ARH-ST-123
Distribution Categories UC-11, UC-70

SOIL MOISTURE TRANSPORT IN ARID SITE VADOSE ZONES

PART II

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July 1975

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ABSTRACT

Measurements for the Lysimeter Experiment and the Thermocouple Psychrometer Experiment have continued with a new series (of measurements) using closely spaced sensors installed to a depth of 1.52 meters. During the 1973-1974 water year the percolation envelope of higher moisture content penetrated to a depth of four meters in the closed-bottom lysimeter and then was eliminated by upward transport of water in late summer. Precipitation during the 1973-1974 water year percolated to a depth of about six meters in the open-bottom lysimeter and remains as a residual perched envelope. The increase over normal percolation was due in part to a residual envelope of higher moisture content from the previous water year. Data to be collected during the 1974-1975 water year should provide information on whether or not the envelope will continue its downward movement or reverse direction and move upward. The equilibration of the thermocouple pyschrometers with the surrounding soil now allows for more accurate measurements of water potential. Future work will develop relationships between matric potential, depth of percolation, soil characteristics, and seasonal climatic variations.

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PART II

INTRODUCTION

The previous report, *Soil Moisture Transport in Arid Site Vadose Zones, Part I*, ARH-2983, October 1974,[1] described the need for a better understanding of soil moisture movement in the vadose zone of the Hanford Reservation.

The safety of radioactive wastes buried on the Hanford site depends upon isolation of the radionuclides in the relatively dry sediments high above the regional water table. The amount and rate of precipitation necessary to establish percolation to the water table in various types and thicknesses of soil and rock have been and continue to be of concern to reviewers of practices at Hanford. The Committee on Geologic Aspects of Radioactive Waste Disposal of the National Academy of Sciences, National Research Council, stated in their report in 1966 that "The Committee is dubious about the concept that in arid and semi-arid lands meteoric water does not percolate downward as far as the water table but instead is lost entirely by evaporation and plant transpiration." The Committee recommended that "The movement of water, both upward and downward, under varying conditions of wetting in the zone or aeration of NRTS (National Reactor Test Site, Idaho) and Hanford, Washington, should be thoroughly studied, particularly with reference to questions about percolation of rain-water and snow melt to the water table." Thus the study of soil-moisture relationships is pursuant to the recommendation of the NAS-NRC Advisory Committee.

In the studies previously reported[1,2] the depth of penetration of meteoric precipitation was determined by profiling fall-out tritium at two locations where the water table is about 90 meters below ground surface. The tritium concentration was observed to decrease exponentially from the surface to a depth of about five meters. From a depth of about seven meters to the water table the tritium units are in range of values associated with water isolated from atmospheric contamination for the past 25 or more years. To investigate these phenomena further, other parameters of the soil moisture profile were studied.

The tritium profile measurements have been supplemented by a number of other studies. A large number of factors influence soil moisture movement. Water is added to the surface by meteoric precipitation and is removed by gravity flow, evapotranspiration, evaporation, advection, and by the influence of annual and diurnal cycling plus climatic vacillations in temperature and barometric pressure at the ground surface. These vacillations create thermal and pressure pumps that remove moisture by small flow mechanisms. A number of questions must be resolved to determine which mechanisms are additive, which are opposing, which experience reversals, what are the relative magnitudes, and whether the net redistribution of moisture is upward or downward.

After the tritium profile measurements, the next major attempt to establish whether or not meteoric water percolates to deep underground water on the 200 Areas plateau of the Hanford Reservation involved the use of thermocouple psychrometers to measure water potential. Because water migrates from a high water potential to a lower water potential, the potential gradient (*i.e.*, the slope of the water potential curve versus depth) can be used to establish the direction of water transport as well as the magnitude of the driving force (isothermal condition). Although this concept is soundly based on thermodynamics, some difficulties were introduced from the high degree of stratification of *in situ* soils. Also, difficulties were encountered in installing thermocouple psychrometers using cored or drilled holes, indicating need for a better technique. A lysimeter experiment was designed to improve measurement capability and to provide flexibility for a variety of experiments.[1,3]

In tests based on natural rainfall conditions, two lysimeters were considered minimal. One lysimeter bottom is open and the other is closed. The purpose of closing the bottom is to provide a more complete definition of the soil column by isolating it from complicating factors such as soil breathing and vapor migration. The general plan of the lysimeter experiment was to use the closed-bottom lysimeter as a container to collect water if it does indeed tend to percolate to the water table on the 200 Areas plateau of the Hanford site. If water percolates past a critical depth believed to have a magnitude of about 10 to 20 meters, the water may continue to percolate to greater depths partly because the retrieving influence of evapotranspiration at the surface dampens out with depth. Also as the capillary height increases, vertical flow upward becomes restricted to the liquid in the smaller and smaller capillaries until it eventually is limited to vapor transport.

