standard conductivity equations are of limited value in layered sediments; however, the complication tends to be camouflaged somewhat in equations I-11 and I-13. Writing equation I-6 as a diffusion-type equation results in:

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial x}[D(\Theta)\frac{\partial \Theta}{\partial x}] + \frac{\partial}{\partial y}[D(\Theta)\frac{\partial \Theta}{\partial y}] + \frac{\partial}{\partial z}[D(\Theta)\frac{\partial \Theta}{\partial z}] + k(\Theta)\frac{\partial \Psi_g}{\partial z} \qquad \text{(I-13)}$$

This provides a moisture content based equation applicable to transient flow systems; thus an isothermal, Darcian-type flow model has been developed that is capable of describing moisture fluxes and redistribution in sediment.

The many assumptions encountered thus far are summarized by Klute.[15] The nonlinearity of equations I-11 and I-13

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prevent them from being solved for the general case. Either further assumptions or numerical techniques must be involved in any attempt to apply these equations quantitatively to field problems. There are two simplifications that are possible under certain profile conditions. First is the reduction from three-dimensional flow to one-dimensional flow. Rewriting equation I-10 in the vertical "z" dimension produces:

$$J_w = -k(\Theta)\frac{\partial \Psi_m}{\partial \Theta}[\frac{\partial \Theta}{\partial z}] - k(\Theta)\frac{\partial \Psi_g}{\partial z} \qquad \text{(I-14)}$$

Secondly, if a zone within the profile which is texturally uniform and has a uniform moisture content is used, then:

$$\frac{\partial \Theta}{\partial z} = 0 \qquad \text{(I-15)}$$

Equation I-14 then reduces to:

$$J_w = - k(\Theta)\frac{\partial \Psi_g}{\partial z} \qquad \text{(I-16)}$$

From equation III-1 in Appendix III, a potential may be written as ρgh for some h. This way of writing potential is often referred to as equivalent head units. In head units, the gravitational potential (Ψ_g) becomes:

$$\rho gz \qquad \text{(I-17)}$$

where z is the distance from the water table or some other arbitrary reference level. Equation I-15 now becomes:

$$J_w = - k(\Theta)\rho g\frac{\partial \Theta}{\partial z} = - k(\Theta)\rho g. \qquad \text{(I-18)}$$

$k(\Theta)\rho g$ may be defined as $k'(\Theta)$, which has dimensions of LT^{-1}. Under the assumptions of equation I-18, the moisture is draining under the force of gravity alone and the drainage rate is equal to the hydraulic conductivity, $k'(\Theta)$.

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APPENDIX II

NEUTRON PROBE CALIBRATION AND PRECISION

Interpretations of moisture content data obtained by neutron probe measurements must include reliability estimates of the data. The following discussion will provide what information is available on the accuracy and precision of the data contained in this report.

van Bavel (1) identifies three sources of error found in neutron probe measurements:

(1) Deviation of actual calibration curve from the experimental calibration curve.
(2) Variations in count ratio produced by random emission of neutrons from the radioactive source.
(3) Failure of counting electronics to accurately count the incoming slow neutrons.

The first category controls the absolute accuracy of the reading while the remaining two largely determine the precision or reproducibility of a measurement.

Calibration of the Model 503 Hydroprobe has resulted in Figure 26. This graph was obtained by matching the hydroprobe readings to count rates obtained from a 1 1/2-inch Nuclear Chicago probe during an actual day of readings at the lysimeters. No clear documentation of the procedures used for the calibration of the Nuclear Chicago probe exists. It was presumably made using large volume drums filled with lysimeter sediment of a known moisture content. Analysis of Figure 26 provides the following least squares regression line:

$$\% \text{ moisture} = 27.11\ [N/Nstd] - 0.88 \qquad \text{(II-1)}$$

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There are two approaches in analyzing this equation for precision. One is to use the σ_{yx} value obtained from the regression analysis. This gives the standard deviation of percent moisture values estimated from known N/Nstd ratios using Equation II-1. This is often used as an indication of the predicting precision of a regression line. In this case, it indicates how well the 503 Hydroprobes readings match what was being read with the Nuclear Chicago probe. The value of this parameter for Equation II-1 is 0.4 percent. Therefore, any readings from the hydroprobe should match the Nuclear Chicago with a precision of about ±1.2 percent (i.e., 3 σ_{yx}). Since it is not known how close the Nuclear Chicago probe's readings matched the actual moisture content, this leaves the absolute accuracy of the instrument in doubt. The fact that the 503 probe does not match the Nuclear Chicago instrument exactly means that any error in the Nuclear Chicago readings will be propagated by this procedure. Another equally important parameter of the probe is the internal reproducibility of the readings. Because the americium/beryllium source does not produce the same number of fast neutrons at all times, it is called a random emitter. It produces a neutron population, which has a density distribution whose standard deviation is $\sqrt{N}$ where N is the number of counts read at any given time. To see how this affects readings, the analysis proposed by Young[1] and Gardner[2] is used. Following Young, we set:

$$\sigma_\theta = \left[\left(\frac{\partial\Theta}{N}\right)^2 \sigma_N^{\,2} + \left(\frac{\partial\Theta}{\partial N_{std}}\right)^2 \sigma N^2{}_{std}\right]^{\frac{1}{2}} \qquad \text{(II-2)}$$

$$\sigma_\theta = \left[\left(\frac{27.11}{40,000}\right)^2 10,151 + \left(\frac{(27.11)(10,151)}{(40,000)}\right)^2 40,000\right]^{\frac{1}{2}} = .08\% \qquad \text{(II-3)}$$

Precision of greater than 0.24 percent of $3\sigma_\theta$ should not be expected because of the random emission pattern of the source. Another aspect of the neutron-measurement reliability is the depth control available. Since these measurements are being taken over a period of months, the surface level is subject to change because of sediment blowing in or off the site. No measurements of surface level changes were taken during the 1976 or 1977 water year; however, preliminary results of the 1977-1978 measurements indicate the surface level may vary by as much as 2 to 3 centimeters over a period of a few months. The effect of this on neutron moisture measurements has not been determined, but work is continuing in this area.

Item #3 in the list from van Bavel (1) includes such things as electronic drift, temperature sensitivity of voltage regulators, and improper adjustment of resistors. These sources for error are very difficult to quantify, yet may play an important role in limiting the interpretations of neutron probe data.

An examination of the moisture content data contained in Tables XII and XIII shows monthly fluctuations in moisture content of approximately ±0.5%. These changes are not systematic but random in nature. October and November 1976 readings indicate that the entire profile gained 0.6% moisture for two consecutive months. This type of increase is unjustifiable on a physical basis and must be ruled out as experimental error. The remaining, more random, monthly fluctuations are also hard to explain as anything but instrument error. While the causes of this type of instrument drift are not well understood, nor are they predictable, they must be recognized and accounted for. In this case, instrument instabilities reduced the precision of measurement more dramatically than the random emission of the radioactive source. The lysimeter data indicate

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that the limit of precision of the neutron probe over long periods of time is closer to 0.5% rather than the 0.08% predicted by variations in neutron emission.

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APPENDIX III

THE SEDIMENT CHARACTERISTIC CURVE

The relationship between moisture content and matric potential must be known in order to evaluate the diffusion-type equations (Appendix I). By applying a set of known pressures or suctions to prewet samples across a porous plate and measuring the resulting equilibrium moisture content, the desorption or sediment characteristic curve unique to that sediment can be determined.[1] It is possible, though considerably more difficult, to establish this potential-moisture content relationship for the sorption (i.e., wetting) process and for desorption (i.e., drying). Different curves are generated depending on which process is used. This effect is called hysteresis and has at least two possible explanations. One is related to the "Haines Jump" phenomena and the other results from the peculiar drainage characteristics of oddly shaped pores, the "ink bottle" effect. These two ideas, as well as a complete discussion of characteristic curves is found in any text on soil physics such as Baver, et al.,[2] Taylor and Ashcroft,[3] and Hillel.[4]

A physical explanation for the potential-moisture content relationship comes from an examination of the air/water interface found in unsaturated media. Because of adhesive forces between water molecules and the sediment particle surface, coupled with the surface tension of the liquid, a curved meniscus develops. This meniscus is much like that which appears in small capillary tubes. The energy distribution across this curved interface will determine the matric potential of the solution. The potential of water below this interface is less than what would be in the same liquid were it not for the curvature induced by the sediments. As the

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sediment moisture content decreases the meniscus steepens, resulting in a more negative potential.*

Relationships between the radius of curvature of the meniscus and the corresponding potential may be derived if the geometry of the pore is known. In a capillary tube, one finds:

$$\Psi_m = \frac{2\sigma \cos \Theta}{r} \qquad \text{(III-1)}$$

where: σ = surface tension of the liquid
Θ = wetting angle between liquid and surface
r = radius of curvature of meniscus
Ψ_m = matric potential

Equation III-1 is the basis of the Millington-Quirk model for hydraulic conductivity. In the Millington-Quirk model, the desorption curve is divided into segments. Then, using Equation III-1, the equivalent number of capillary

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* Potentials are not measured in absolute terms. They are always a relative measurement between defined reference states. In the case of matric potential, the reference state is pure, free water at the same elevation and temperature as the sediment moisture in question. The potential of this moisture is defined as zero. Since the potential of the sediment moisture beneath a curved meniscus is less than the reference potential, the potential of the sediment moisture is written as a negative number. However, this does not imply that the sediment moisture contains a negative amount of energy. One can interpret this negative potential to mean that the moisture held by the sediment matrix is in a lower energy state than the water in the defined reference state and is therefore able to do less work than this "reference water". Because of this, the sediment moisture is said to be under suction or tension. The difference between saturated and unsaturated sediments may be explained in terms of how the moisture is held. In saturated sediments, the moisture is under a positive pressure (i.e., in a higher energy state than the reference). In unsaturated sediments, the moisture is held under tension (i.e., in a lower energy state).

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tubes, which are required to hold the amount of moisture contained in a given segment at the average potential contained in that segment, is calculated for the entire curve. This produces a "capillary bundle" representation of a soil or sediment. Since the geometry of the capillary tubes is known, the hydraulic conductivity may be computed from the Hagean-Poiseville equation.[2] This capillary bundle's hydraulic conductivity is assumed to be related to the sediment hydraulic conductivity.[2]

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APPENDIX IV

SEDIMENT MOISTURE DATA TABLES

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TABLE I

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	9/15/76			9/16/76		
STANDARD COUNT	40258			40094		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	4.7	4.4	3.9	7.6	8.0	6.8
0.38	6.7	7.2	7.1	8.6	8.3	8.0
0.53	6.9	7.7	7.6	8.4	8.6	7.8
0.68	7.3	8.2	7.9	8.3	9.2	8.4
0.83	7.8	8.4	8.2	9.1	9.4	8.5
0.94	7.6	8.2	7.8	8.9	9.0	8.2
1.04	6.8	7.7	7.4	8.4	8.5	7.8
1.19	5.4	6.6	6.3	6.8	7.1	6.3
1.44	4.4	5.0	4.9	5.1	5.2	5.1
1.71	4.5	4.6	4.5	4.9	5.4	5.2
1.96	4.6	4.3	4.5	4.7	5.0	4.9
2.21	4.7	4.3	4.6	5.0	5.2	5.2
2.47	5.2	4.8	5.0	4.9	4.8	5.0
2.71	5.3	5.5	5.6	5.4	5.8	5.7
3.46	5.9	6.6	6.2	5.5	6.0	6.2
3.71	6.6	6.9	6.9	5.5	6.1	6.2
3.95	7.5	7.6	7.8	5.6	6.0	5.8
4.20	7.0	7.9	7.9	--	--	--
4.45	7.4	7.5	8.4	5.5	5.7	5.4
4.69	7.7	7.3	8.2	--	--	--
4.94	8.4	8.2	8.8	5.8	5.7	5.6
5.19	7.8	7.7	8.2	--	--	--
5.44	8.9	9.3	8.9	5.9	6.2	6.0
5.69	8.2	8.7	8.0	--	--	--
5.93	7.6	7.8	7.4	5.8	5.7	5.4
6.18	7.2	8.0	7.1	--	--	--
6.43	6.7	7.3	6.8	5.5	5.6	5.1
7.43	5.8	6.2	6.4	5.7	5.5	5.6
8.43	6.2	6.2	6.2	5.8	6.0	5.9
9.43	6.2	6.4	6.2	6.0	6.1	5.7
10.42	5.6	5.8	5.6	6.0	5.8	5.7
11.42	5.7	5.5	5.6	6.0	5.9	5.8
12.42	6.0	6.0	5.8	5.9	6.2	6.2
13.41	5.6	6.0	6.0	5.7	5.7	5.6
14.41	5.6	5.7	6.0	5.8	6.0	5.7
15.41	5.6	5.9	5.7	6.0	5.9	6.0
16.41	5.8	5.4	5.9	5.7	5.7	5.7
17.41	6.1	6.2	6.3	5.5	5.7	5.4
18.41	4.9	5.2	5.3	5.7	5.3	5.6

9 2 1 2 4 5 6 1 1 9 2

TABLE II

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	10/21/76			10/28/76		
STANDARD COUNT	39402			39792		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	3.8	4.3	3.6	5.7	7.3	6.4
0.38	6.2	7.4	6.8	6.6	8.1	7.7
0.53	6.7	8.3	7.8	7.8	9.1	8.5
0.68	7.1	8.3	7.9	8.1	10.3	10.5
0.83	7.6	8.5	7.9	8.9	9.9	8.6
0.94	7.4	8.6	8.1	8.7	9.2	8.4
1.04	6.7	7.9	7.4	8.4	8.5	7.8
1.19	5.6	6.7	6.4	7.0	7.3	6.6
1.44	4.5	5.5	5.1	5.1	5.3	5.1
1.71	4.6	4.8	4.6	5.1	5.2	5.3
1.96	4.6	4.6	4.6	4.7	5.1	4.8
2.21	4.9	4.7	4.7	5.0	5.2	5.1
2.47	5.3	5.2	5.3	4.9	5.0	5.1
2.71	5.5	5.7	5.8	5.5	5.9	5.7
3.46	6.0	6.9	6.4	5.5	6.2	6.1
3.71	6.9	7.2	7.1	5.5	6.4	6.1
3.95	7.6	7.9	8.3	5.6	6.1	5.8
4.20	7.1	8.2	8.0	--	--	--
4.45	7.9	8.0	8.6	5.8	6.0	5.6
4.69	7.6	7.9	8.7	--	--	--
4.94	8.7	8.6	8.9	5.8	5.8	5.9
5.19	7.9	8.1	8.4	--	--	--
5.44	9.3	9.8	9.3	6.2	6.4	6.1
5.69	8.0	9.2	8.4	--	--	--
5.93	7.8	8.4	7.9	5.9	5.7	5.6
6.18	7.2	8.7	7.4	--	--	--
6.43	6.9	8.1	7.2	5.6	5.4	5.6
7.43	6.1	7.0	6.7	5.8	5.6	5.6
8.43	6.2	7.0	6.4	6.0	6.1	5.9
9.43	6.4	6.9	6.9	6.6	6.0	5.8
10.42	5.7	6.5	6.1	6.4	6.0	5.6
11.42	5.7	6.3	6.1	6.1	6.0	5.9
12.42	6.0	6.6	6.4	6.0	6.2	6.0
13.41	5.6	6.8	6.4	5.9	5.9	5.4
14.41	5.7	6.9	6.6	6.0	6.1	5.8
15.41	5.9	7.0	6.2	6.6	6.1	6.0
16.41	5.8	6.7	6.6	6.1	5.6	5.7
17.41	6.2	7.5	6.7	5.6	5.7	5.6
18.41	5.0	6.3	5.6	5.6	5.2	5.4

9 2 1 2 4 6 6 1 1 9 3

TABLE III

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	11/ 5/76			11/ 8/76		
STANDARD COUNT	43919			43907		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	2.8	2.2	1.8	6.4	6.1	5.1
0.38	7.1	7.2	7.2	9.6	8.4	8.7
0.53	7.4	7.9	7.6	9.9	8.2	9.1
0.68	7.7	8.6	8.4	9.5	8.5	9.0
0.83	8.0	9.2	8.8	9.7	9.2	9.5
0.94	8.4	9.2	8.7	10.3	9.4	9.4
1.04	8.6	9.1	8.9	10.1	8.9	9.2
1.19	8.2	8.9	8.9	10.0	9.1	9.0
1.44	5.9	7.1	6.7	7.3	7.5	6.9
1.71	5.4	6.0	5.8	6.2	6.4	6.2
1.96	5.6	5.6	5.4	6.5	6.2	6.3
2.21	5.6	5.4	5.5	6.1	6.3	6.1
2.47	5.8	5.6	5.5	6.4	6.3	6.4
2.71	6.0	6.4	5.7	6.3	6.6	6.4
3.46	6.7	6.7	6.5	6.8	7.5	7.0
3.71	7.6	8.1	7.6	6.6	7.0	7.3
3.95	7.9	8.1	8.0	6.7	7.3	7.5
4.20	8.6	8.8	9.2	--	--	--
4.45	8.3	8.9	8.8	7.1	7.5	7.3
4.69	8.7	8.8	9.4	--	--	--
4.94	9.2	8.7	9.7	7.1	7.0	7.0
5.19	9.4	9.3	9.7	--	--	--
5.44	8.9	9.2	9.3	7.1	7.1	6.8
5.69	10.1	10.1	9.7	--	--	--
5.93	8.8	9.3	9.2	7.4	7.1	6.9
6.18	8.7	9.1	8.7	--	--	--
6.43	8.1	8.8	8.0	7.2	7.0	7.1
7.43	6.9	7.3	7.3	6.9	7.5	7.3
8.43	7.0	7.5	7.6	6.4	6.6	6.5
9.43	7.5	7.6	7.5	7.0	6.9	7.0
10.42	6.7	7.1	6.7	7.0	7.0	7.1
11.42	6.5	6.8	6.6	6.8	7.0	6.8
12.42	7.0	7.1	7.2	7.0	7.3	7.3
13.41	6.7	7.3	7.2	7.1	7.2	7.1
14.41	6.7	6.8	7.3	6.5	6.7	6.6
15.41	6.8	7.2	7.0	6.8	7.2	6.8
16.41	6.8	6.6	6.7	6.9	7.0	7.3
17.41	7.3	7.1	7.4	6.0	6.8	6.8
18.41	6.1	6.6	6.4	5.9	6.3	6.3