The closed-bottom lysimeter experiment will provide some positive answers to the question posed. If water is percolating to the water table during a specific year, an accumulation of moisture in the bottom zone of the closed-bottom lysimeter will be observed. On the other hand, if the potential for evaporation exceeds that for percolation, the bottom zone of the lysimeter will slowly lose moisture. The columns of soil in both lysimeters are capable of exchanging moisture and heat with the atmosphere and sky. With one lysimeter closed and one open at the bottom, the subtle influence of soil breathing and vapor transport may be evaluated. Also the more precise definition of the soil-air-sky system is expected to permit improvement in the accuracy of the heat balance.

THE LYSIMETER EXPERIMENT

Prevention of leaching of stored radionuclides is important in their management. The (NAS-NRC) Advisory Committee has had concern about the concept that in arid and semi-arid lands, meteoric water does not percolate downward as far as the water table. Instead they propose that long-lived radionuclides, such as those contained in Hanford soils, in the course of a century or two may be carried to the water table. They commented on the lack of "any past or present research that might aid in determining the extent of this risk." They state further in regard to water movement in the vadose zone of the soil in the Hanford area that "It is a field of investigation which should not be overlooked as a part of the research pertinent to ground disposals of long-lived radioactivity." Contrary to their opinions, data on tritium analyses of soil samples indicate that meteoric water is not migrating through the vadose zone high above the water table in the semi-arid Hanford Reservation but these observations are inconclusive and further proof is required.

THE TWO LYSIMETERS

Two lysimeters with uniformly mixed soil were considered necessary to eliminate the added variables introduced by stratification. One lysimeter is closed at the bottom to intercept any water tending to percolate, and the other is open at the bottom to provide a control. The two lysimeters have a diameter of 3 meters and a depth of 18 meters.

A "dry" zone has been identified from soil samples from Wells 12 and 2D beginning at the 6- to 10-meter depth with a drier than average zone to 15 meters. A lysimeter depth of 18 meters was considered necessary to encompass all of the "dry" zone.

There are three sets of instrumentation for each lysimeter. One is simply a 3.75-cm diameter tube of 60616-T6 aluminum alloy for use with a Nuclear of Chicago Model P-19 neutron log sensor. The second sensor system for the two 18-meter lysimeters consists of thermocouple psychrometers with temperature sensors attached (Wescor, Incorporated, sensor Model PT51-05). Plans were to read these sensors using a Model HR33 microvoltmeter available from Westcor, Inc. The third sensor system that will be used in the two lysimeters will include instrumentation of existing stainless steel tubes that can be used to read and record the local pressure in the soil pores as a function of time and depth.

Yet to be studied is an existing complex thermal pumping effect which brings water to the surface. Soil moisture measurements from soil samples in the 200 Areas plateau indicate that water from winter and spring precipitation may percolate to depths of 3 or more meters by late spring. The total solar heat and the rate of input increase with the approach of summer and the water balance in the upper few meters of soil becomes negative; that is, in spite of spring rain during May and June, water is removed by evaporation at a greater rate than it is being added by precipitation. This causes water from lower depths to flow vertically upward by capillary action toward the surface to replace that removed by evaporation. In the measurements to date this process has the net result of limitation of the front of downward percolation to a depth of about 4 or more meters. Some desert plants growing in the area may have roots that reach down to 6 or more meters and are capable of removing moisture from that depth. The plant roots extend the range of soil capillarity. The combined influence of evapotranspiration from desert plants and surface evaporation as a result of vertical flow of water by soil and rootlet capillarity are believed to reach depths of 10 meters or more. These two mechanisms and the large heat input from summer solar radiation are believed to be the prime cause of desiccation in the top 10 meters of Hanford soil in the 200 Areas plateau.

A barometric pumping effect also exists due to "breathing" of the soil with changes in barometric pressure; this yet must be studied. The periodic changes in barometric pressure are known to cause an intake of air at about 50% annual average relative humidity when a high-pressure air mass moves into the area. Release of nearly saturated air occurs as a high barometric pressure is followed by a lower pressure. This effect must decrease with depth but its limits and relative importance are not known. The pressure sensor tubing installed in both lysimeters will be used to establish the limit and magnitude of this phenomenon. This effect acts in combination with the soil and plant root capillarity to remove water from the upper 10 or more meters during summer desiccation. None of these methods of moisture removal are believed to be very significant below a depth of about 10 meters. For this reason the statement was made that if water is able to percolate to a depth of 10 meters it may travel all the distance to the water table. Very dry soil samples with about 1.4 wt% water have been removed from the 32-49 coordinate site in the 200 Areas plateau during drilling operations. This dry zone appears to exist to depths of about 15 meters and may be the result of equilibration with the desiccated zone above. If its existence is verified in the lysimeter experiments, it could be considered as an added barrier to percolation to the water table. An answer to these questions will require careful *in situ* measurements under controlled conditions. This is the second justification for the lysimeter experiment--the first being demonstration that water does or does not tend to percolate past a depth of about 15 meters in Hanford soil at the 32-49 coordinate site.