9 2 1 2 4 6 1 1 9 4

TABLE IV

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	1/ 5/77			1/ 6/77		
STANDARD COUNT	42735			42186		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	4.1	4.4	3.8	6.3	6.7	5.8
0.38	6.0	6.4	6.1	7.8	7.8	7.6
0.53	6.2	6.8	6.7	8.0	7.8	7.6
0.68	6.5	7.5	7.3	7.8	8.4	7.8
0.83	7.0	7.7	7.3	8.6	8.9	8.0
0.94	7.1	7.8	7.4	8.6	8.7	8.0
1.04	6.9	7.5	7.4	8.5	8.6	7.7
1.19	6.2	6.8	6.1	7.7	7.8	7.4
1.44	4.6	5.4	5.4	5.6	6.1	5.5
1.71	4.7	4.8	4.7	4.9	5.3	5.1
1.96	4.6	4.4	4.5	4.9	5.1	5.0
2.21	4.9	4.6	4.6	5.0	5.2	5.1
2.47	5.1	4.7	5.0	5.1	5.0	5.2
2.71	5.0	5.3	5.4	5.4	5.9	5.7
3.46	5.5	6.0	5.9	5.6	6.2	6.2
3.71	6.8	7.0	6.9	5.5	6.0	6.2
3.95	6.9	7.1	7.5	5.7	6.1	5.8
4.20	7.2	7.7	7.7	--	--	--
4.45	7.5	7.5	8.0	5.7	6.0	5.8
4.69	7.5	7.3	7.8	--	--	--
4.94	8.3	8.0	8.6	5.9	5.8	5.8
5.19	7.7	7.5	7.8	--	--	--
5.44	8.7	8.9	8.9	6.0	6.3	6.0
5.69	8.1	8.5	8.0	--	--	--
5.93	7.5	7.7	7.4	5.9	5.8	5.6
6.18	7.5	8.1	7.2	--	--	--
6.43	6.7	7.5	6.7	5.6	5.9	5.5
7.43	5.9	5.9	6.2	5.7	5.8	5.7
8.43	6.1	5.7	6.2	5.8	5.9	5.9
9.43	6.2	6.3	6.3	6.1	6.2	5.9
10.42	5.6	5.9	5.6	6.0	6.1	5.9
11.42	5.6	5.5	5.7	6.1	6.1	5.7
12.42	6.1	6.0	5.9	6.0	6.2	6.0
13.41	5.6	6.0	5.9	6.0	6.0	5.8
14.41	5.7	5.8	6.0	5.6	5.9	5.6
15.41	5.7	5.8	5.8	6.1	6.1	6.0
16.41	5.8	5.5	5.9	5.9	5.9	5.9
17.41	6.1	6.3	6.2	5.6	5.9	5.5
18.41	5.0	5.6	5.2	5.6	5.4	5.5

9 2 1 2 4 5 6 1 1 9 5

TABLE V

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	2/10/77			2/11/77		
STANDARD COUNT	42994			42961		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	4.8	4.4	3.8	6.4	6.7	6.5
0.38	5.9	6.4	6.3	7.6	7.4	7.1
0.53	6.3	6.8	6.6	7.6	7.6	7.2
0.68	6.4	7.3	6.9	7.5	8.0	7.5
0.83	7.0	7.4	7.2	8.3	8.7	7.9
0.94	7.0	7.7	7.4	8.3	8.3	7.6
1.04	6.8	7.2	7.5	8.2	8.0	7.6
1.19	5.8	6.5	6.5	7.4	7.5	7.0
1.44	4.6	5.6	5.2	5.7	5.7	5.3
1.71	4.6	4.8	4.7	5.0	5.2	5.1
1.96	4.5	4.5	4.5	4.8	5.0	4.9
2.21	4.7	4.6	4.7	5.0	5.1	5.0
2.47	5.0	4.7	4.9	5.0	4.9	5.1
2.71	5.1	5.4	5.3	5.5	5.8	5.5
3.46	5.6	6.1	6.0	5.3	6.1	6.1
3.71	6.6	6.7	6.9	5.3	5.9	6.0
3.95	7.3	7.1	7.4	5.6	6.0	5.8
4.20	7.0	7.6	7.9	--	--	--
4.45	7.4	7.3	8.0	5.6	6.3	5.6
4.69	7.3	7.3	7.7	--	--	--
4.94	8.4	7.7	8.7	5.8	5.9	5.8
5.19	7.5	7.4	7.7	--	--	--
5.44	8.7	8.7	8.9	5.9	6.1	6.0
5.69	7.9	8.4	7.9	--	--	--
5.93	7.4	7.5	7.5	5.7	5.8	5.5
6.18	7.2	7.8	7.3	--	--	--
6.43	6.8	7.3	6.8	5.5	5.8	5.3
7.43	5.9	6.1	6.2	5.7	5.6	5.6
8.43	6.1	6.0	6.1	5.6	5.7	5.6
9.43	6.2	6.4	6.2	5.9	5.9	5.8
10.42	5.8	5.9	5.6	5.9	5.8	5.7
11.42	5.7	5.7	5.5	5.9	6.0	5.7
12.42	6.1	6.1	6.0	5.7	6.2	6.1
13.41	5.6	6.1	5.9	5.8	5.8	5.5
14.41	5.6	5.8	6.1	5.6	5.9	5.6
15.41	5.6	5.8	5.7	5.9	6.0	6.0
16.41	5.7	5.5	5.8	5.7	5.7	5.9
17.41	6.0	6.2	6.3	5.4	5.7	5.3
18.41	5.1	5.3	5.1	5.5	5.3	5.4

9 2 1 2 4 6 6 1 1 9 6

TABLE VI

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	3/10/77			3/10/77		
STANDARD COUNT	42837			42837		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	7.2	5.9	6.0	9.4	9.7	9.1
0.38	7.0	7.4	7.8	7.9	7.8	7.3
0.53	--	6.9	--	--	7.4	--
0.68	--	7.0	--	--	7.9	--
0.83	--	7.2	--	--	8.4	--
0.94	--	7.1	--	--	8.1	--
1.04	--	7.2	--	--	8.0	--
1.19	5.6	6.4	6.5	7.8	7.4	7.3
1.44	4.7	5.4	5.5	5.6	5.9	5.5
1.71	4.7	4.7	4.8	5.0	5.1	5.0
1.96	--	4.5	--	--	4.9	--
2.21	--	4.6	--	--	5.2	--
2.47	--	4.8	--	--	4.9	--
2.71	--	5.2	--	--	5.9	--
3.46	--	5.7	--	--	6.1	--
3.71	--	6.9	--	--	5.8	--
3.95	--	7.4	--	--	6.0	--
4.20	--	7.7	--	--	6.5	--
4.45	--	8.1	--	--	5.8	--
4.69	--	7.7	--	--	6.0	--
4.94	--	8.5	--	--	5.8	--
5.19	--	7.8	--	--	5.5	--
5.44	--	8.9	--	--	6.0	--
5.69	--	7.7	--	--	6.1	--
5.93	--	7.6	--	--	5.7	--
6.18	--	7.4	--	--	6.0	--
6.43	--	6.9	--	--	5.5	--
7.43	--	6.1	--	--	5.6	--
8.43	--	6.1	--	--	5.9	--
9.43	--	6.3	--	--	5.9	--
10.42	--	5.6	--	--	5.9	--
11.42	--	5.7	--	--	5.9	--
12.42	--	5.8	--	--	6.1	--
13.41	--	5.8	--	--	5.8	--
14.41	--	6.2	--	--	5.8	--
15.41	--	5.8	--	--	6.0	--
16.41	--	5.9	--	--	5.9	--
17.41	--	6.3	--	--	5.8	--
18.41	--	5.2	--	--	5.3	--

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TABLE VII

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	4/19/77			4/19/77		
STANDARD COUNT	42470			42470		
Depth Meters	Tube # 1	2	3	Tube # 4	5	6
0.20	4.3	4.0	3.5	7.7	8.5	7.2
0.38	7.1	7.5	7.2	8.6	8.6	8.0
0.53	--	7.8	--	--	8.2	--
0.68	--	7.7	--	--	8.4	--
0.83	--	7.7	--	--	8.5	--
0.94	--	7.3	--	--	8.4	--
1.04	--	6.4	--	--	8.1	--
1.19	5.9	5.4	6.3	7.5	7.5	7.2
1.44	4.8	4.8	5.2	5.7	6.0	4.8
1.71	4.7	4.5	4.8	4.8	5.3	5.1
1.96	--	4.5	--	--	5.1	--
2.21	--	4.6	--	--	5.2	--
2.47	--	4.9	--	--	5.0	--
2.71	--	5.4	--	--	5.9	--
3.46	--	6.2	--	--	6.2	--
3.71	--	6.9	--	--	6.1	--
3.95	--	7.3	--	--	6.2	--
4.20	--	7.7	--	--	6.4	--
4.45	--	7.4	--	--	5.8	--
4.69	--	7.4	--	--	5.9	--
4.94	--	7.8	--	--	5.9	--
5.19	--	7.6	--	--	5.6	--
5.44	--	8.8	--	--	6.1	--
5.69	--	8.4	--	--	6.2	--
5.93	--	7.7	--	--	5.9	--
6.18	--	8.1	--	--	6.0	--
6.43	--	7.7	--	--	5.8	--
7.43	--	6.1	--	--	5.7	--
8.43	--	6.1	--	--	6.0	--
9.43	--	6.5	--	--	6.0	--
10.42	--	5.9	--	--	6.0	--
11.42	--	5.7	--	--	6.0	--
12.42	--	5.9	--	--	6.1	--
13.41	--	6.1	--	--	5.8	--
14.41	--	5.7	--	--	5.9	--
15.41	--	5.9	--	--	6.0	--
16.41	--	5.5	--	--	5.9	--
17.41	--	6.2	--	--	5.8	--
18.41	--	5.2	--	--	5.2	--

2 2 1 2 4 6 6 1 1 9 8

TABLE VIII

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	5/10/77			5/10/77		
STANDARD COUNT	42395			42395		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	4.5	3.9	3.6	7.3	8.1	7.2
0.38	6.4	6.9	6.8	8.5	8.2	8.1
0.53	--	7.2	--	--	8.1	--
0.68	--	7.6	--	--	8.6	--
0.83	--	7.8	--	--	8.7	--
0.94	--	7.7	--	--	8.4	--
1.04	--	7.4	--	--	8.1	--
1.19	6.0	6.5	6.5	7.5	7.6	7.2
1.44	5.0	6.5	5.3	5.8	6.0	5.7
1.71	4.6	4.8	4.7	4.9	5.4	5.3
1.96	--	4.5	--	--	5.0	--
2.21	--	4.5	--	--	5.1	--
2.47	--	4.9	--	--	5.0	--
2.71	--	5.5	--	--	6.0	--
3.46	--	6.2	--	--	6.0	--
3.71	--	7.0	--	--	5.9	--
3.95	--	7.2	--	--	6.1	--
4.20	--	7.8	--	--	6.5	--
4.45	--	7.5	--	--	6.0	--
4.69	--	7.2	--	--	6.1	--
4.94	--	8.0	--	--	5.7	--
5.19	--	5.7	--	--	5.6	--
5.44	--	8.8	--	--	6.1	--
5.69	--	8.3	--	--	6.1	--
5.93	--	7.7	--	--	5.9	--
6.18	--	8.1	--	--	5.8	--
6.43	--	7.6	--	--	5.7	--
7.43	--	6.0	--	--	5.7	--
8.43	--	6.2	--	--	6.0	--
9.43	--	6.5	--	--	6.1	--
10.42	--	5.9	--	--	6.0	--
11.42	--	5.6	--	--	6.0	--
12.42	--	6.0	--	--	6.1	--
13.41	--	6.1	--	--	5.8	--
14.41	--	5.9	--	--	5.9	--
15.41	--	6.0	--	--	6.0	--
16.41	--	5.5	--	--	5.8	--
17.41	--	6.2	--	--	5.8	--
18.41	--	5.4	--	--	5.2	--

9212456119 9

TABLE IX

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	6/14/77			6/14/77		
STANDARD COUNT	42316			42316		
Depth Meters	Tube # 1	2	3	Tube # 4	5	6
0.20	5.4	5.6	4.8	5.4	5.7	5.9
0.38	4.2	4.7	4.3	5.3	5.3	5.2
0.53	--	4.7	--	--	5.2	--
0.68	--	4.9	--	--	5.6	--
0.83	4.7	5.1	5.1	5.5	7.0	5.8
0.94	--	5.2	--	--	7.5	--
1.04	--	5.0	--	--	7.6	--
1.19	4.4	4.6	4.8	6.8	7.3	6.7
1.44	4.2	4.4	4.8	5.9	6.1	5.7
1.71	4.7	4.8	4.8	5.2	5.4	5.3
1.96	--	4.7	--	--	5.1	--
2.21	--	4.6	--	--	5.3	--
2.47	--	4.9	--	--	5.0	--
2.71	--	5.5	--	--	5.9	--
3.46	--	6.3	--	--	6.0	--
3.71	--	6.8	--	--	6.0	--
3.95	--	7.1	--	--	6.1	--
4.20	--	7.6	--	--	6.6	--
4.45	--	7.4	--	--	6.0	--
4.69	--	7.2	--	--	6.1	--
4.94	--	7.9	--	--	5.9	--
5.19	--	7.4	--	--	5.6	--
5.44	--	8.9	--	--	6.2	--
5.69	--	8.5	--	--	6.1	--
5.93	--	--	--	--	--	--
6.18	--	8.1	--	--	6.0	--
6.43	--	7.6	--	--	6.1	--
7.43	--	6.1	--	--	5.7	--
8.43	--	6.2	--	--	5.9	--
9.43	--	6.4	--	--	6.1	--
10.42	--	6.1	--	--	6.0	--
11.42	--	5.8	--	--	6.1	--
12.42	--	6.0	--	--	6.2	--
13.41	--	6.2	--	--	5.9	--
14.41	--	5.9	--	--	6.0	--
15.41	--	5.9	--	--	6.1	--
16.41	--	5.8	--	--	5.8	--
17.41	--	6.2	--	--	5.9	--
18.41	--	5.3	--	--	5.4	--

9 2 1 2 4 6 6 1 2 0 0

TABLE X

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	7/18/77			7/18/77		
STANDARD COUNT	41768			41768		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	2.0	1.6	1.6	3.7	4.1	3.5
0.38	3.8	4.0	3.9	4.9	4.9	4.9
0.53	--	4.3	--	--	4.8	--
0.68	--	4.6	--	--	5.1	--
0.83	4.4	4.8	4.7	5.0	5.3	5.0
0.94	--	4.8	--	--	5.3	--
1.04	--	4.6	--	--	5.4	--
1.19	4.3	4.2	4.5	5.1	5.2	5.1
1.44	4.1	4.1	4.3	4.7	5.0	4.8
1.71	4.6	4.5	4.5	5.0	5.4	5.4
1.96	--	4.5	--	--	5.3	--
2.21	--	4.7	--	--	5.3	--
2.47	--	5.1	--	--	5.1	--
2.71	--	5.5	--	--	5.9	--
3.46	--	6.4	--	--	6.3	--
3.71	--	7.0	--	--	6.0	--
3.95	--	7.3	--	--	6.2	--
4.20	--	7.8	--	--	6.6	--
4.45	--	7.4	--	--	6.0	--
4.69	--	7.2	--	--	6.1	--
4.94	--	7.9	--	--	6.0	--
5.19	--	7.7	--	--	5.6	--
5.44	--	9.1	--	--	6.3	--
5.69	--	8.5	--	--	6.2	--
5.93	--	--	--	--	--	--
6.18	--	8.4	--	--	6.2	--
6.43	--	7.7	--	--	5.8	--
7.43	--	6.2	--	--	5.9	--
8.43	--	6.3	--	--	5.8	--
9.43	--	6.6	--	--	6.2	--
10.42	--	6.1	--	--	6.2	--
11.42	--	6.0	--	--	6.2	--
12.42	--	6.2	--	--	6.3	--
13.41	--	6.4	--	--	6.2	--
14.41	--	5.9	--	--	6.0	--
15.41	--	6.0	--	--	6.3	--
16.41	--	5.6	--	--	6.0	--
17.41	--	6.3	--	--	6.1	--
18.41	--	5.5	--	--	5.5	--

9 2 1 2 4 6 6 1 2 0 1

TABLE XI

SEDIMENT MOISTURE DATA
% BY VOLUME

	OPEN LYSIMETER			CLOSED LYSIMETER		
DATE	8/19/77			8/22/77		
STANDARD COUNT	41988			41801		
Depth Meters	Tube #			Tube #		
	1	2	3	4	5	6
0.20	1.6	1.2	1.2	3.2	3.5	3.2
0.38	3.3	3.6	3.5	4.7	4.6	4.5
0.53	--	4.1	--	--	4.7	--
0.68	--	4.4	--	--	5.0	--
0.83	4.4	4.7	4.5	5.0	5.2	4.8
0.94	--	4.7	--	--	5.3	--
1.04	--	4.5	--	--	5.2	--
1.19	4.1	4.3	4.3	5.0	5.0	4.9
1.44	4.2	4.1	4.3	4.6	4.7	4.9
1.71	4.6	4.6	4.5	5.0	5.2	5.1
1.96	--	4.6	--	--	5.3	--
2.21	--	4.6	--	--	5.3	--
2.47	--	4.7	--	--	5.2	--
2.71	--	4.9	--	--	6.0	--
3.46	--	6.3	--	--	6.2	--
3.71	--	6.9	--	--	6.0	--
3.95	--	7.3	--	--	6.2	--
4.20	--	7.8	--	--	6.7	--
4.45	--	7.6	--	--	6.1	--
4.69	--	7.2	--	--	6.1	--
4.94	--	7.7	--	--	6.2	--
5.19	--	7.3	--	--	5.8	--
5.44	--	8.8	--	--	6.3	--
5.69	--	8.5	--	--	6.2	--
5.93	--	--	--	--	--	--
6.18	--	8.2	--	--	6.4	--
6.43	--	7.8	--	--	5.8	--
7.43	--	6.2	--	--	6.0	--
8.43	--	6.3	--	--	5.9	--
9.43	--	6.6	--	--	6.3	--
10.42	--	6.0	--	--	6.1	--
11.42	--	5.7	--	--	6.2	--
12.42	--	6.0	--	--	6.4	--
13.41	--	6.4	--	--	6.1	--
14.41	--	5.9	--	--	6.1	--
15.41	--	6.0	--	--	6.2	--
16.41	--	5.7	--	--	5.9	--
17.41	--	6.3	--	--	5.9	--
18.41	--	5.4	--	--	5.4	--

2 1 2 4 6 1 2 0 2

TABLE XII

MOISTURE CONTENTS FOR THE 12.4 TO 18.4 METER DEPTHS
1976-1977
OPEN BOTTOM LYSIMETER

DEPTH (Meters)	SEPTEMBER	OCTOBER	NOVEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
	(Percent by Volume)										
12.42	5.9	6.3	7.1	6.0	6.1	5.8	5.9	6.0	6.0	6.2	6.0
13.41	5.9	6.3	7.1	5.8	5.9	5.8	6.1	6.1	6.2	6.4	6.4
14.41	5.8	6.4	7.0	5.8	5.8	6.2	5.7	5.9	5.9	5.9	5.9
15.41	5.7	6.4	7.0	5.8	5.7	5.8	5.9	6.0	5.9	6.0	6.0
16.41	5.7	6.4	6.7	5.7	5.7	5.9	5.5	5.5	5.8	5.6	5.7
AVG.	5.8	6.4	7.0	5.8	5.8	5.9	5.8	5.9	6.0	6.0	6.0
STD.	.10	.05	.16	.11	.17	.17	.23	.23	.15	.30	.25
	Average = 6.0		w/o October and November			Average = 5.9					
	Std. Dev. = .38					Std. Dev. = .20					
17.41	6.2	6.8	7.3	6.2	6.2	6.3	6.2	6.2	6.2	6.3	6.3
	Average = 6.4		w/o October and November			Average = 6.2					
	Std. Dev. = .35					Std. Dev. = .05					
18.41	5.1	5.6	6.4	5.3	5.2	5.2	5.2	5.4	5.3	5.5	5.4
	Average = 5.4		w/o October and November			Average = 5.3					
	Std. Dev. = .36					Std. Dev. = .13					

TABLE XIII

MOISTURE CONTENTS FOR THE 12.4 TO 18.4 METER DEPTHS
1976-1977
CLOSED BOTTOM LYSIMETER

DEPTH (Meters)	SEPTEMBER	OCTOBER	NOVEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
	(Percent by Volume)										
12.41	6.1	6.1	7.2	6.1	6.0	6.1	6.1	6.1	6.2	6.3	6.4
13.42	5.7	5.7	7.1	5.9	5.7	5.8	5.8	5.8	5.9	6.2	6.1
14.42	5.8	6.0	6.6	5.7	5.7	5.8	5.9	5.9	6.0	6.0	6.1
15.42	6.0	6.2	6.9	6.1	6.0	6.0	6.0	6.0	6.1	6.3	6.2
16.42	5.7	5.8	7.1	5.9	5.8	5.9	5.9	5.8	5.8	6.0	5.9
AVG.	5.9	6.0	7.0	5.9	5.8	5.9	5.9	5.9	6.0	6.2	6.1
STD.	.18	.21	.24	.14	.15	.13	.11	.13	.16	.15	.18
	Average = 6.1		w/o October and November			Average = 6.0					
	Std. Dev. = .34					Std. Dev. = .18					
17.42	5.5	5.6	6.5	5.7	5.5	5.8	5.8	5.8	5.9	6.1	5.9
	Average = 5.8		w/o October and November			Average = 5.8					
	Std. Dev. = .29					Std. Dev. = .19					
18.42	5.5	5.4	6.2	5.5	5.4	5.3	5.2	5.2	5.4	5.5	5.4
	Average = 5.4		w/o October and November			Average = 5.4					
	Std. Dev. = .27					Std. Dev. = .12					

APPENDIX V — FIGURES

FIGURES V-1 THROUGH V-22
SHOWING OPEN and CLOSED LYSIMETER DATA,

and

FIGURES V-23 THROUGH V-26
SHOWING OTHER DATA
AFFECTING SEDIMENT MOISTURE

9212461205

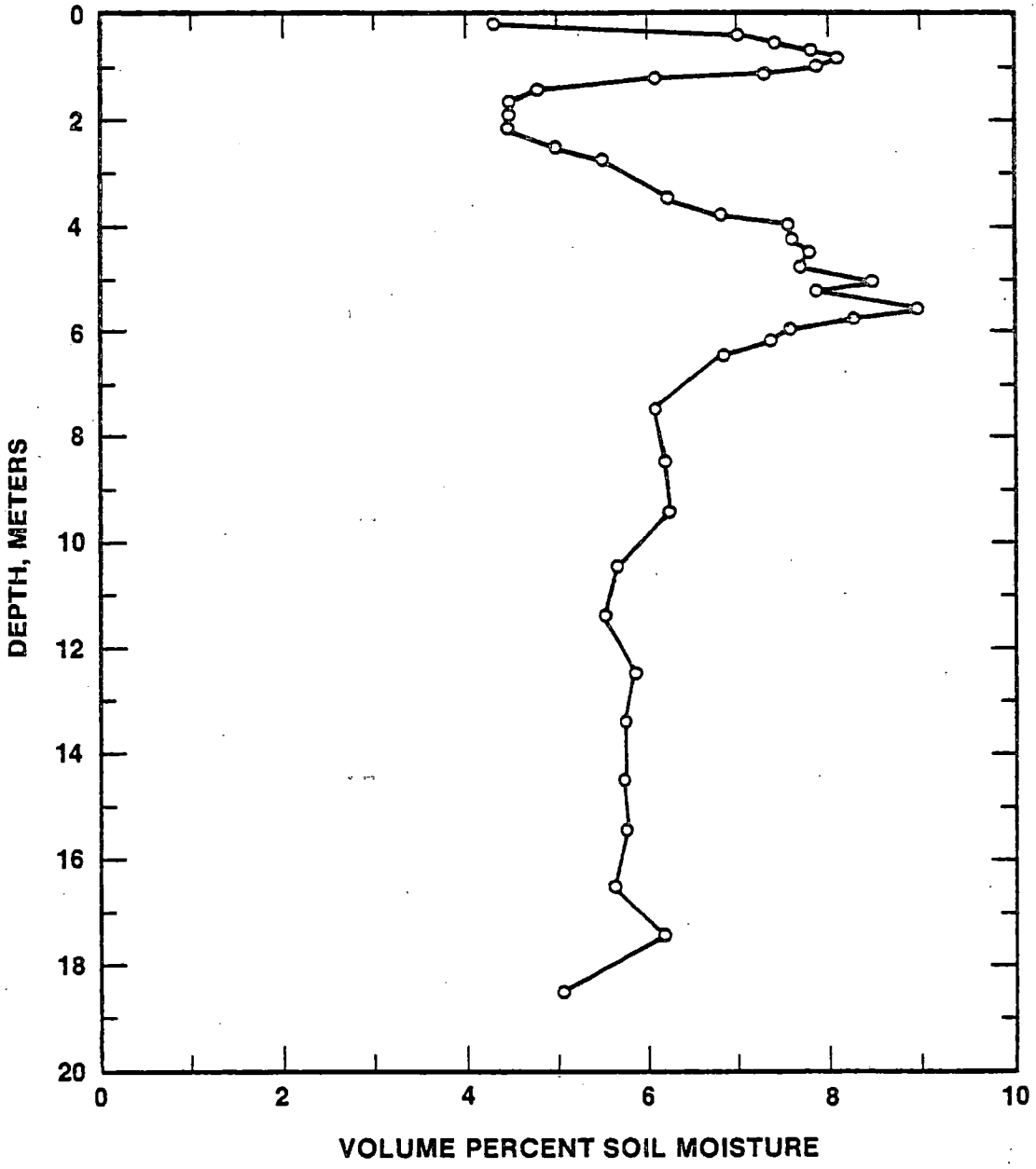

FIGURE V-1

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 9/15/76

9 2 1 2 4 6 6 1 2 0 6

9 2 1 2 4 6 6 1 2 0 7

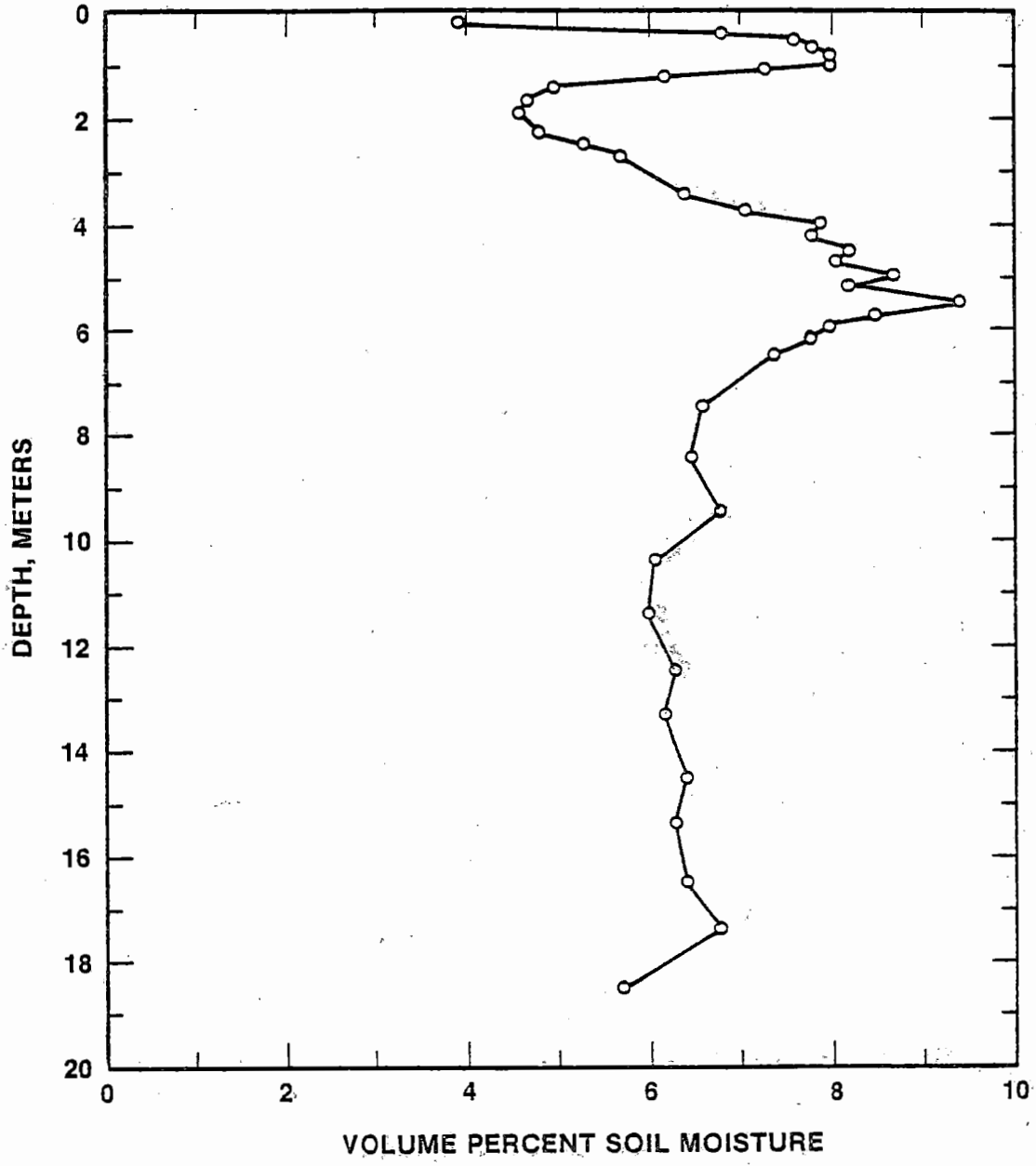

FIGURE V-2

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 10/21/76

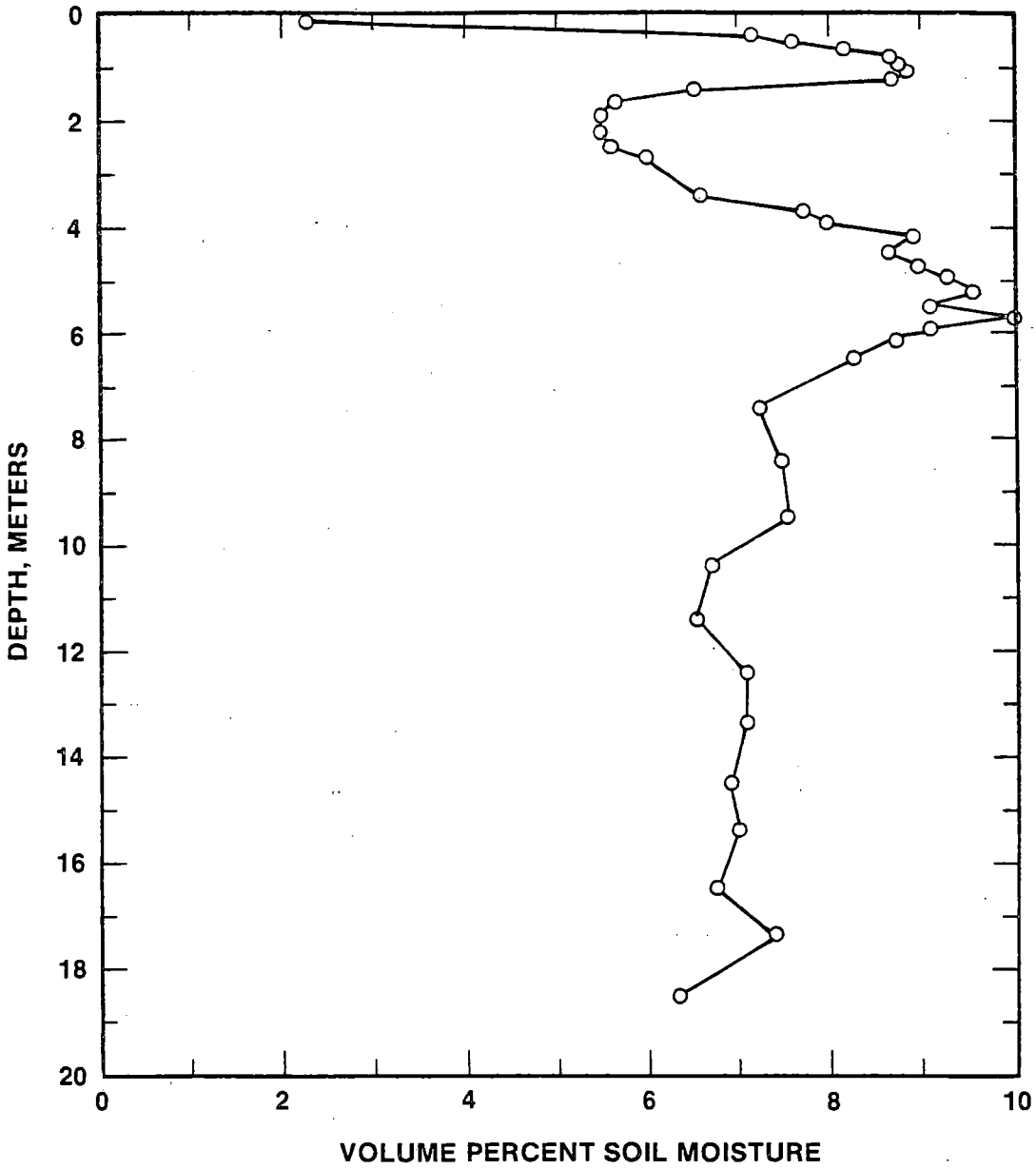

FIGURE V-3

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 11/5/76

9 2 1 2 4 5 6 1 2 0 8

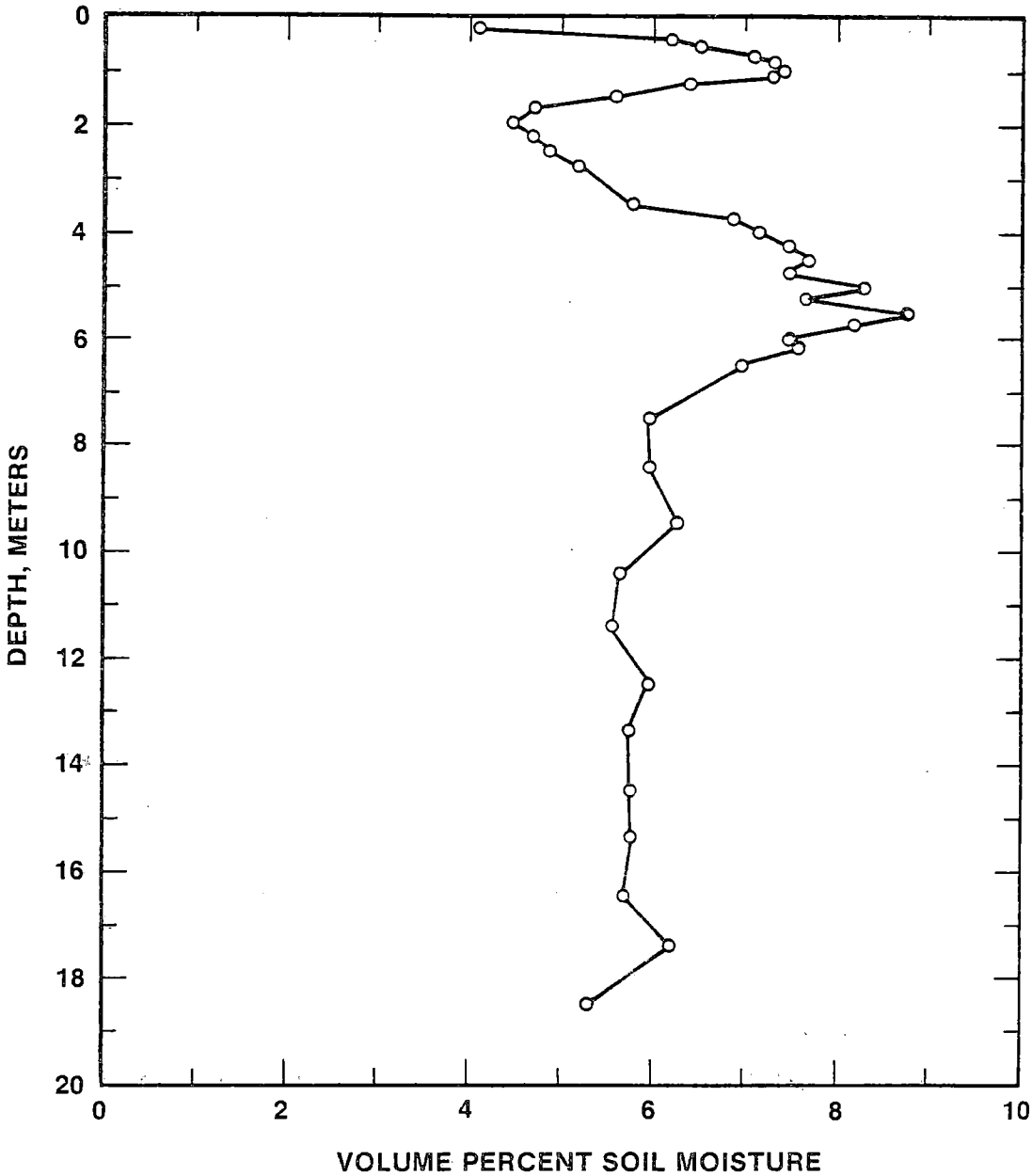

FIGURE V-4

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 1/5/77

9 2 1 2 4 6 6 1 2 0 9

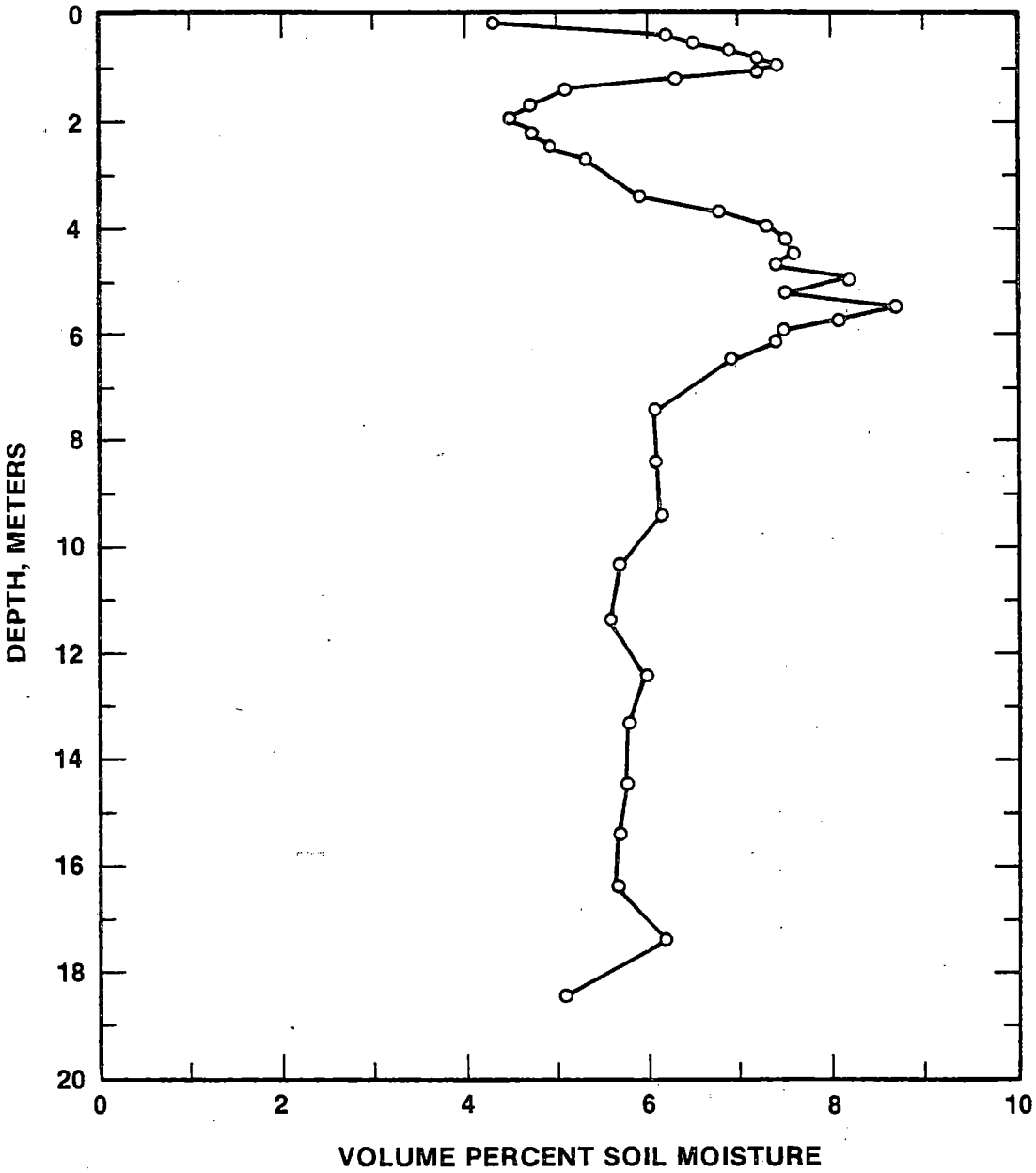

FIGURE V-5

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 2/10/77

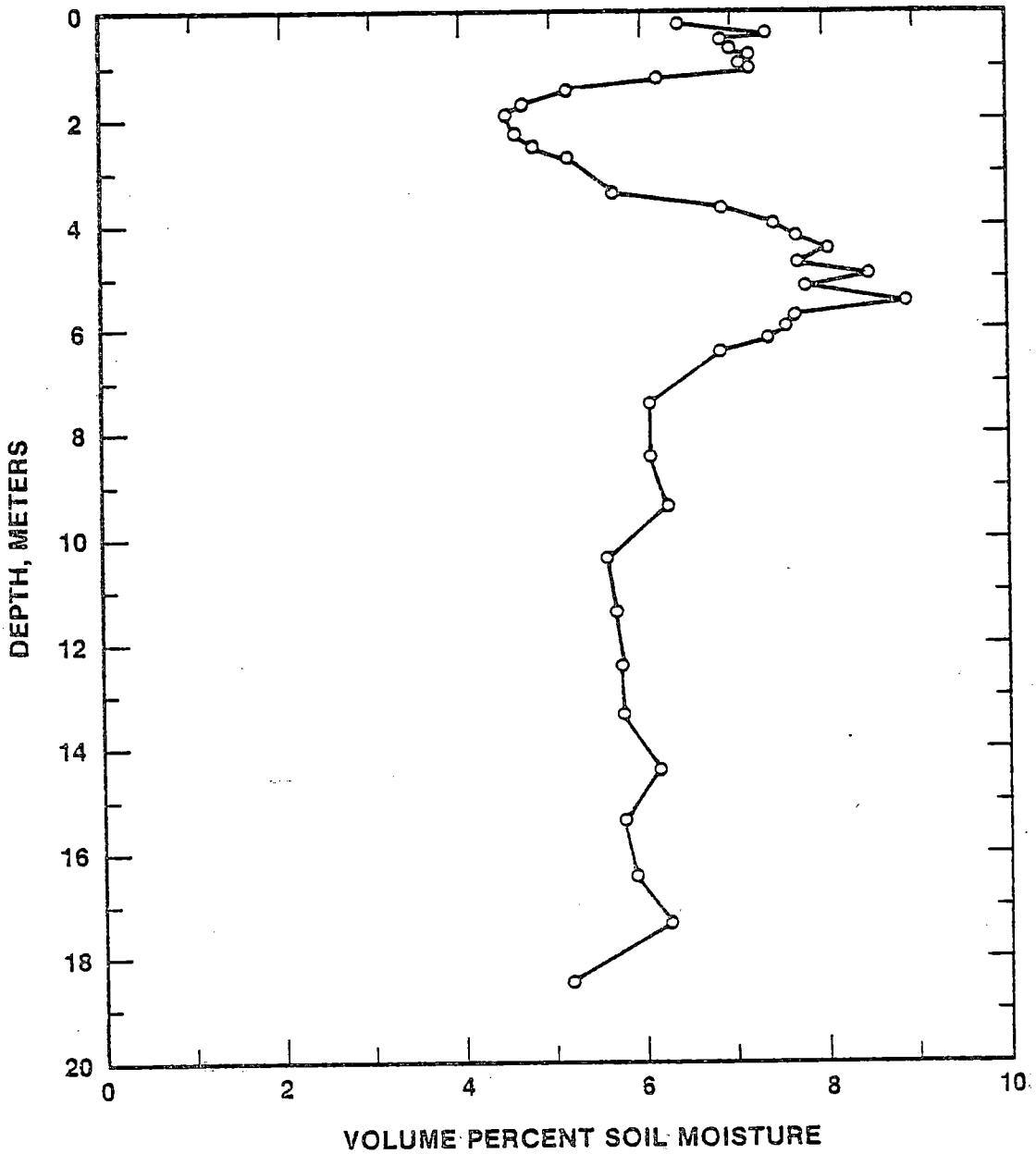

FIGURE V-6

AVERAGE MOISTURE CONTERNT OF OPEN LYSIMETER, 3/10/77

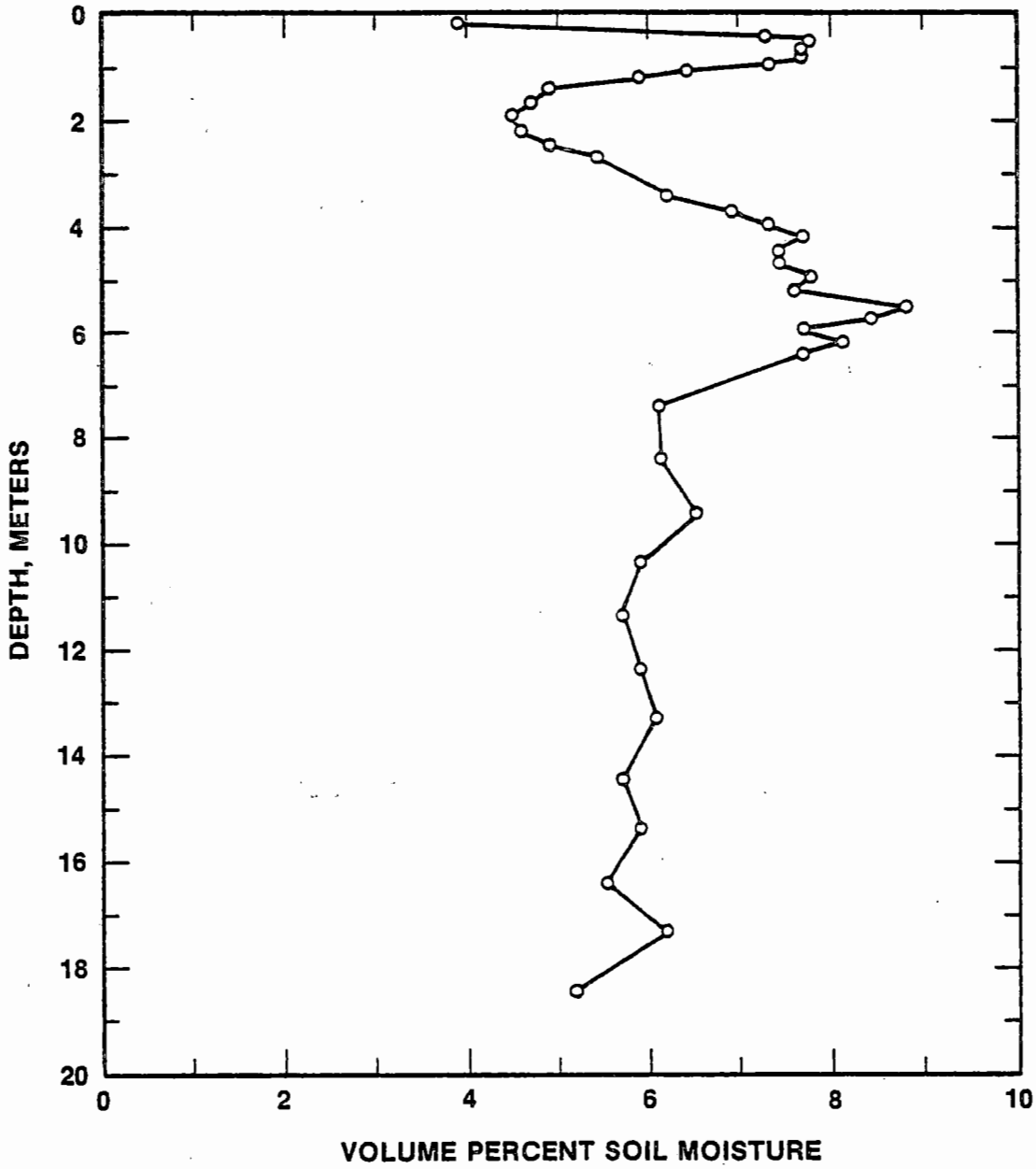

FIGURE V-7

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 4/19/77

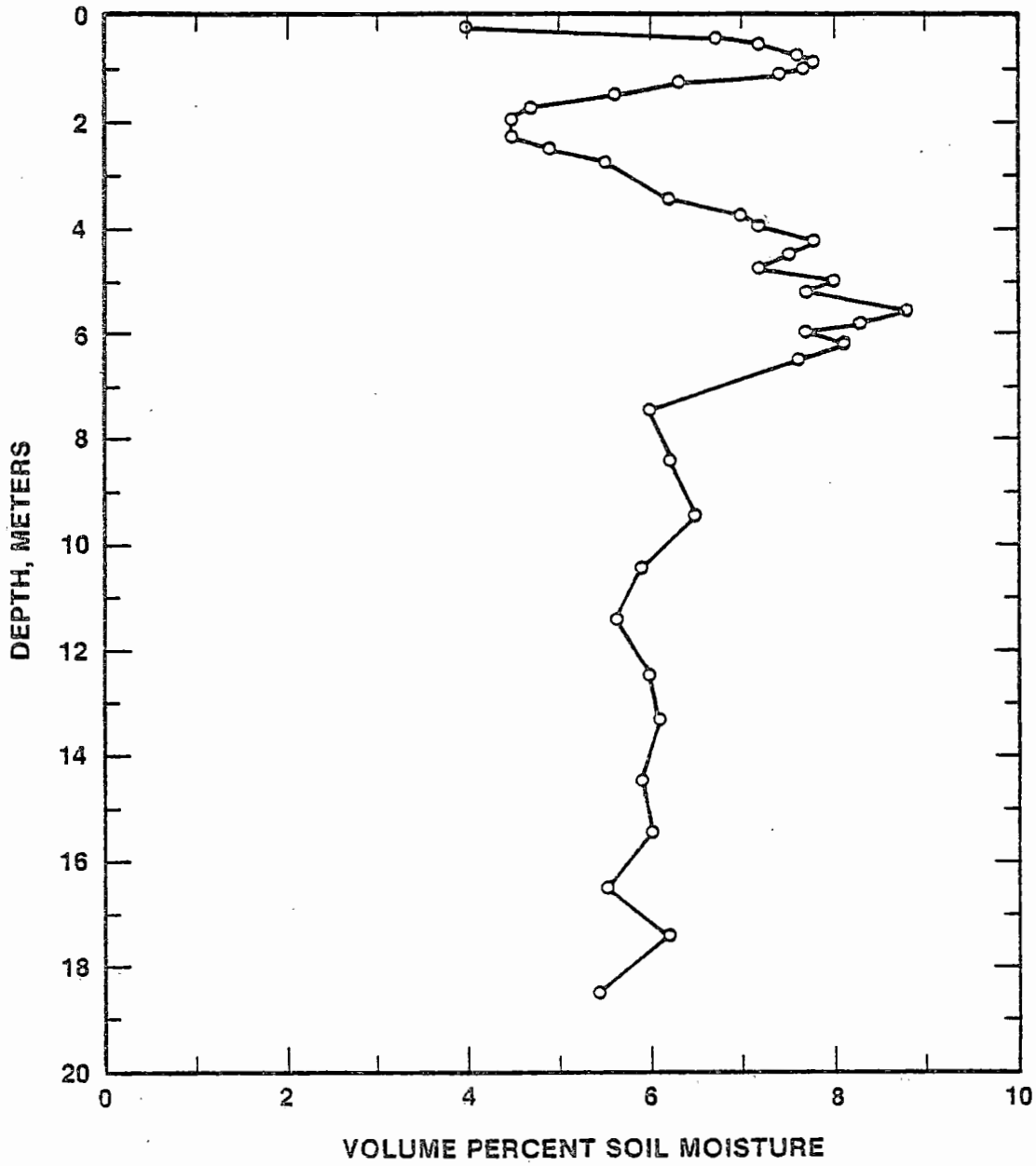

FIGURE V-8

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 5/10/77

9 2 1 2 4 5 6 1 2 1 3

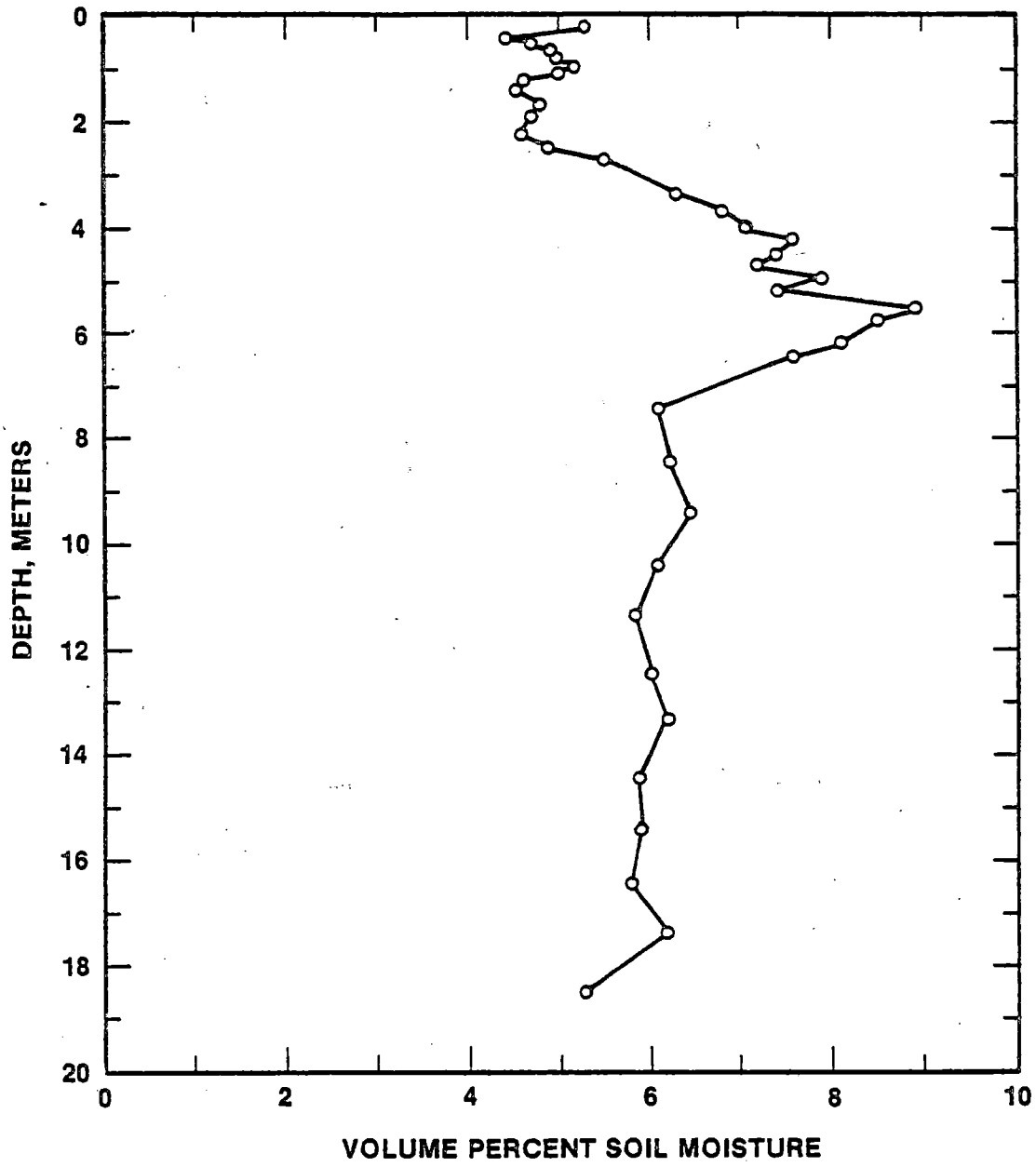

FIGURE V-9

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 6/14/77

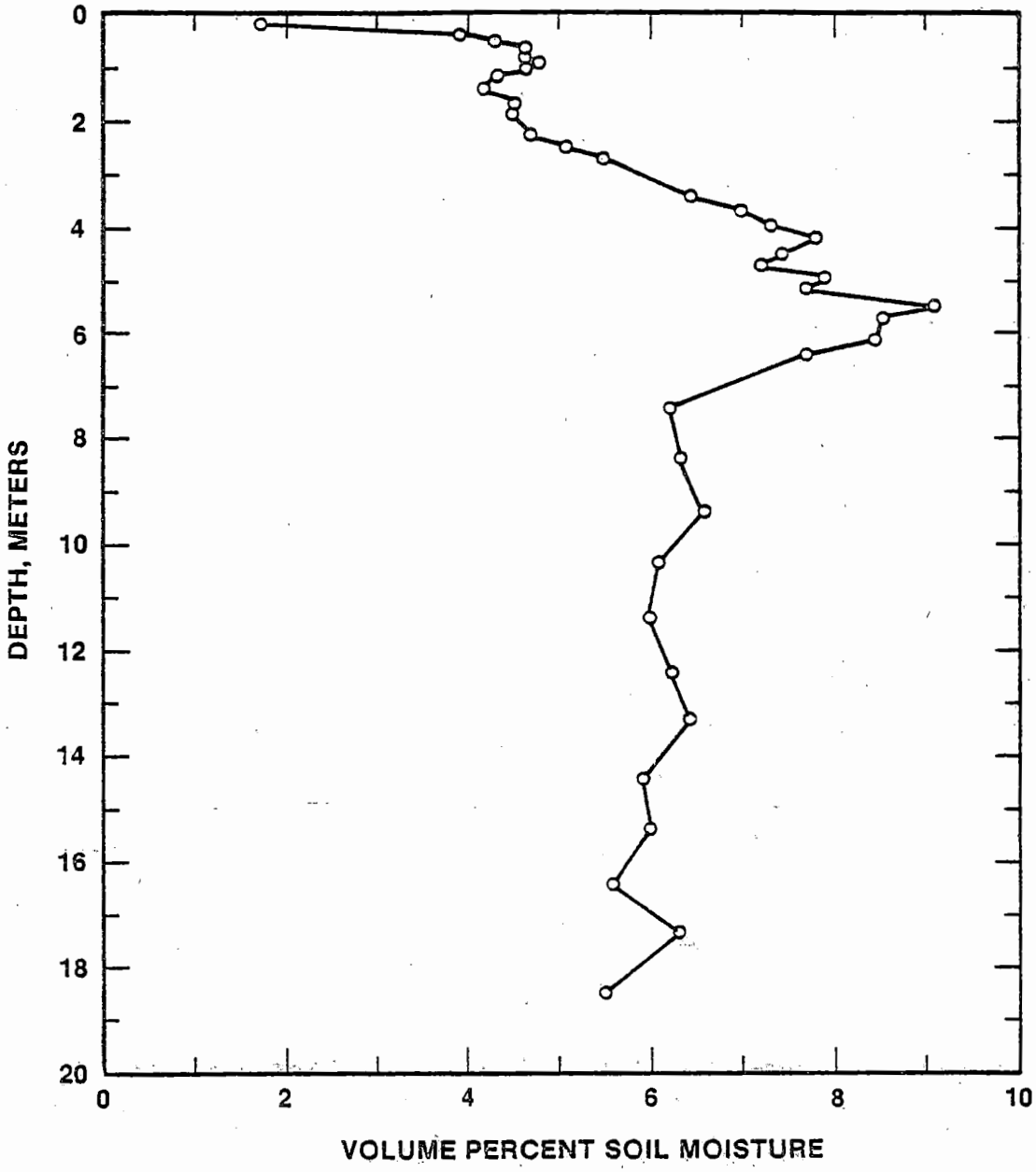

FIGURE V-10

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 7/18/77

9 2 1 2 4 6 6 1 2 1 5

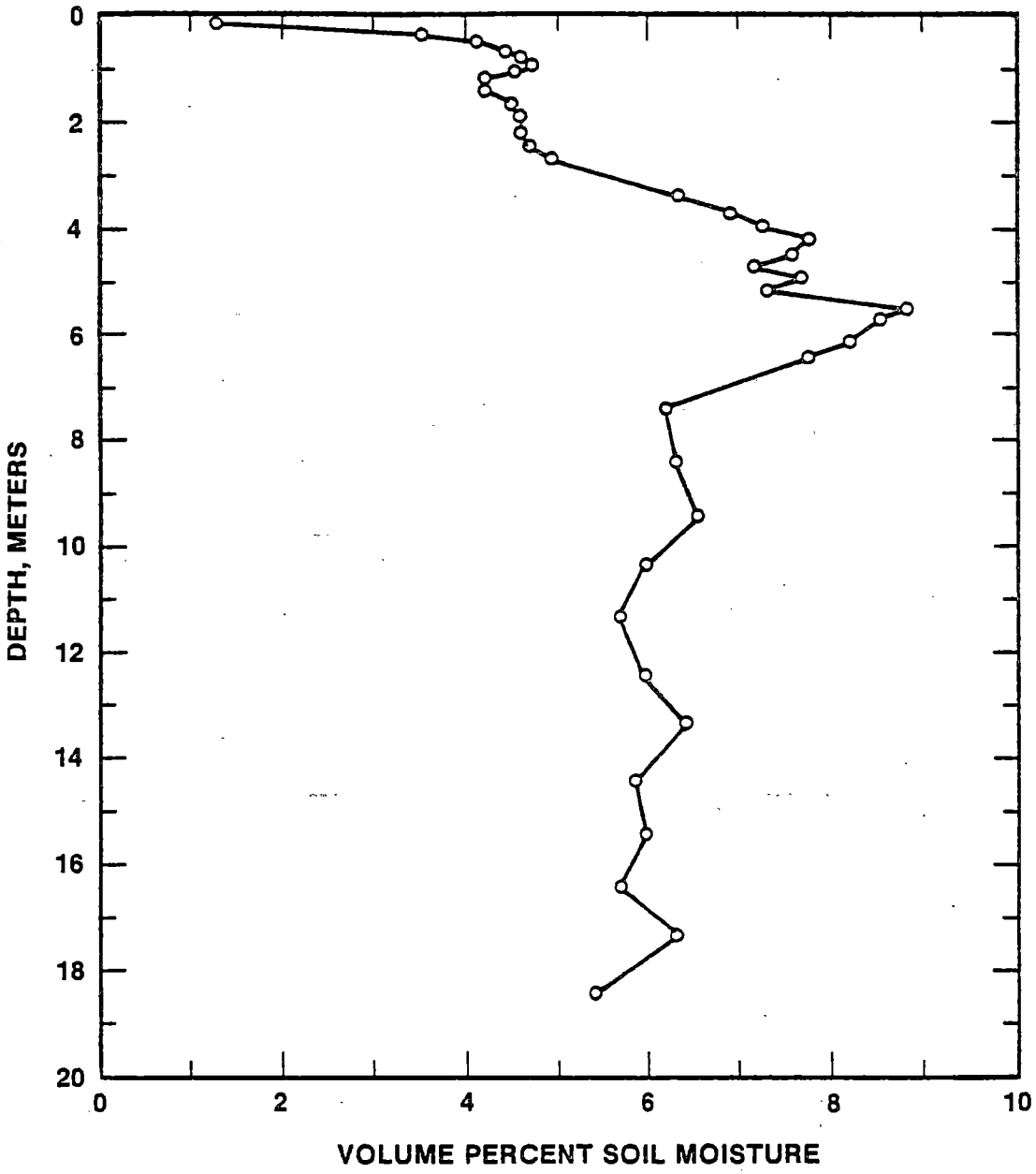

FIGURE V-11

AVERAGE MOISTURE CONTENT OF OPEN LYSIMETER, 8/19/77

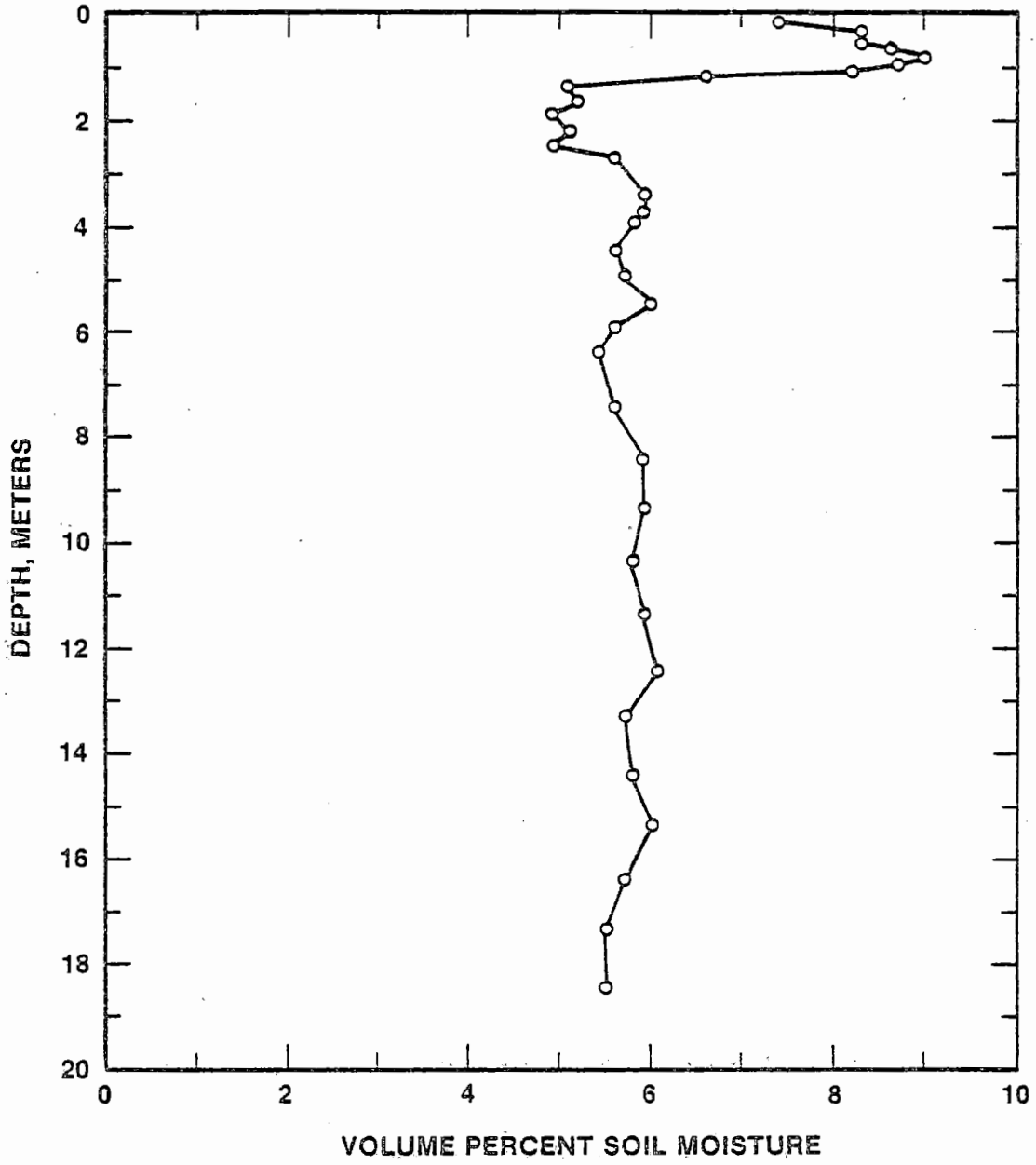

FIGURE V-12

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 9/16/76

9 2 1 2 4 6 6 1 2 1 7

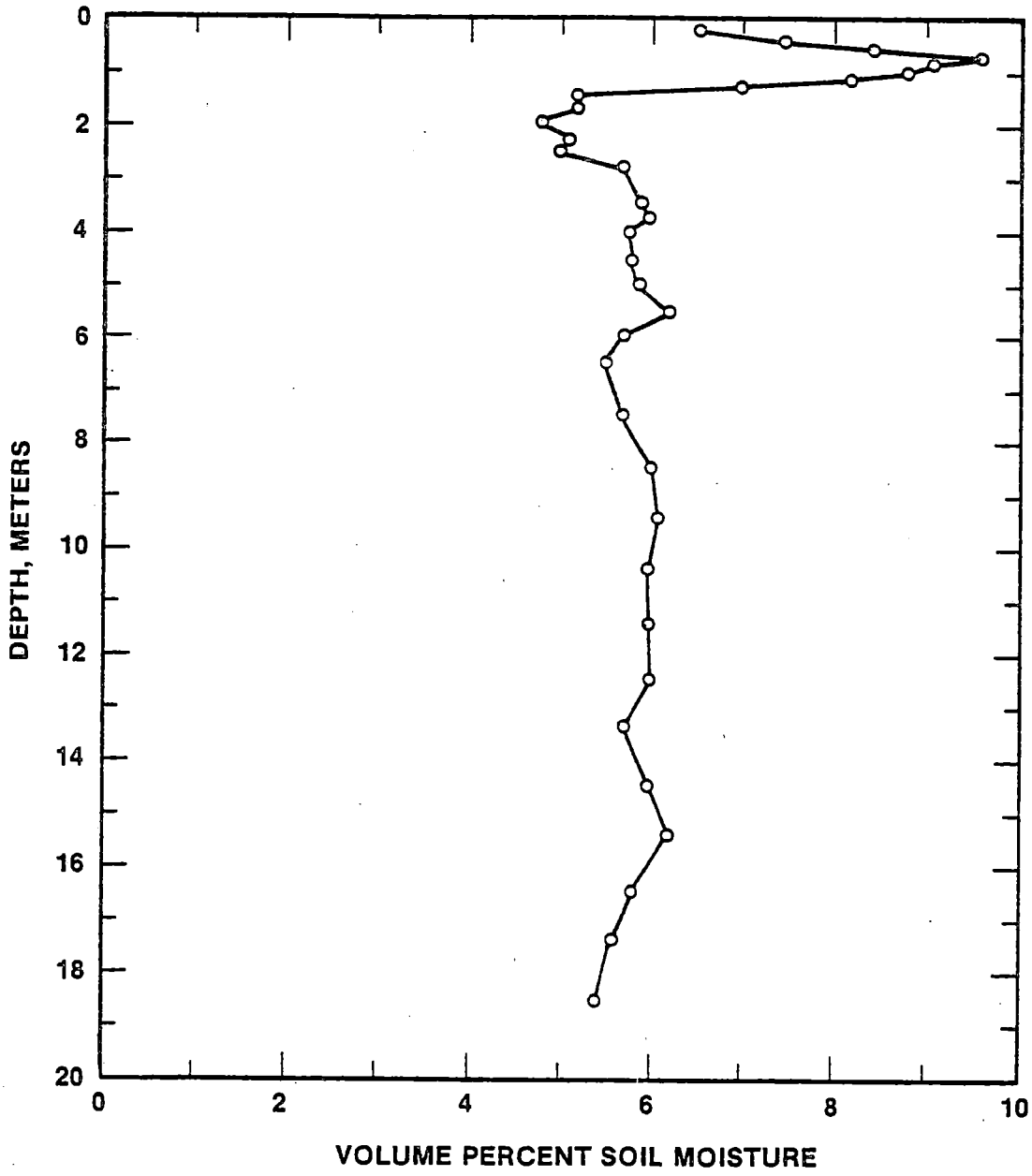

FIGURE V-13

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 10/28/76

9 2 1 2 4 6 6 1 2 1 8

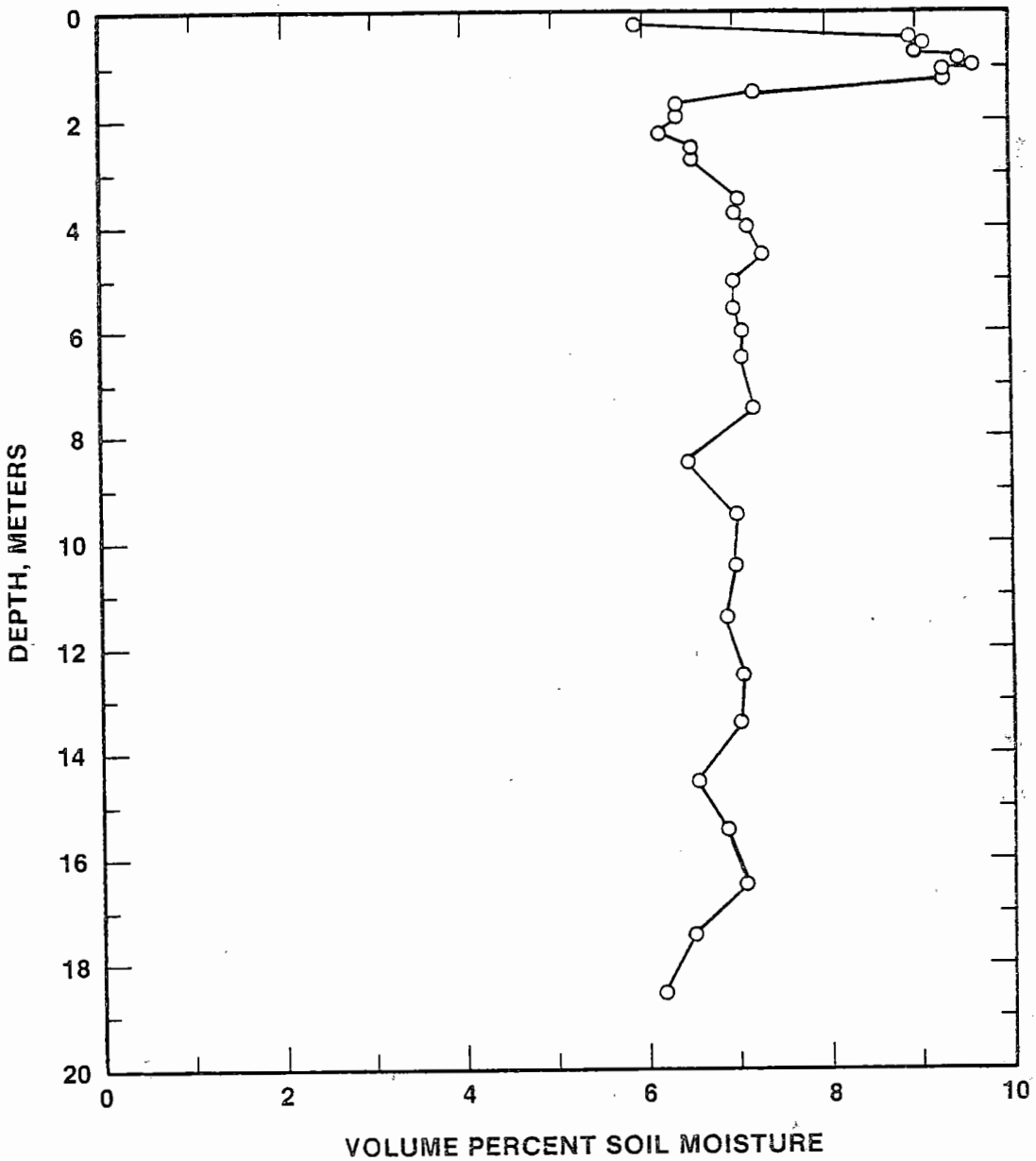

FIGURE V-14

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 11/8/76

9 2 1 2 4 6 6 1 2 1 9

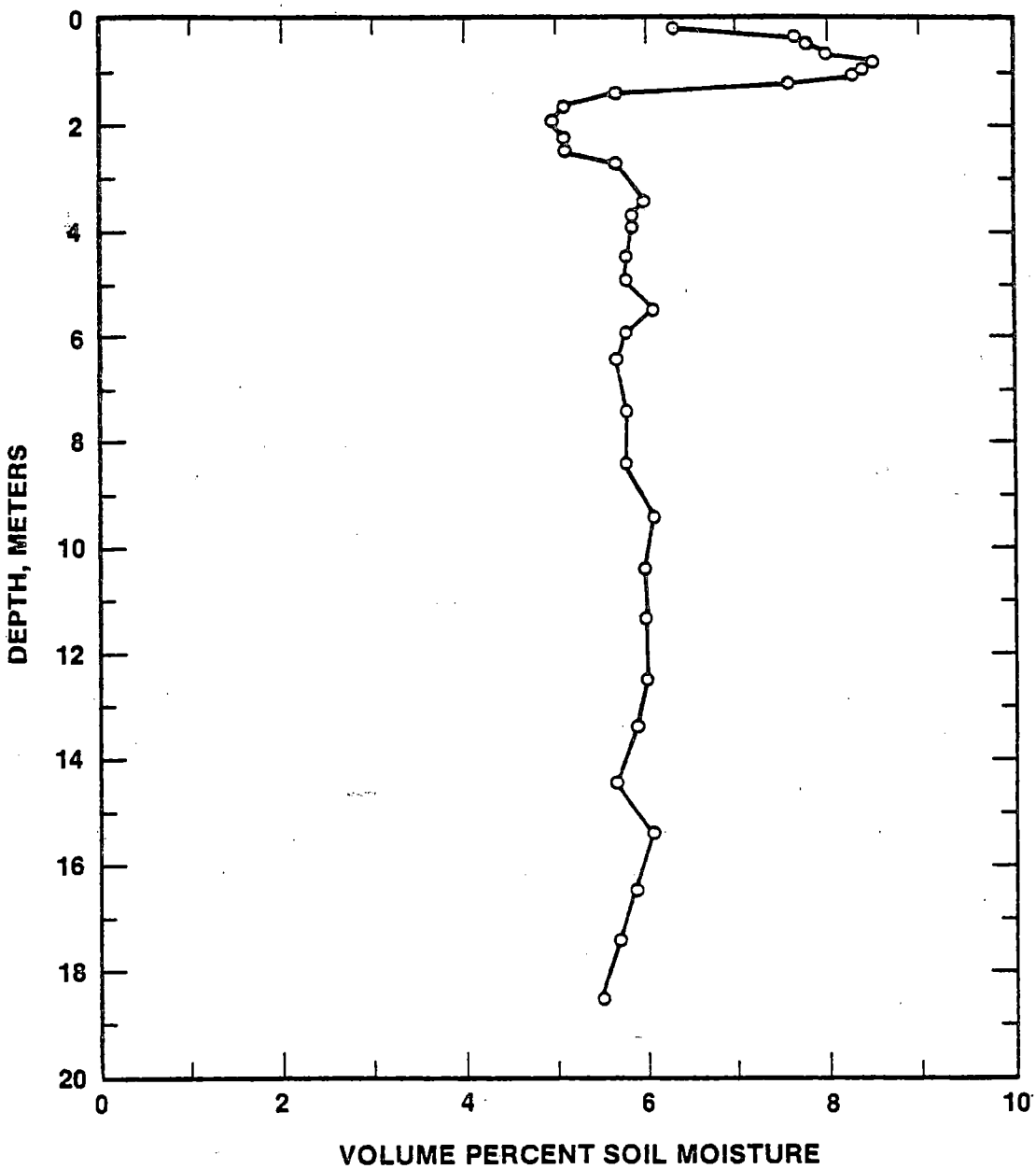

FIGURE V-15

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 1/6/77

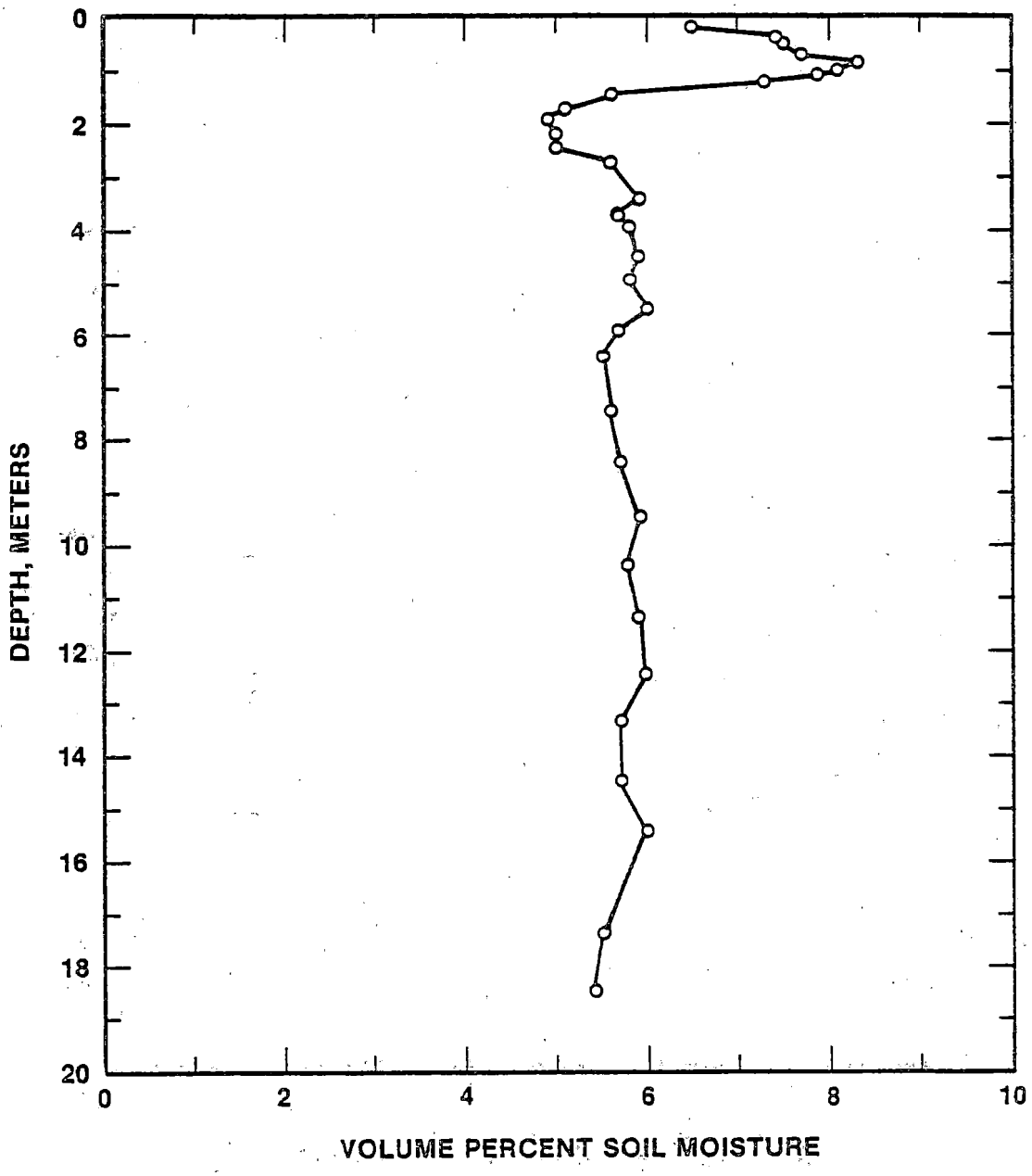

FIGURE V-16

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 2/11/77

9 2 1 2 4 6 6 1 2 2 1

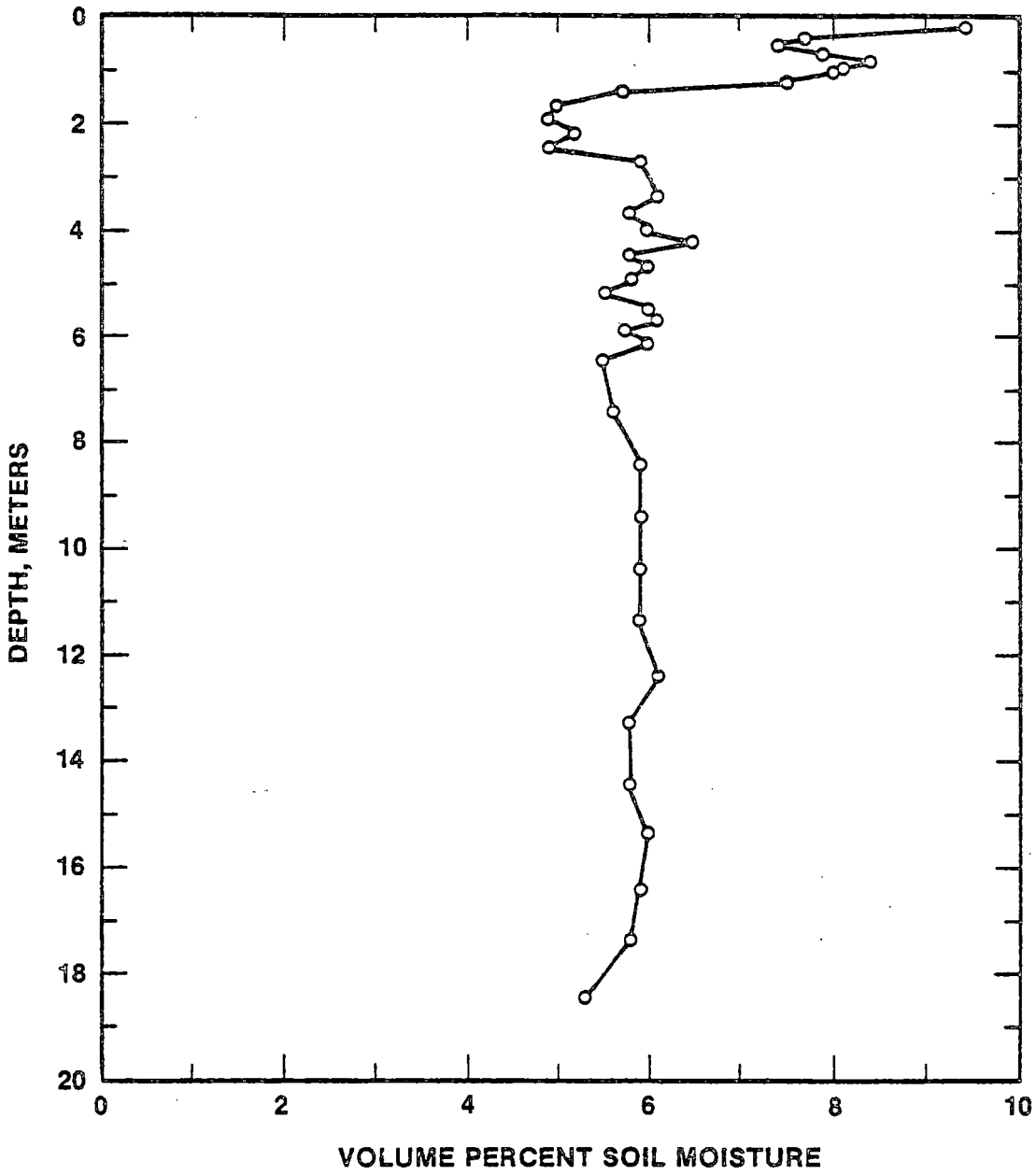

FIGURE V-17

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 3/10/77

9 2 1 2 4 6 6 1 2 2 2

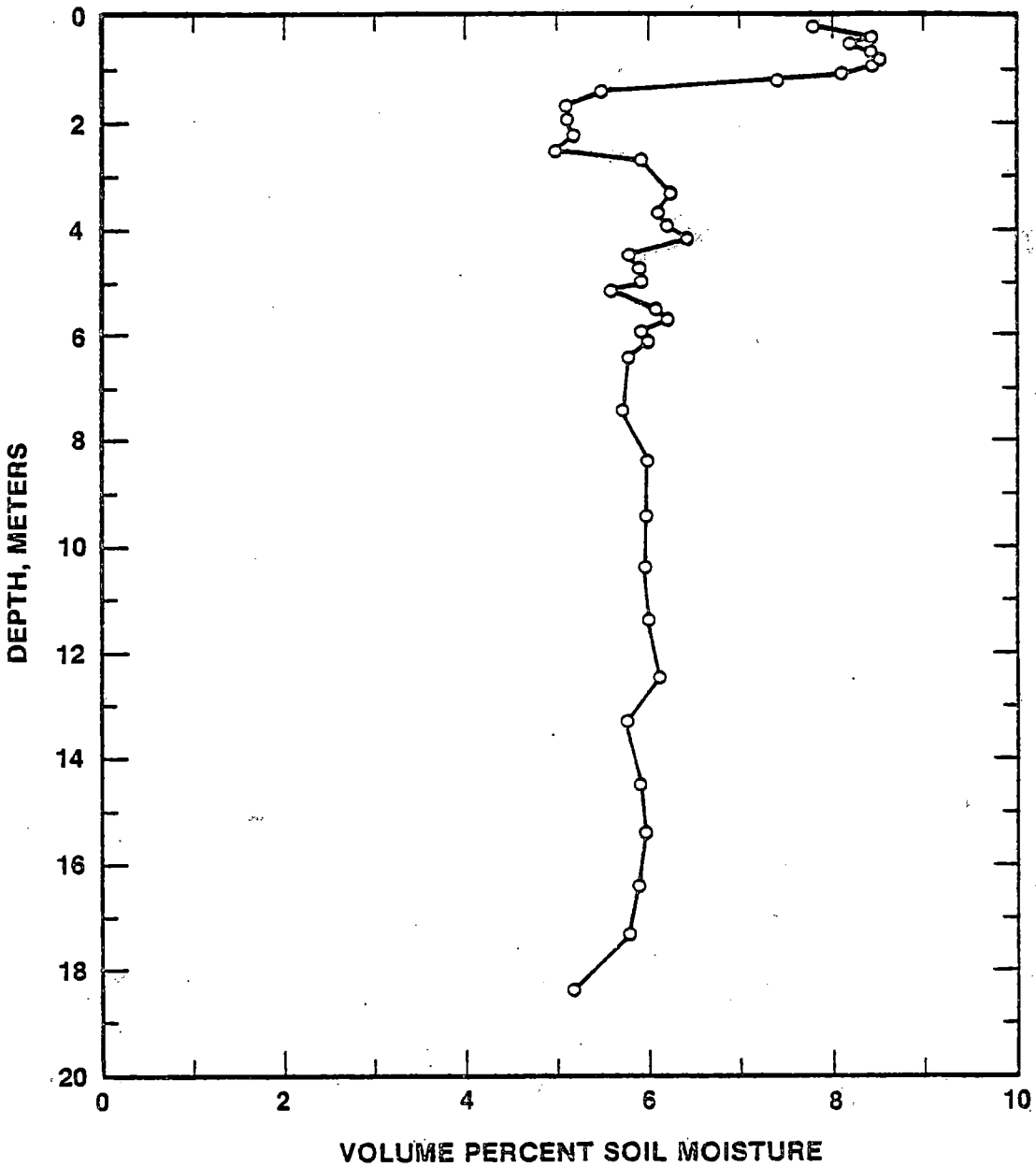

FIGURE V-18

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 4/19/77

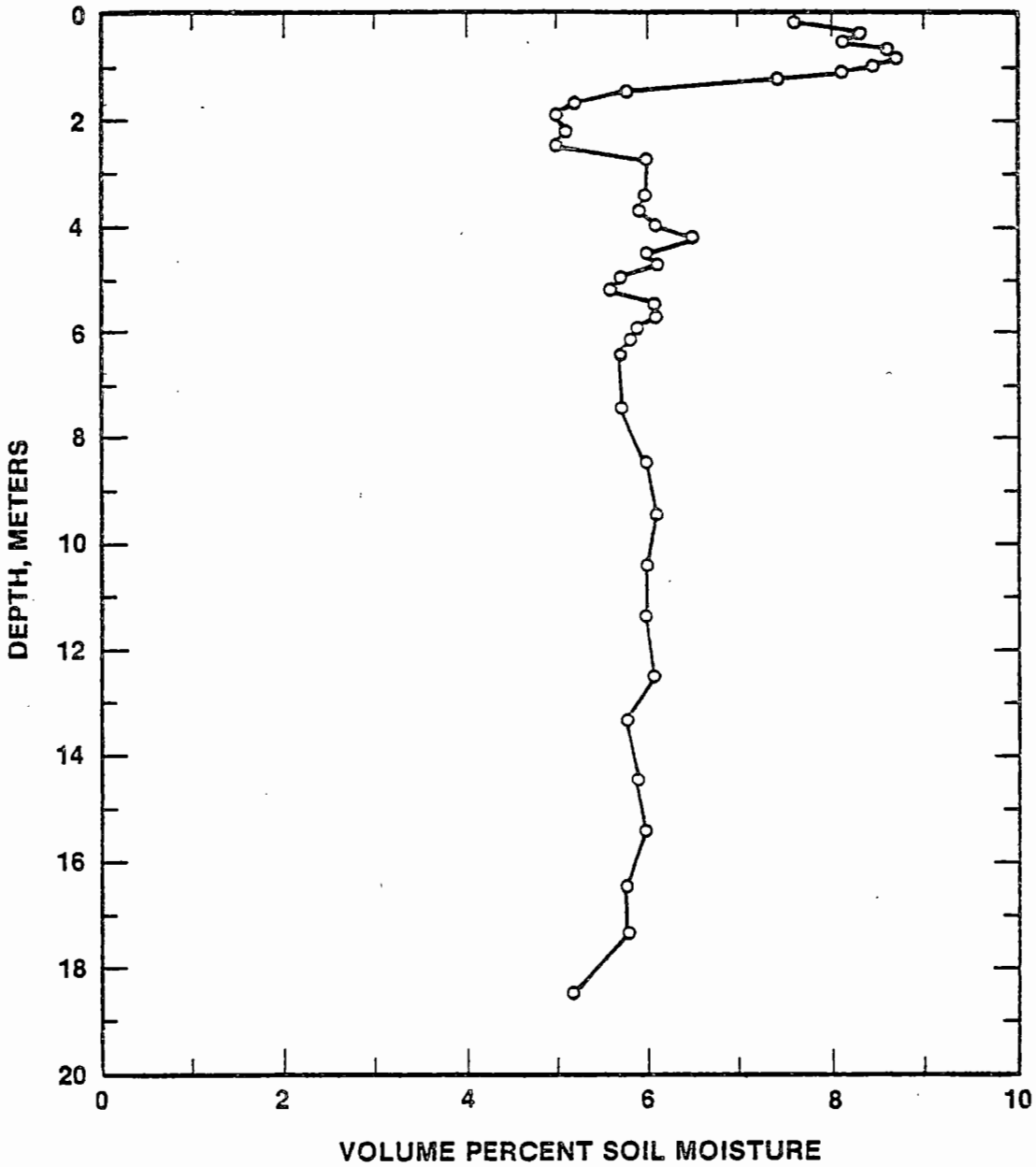

FIGURE V-19

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 5/10/77

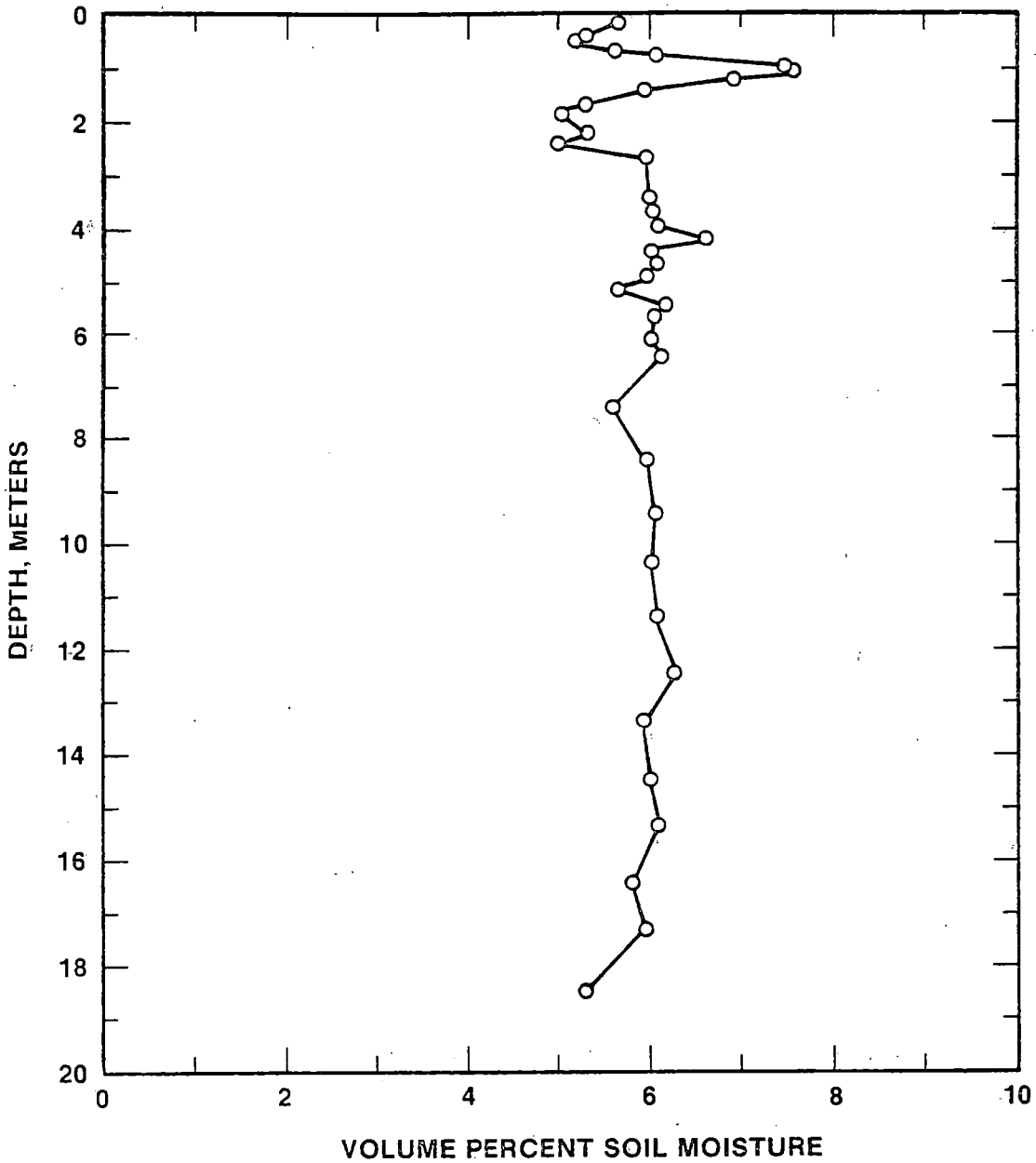

FIGURE V-20

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 6/14/77

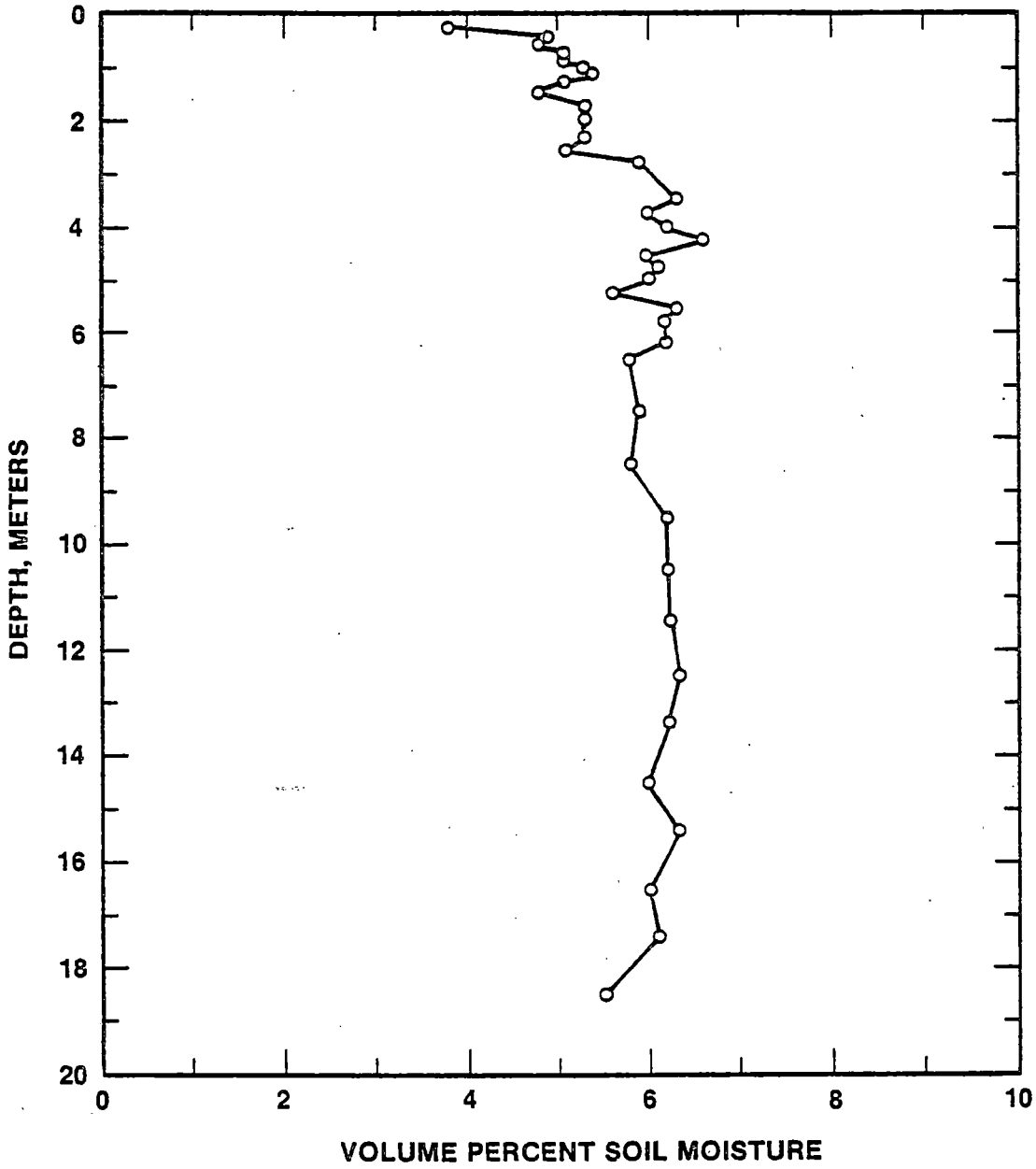

FIGURE V-21

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 7/18/77

9 2 1 2 4 6 6 1 2 2 6

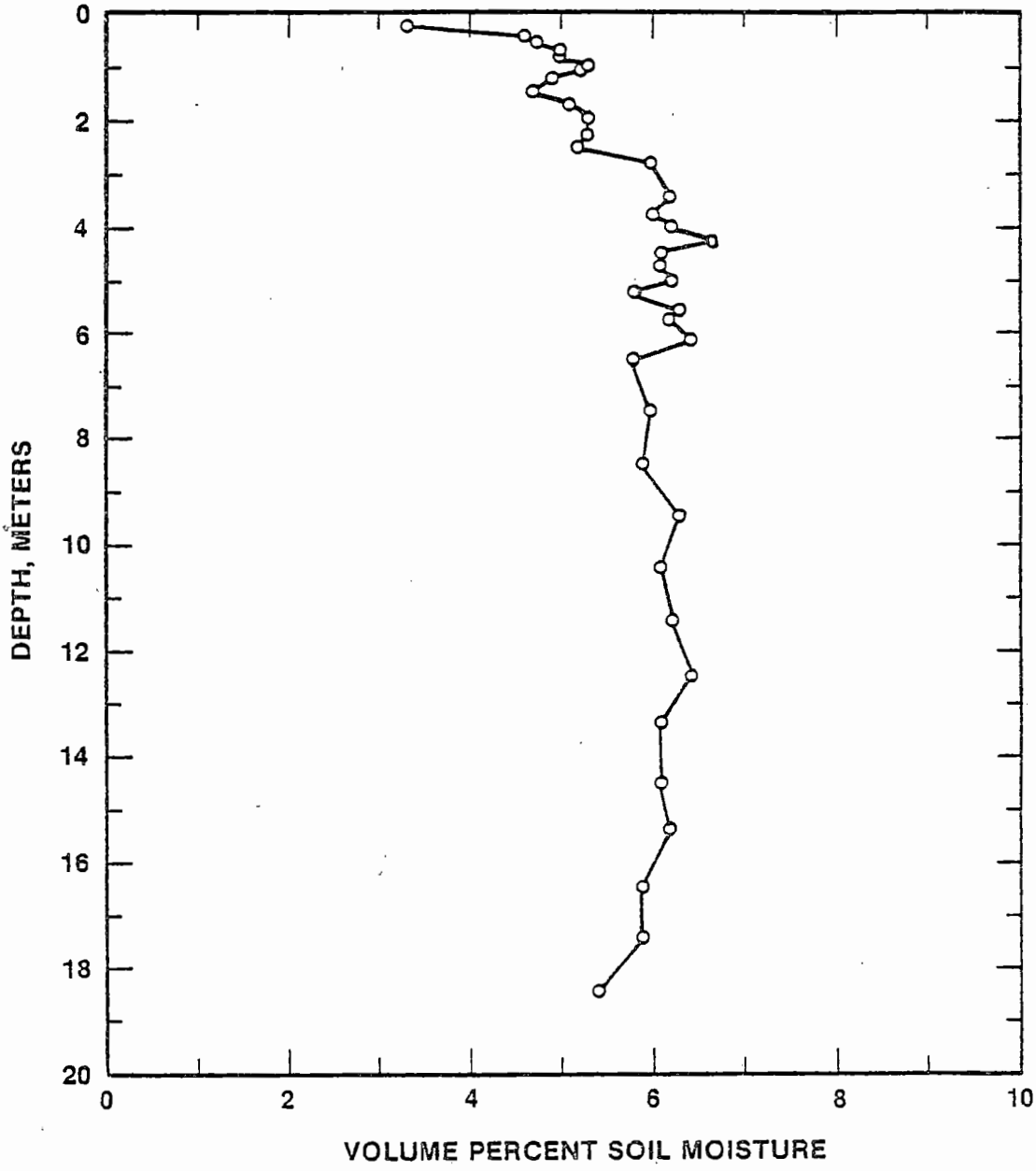

FIGURE V-22

AVERAGE MOISTURE CONTENT OF CLOSED LYSIMETER, 8/22/77

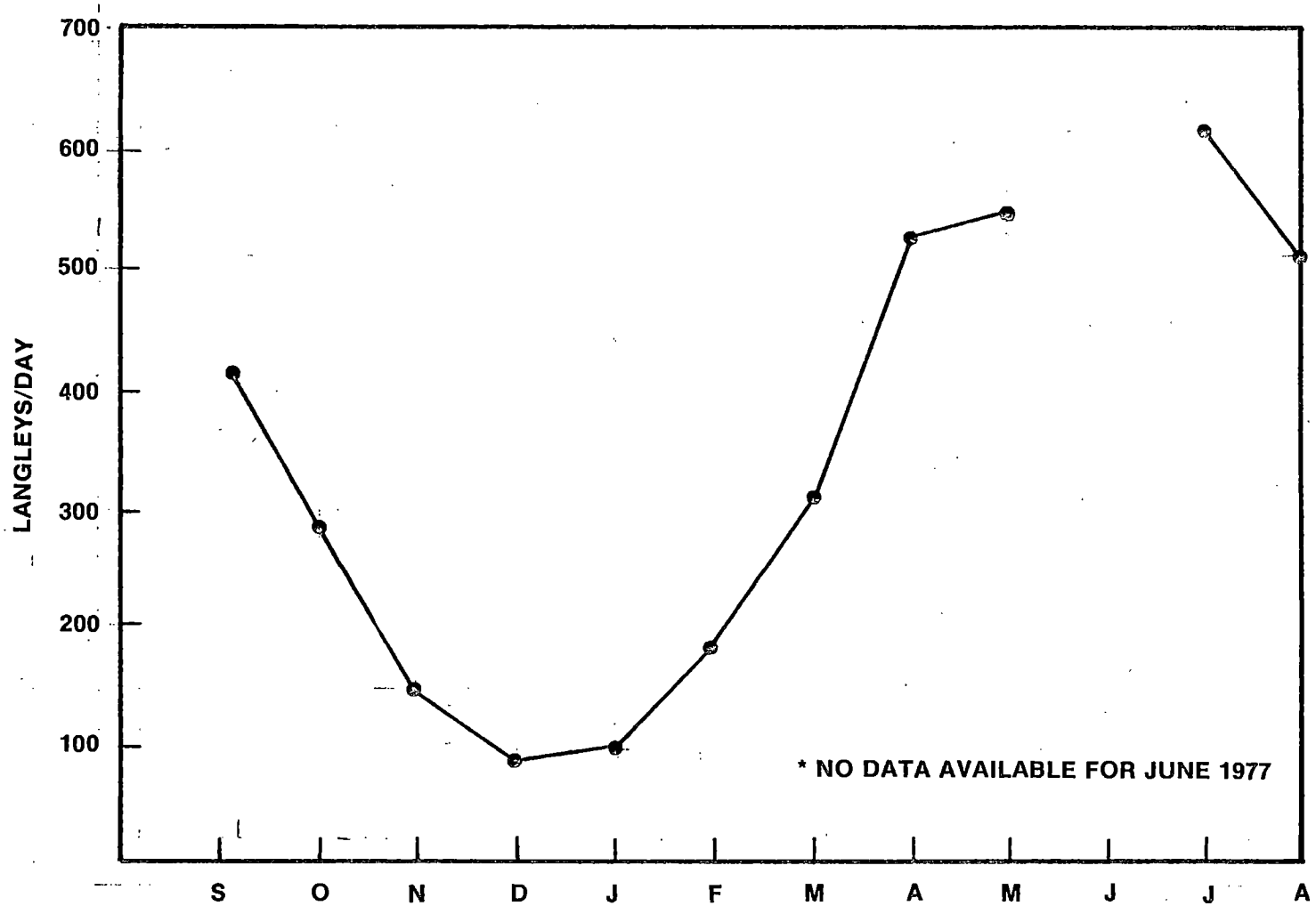

FIGURE V-23

TOTAL SOLAR RADIATION (Sept 76-Aug 77)

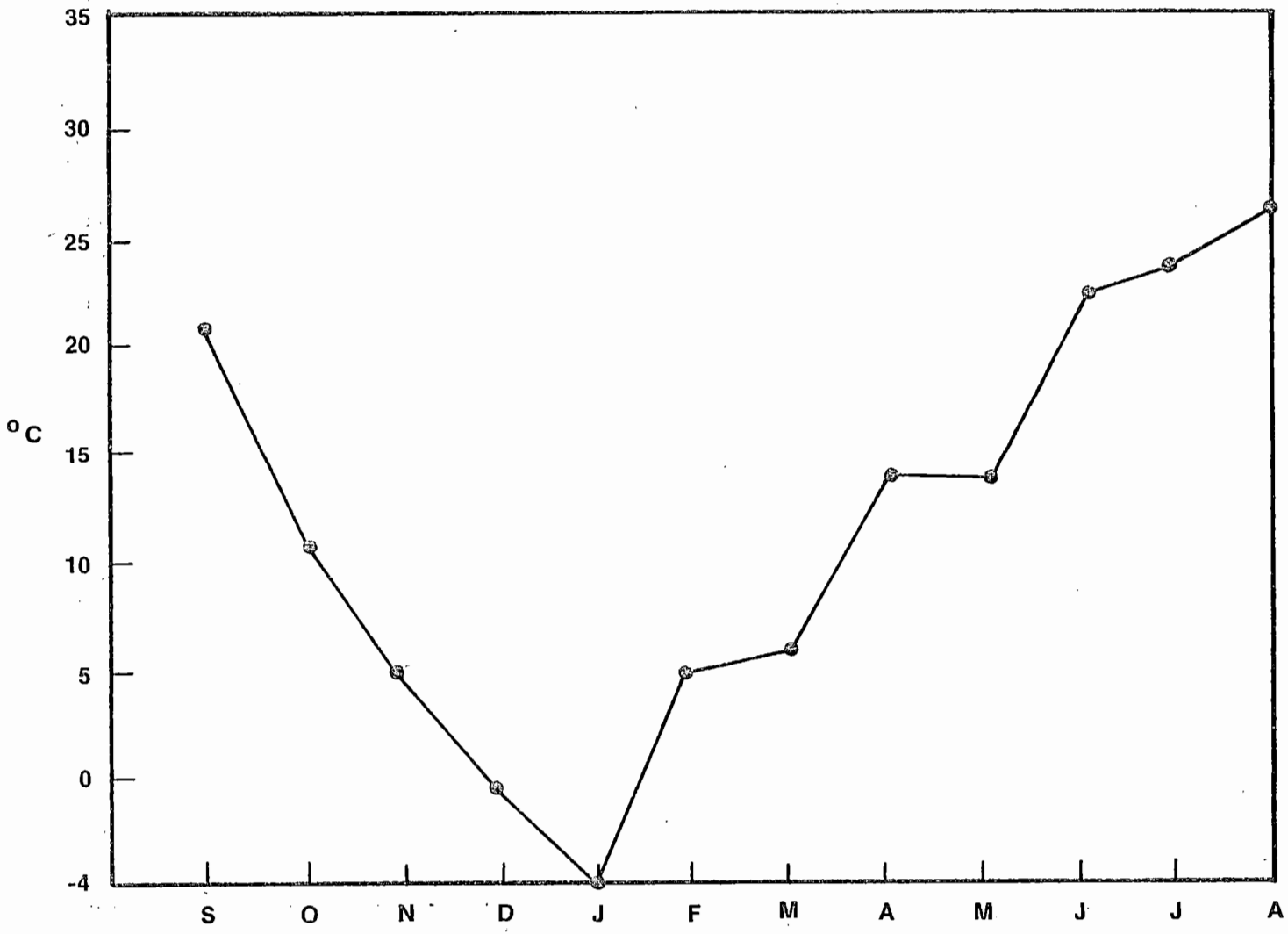

FIGURE V-24

AVERAGE AIR TEMPERATURE (Sept 76-Aug 77)

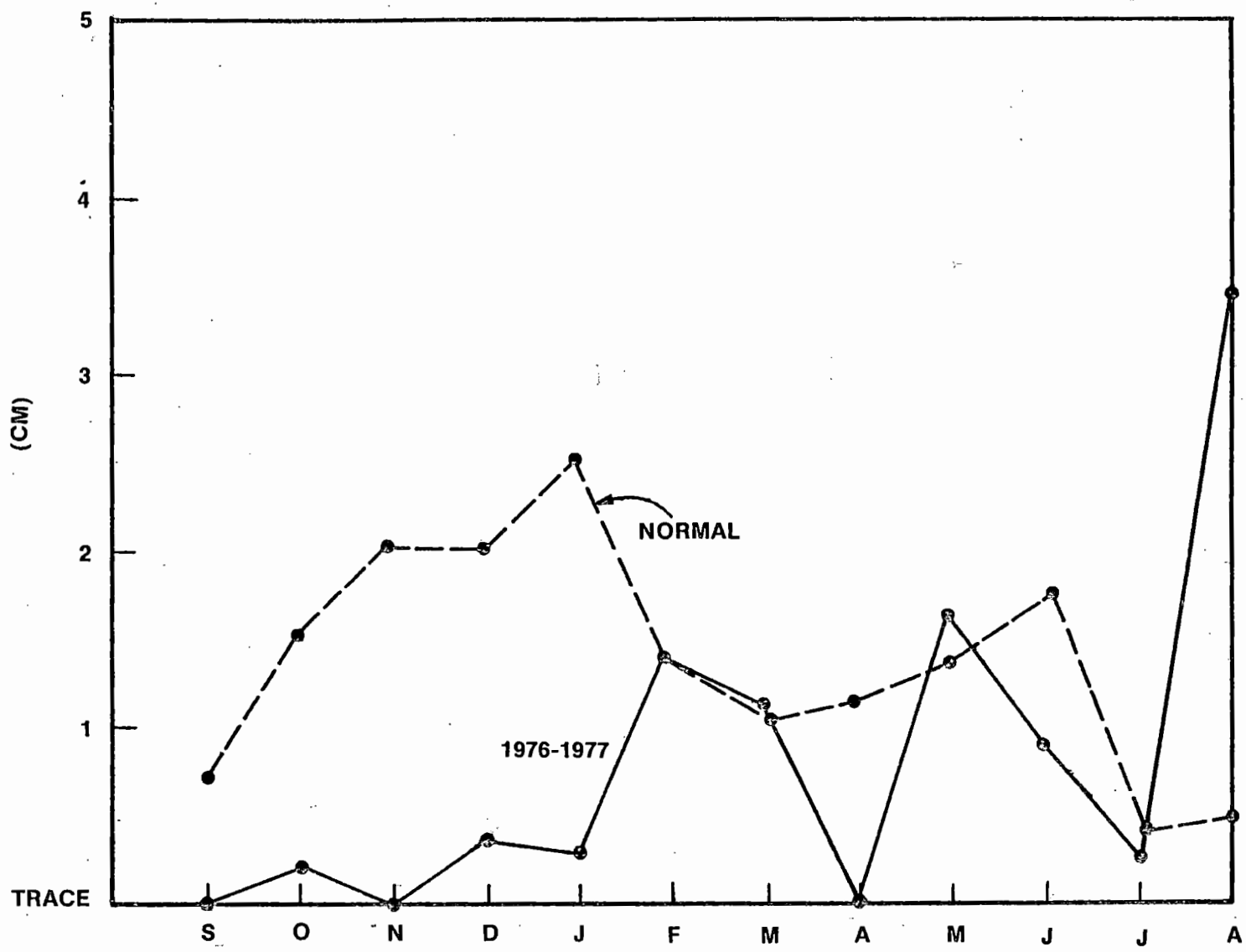

FIGURE V-25

TOTAL PRECIPITATION

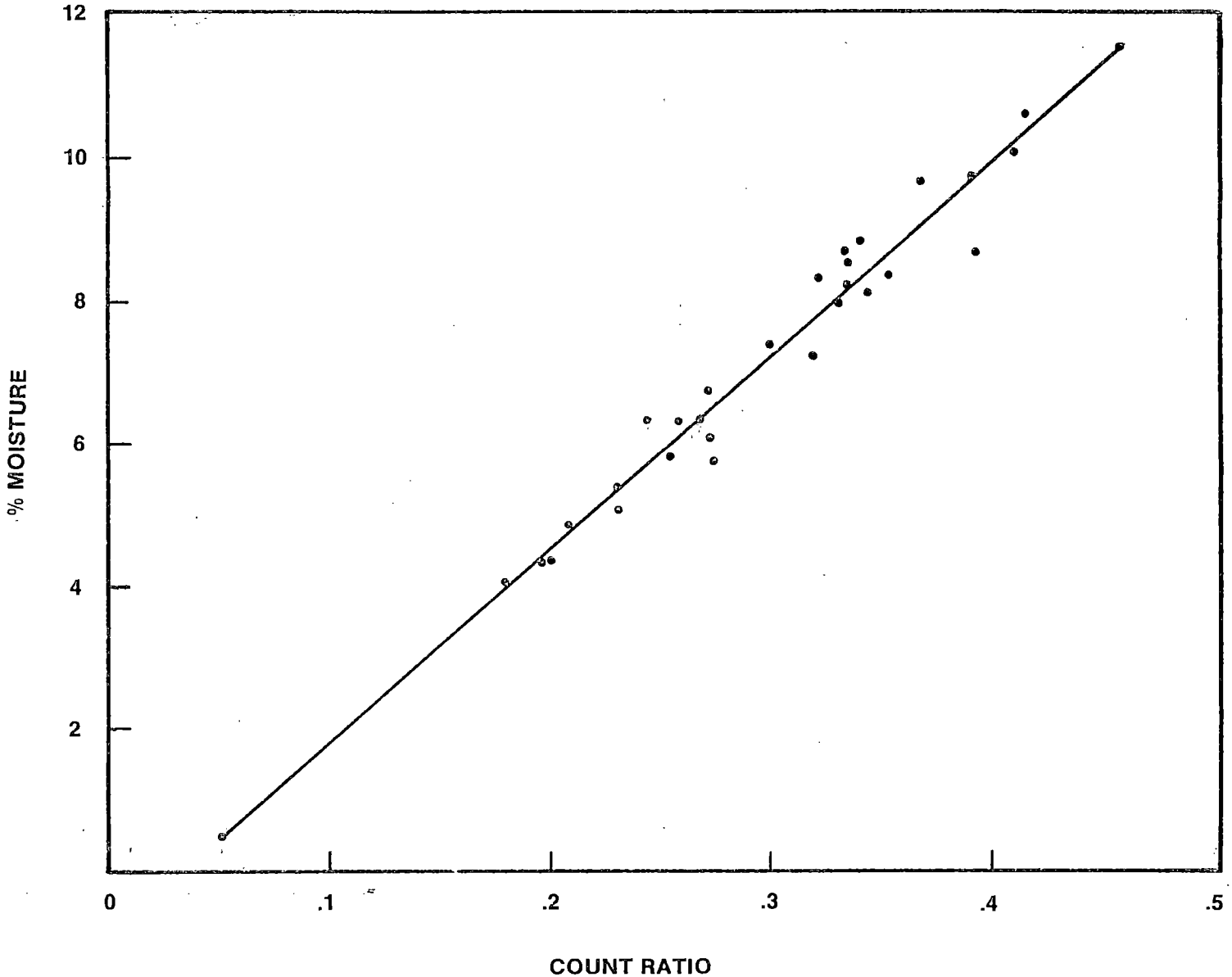

FIGURE V-26

SCATTER DIAGRAM SHOWING FIELD COMPARISON OF
CPN HYDROPROBE AND NUCLEAR CHICAGO MOISTURE PROBE

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