The NAS-NRC Advisory Committee was most concerned about the possibility of a "catastrophic once-a-century-deluge" or a "rare calamitous flood" rather than the normal average condition of about 15 to 18 centimeters of annual precipitation on the Hanford site.[4] An answer as to what conditions are required to bring about percolation to the water table under catastrophic conditions will require tests in addition to the present lysimeter experiment. This need for additional measurements was indicated by comments of the consultants who reviewed the Atlantic Richfield Hanford Company programs.

The need also was recognized at the time of planning the closed lysimeter experiment and tentative plans were made to study the other parameters involved. These other parameters include (1) a range of soil types (as the closed lysimeter experiment will give results for only a single type of soil); (2) a range of precipitation such as 1p, 2p, and 4p (where p equals annual natural precipitation at the site of the closed lysimeter); and (3) a range of stratification of different soil types.[3]

In addition to the data obtained from the equilibrating lysimeter, data must be obtained on the soil used to fill the lysimeter to establish the constants characterizing the soil. To escape the limitations of the isothermal concepts of water potential, values of these constants as a function of temperature will be required.

Consideration also was given to a second experiment involving the use of a matrix of smaller lysimeters. One of the parameters used would be particle size: fine, medium and coarse, and layered (fine and medium). The second parameter used would be artificial rainfall with possible values of normal, double, and triple the annual value. This experiment would be useful in relating soil properties to the critical value of precipitation (p_c) necessary to cause percolation to the water table.

SPECIFIC OBJECTIVES OF LYSIMETER PROGRAM

- To study soil moisture transport in the vadose zone on the Hanford Reservation.
- To determine the conditions necessary to prevent percolation of meteoric water to underground water.
- To explore the extent and influence of a purported "partly desiccated" zone in the upper vadose region.
- To remove the complexing influence of stratification by mixing all soil in the lysimeter to a uniform moisture content.

- To use modern instruments such as the thermocouple psychrometer and neutron back-scatter probe to measure changes in moisture content rather than using weighing scales as in earlier lysimeter studies.[5]
- To select a site sufficiently above the water table to permit full development of a "partly desiccated" zone purported to block meteoric water from percolation to the underground water.
- To have a sufficiently deep lysimeter to encompass completely the partly desiccated zone.
- To close the bottom of one lysimeter so as to intercept and collect any water that would otherwise percolate. To demonstrate beyond all doubt whether or not meteoric water is percolating to the underground water from the surface at the 32-49 Hanford coordinates.
- To use an identical lysimeter as a control but without a bottom closure.
- To install thermocouple psychrometers in both lysimeters to measure water potential, and from a calibration of the lysimeter soil, determine moisture content versus depth.
- To determine the direction of water transport from the slope of the curve of water potential versus depth.
- To install in both lysimeters stainless steel tubing with openings at selected depths to measure the barometric pressure at various depths below ground level. These sensors are intended for use in exploration of the extent of "breathing" of soil in

the lysimeter and to permit measurement of the depth to which atmospheric changes in barometric pressure penetrate.

- To minimize measurement errors caused by temperature differences by bringing sensor leads from the lysimeters into the instrument room which is at a depth of about 4.8 meters below grade. At this depth the temperature is 16° ± 2° C the year around.
- To obtain readings of temperature versus depth throughout all the vadose zone to the water table by incorporation of measurements from sensors of Well 32-49D with other measurements recorded in the instrument room.
- To add sensors to the surface zone at the lysimeter site to measure air temperature, air humidity, and air velocity to permit calculation of heat and water balance for advective air at the 32-49 coordinate site.
- To add sensors to the surface at the lysimeter site to measure rainfall and solar radiation at the 32-49 coordinate site to permit complete heat and material balances. These data will permit accountability by an annual water balance for all meteoric water added to the surface during the year.

DETAILS OF LYSIMETER PROGRAM PLANS

Pressure Sensors

Fifteen pressure sensor tubes were located such that the absolute pressure can be recorded at the following depths: 0 (above soil surface), 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, and 18.3 meters below the surface in each lysimeter as indicated in Figure 1. The maximum depth of 18.3 meters is the lysimeter depth after completion. An aluminum plate was installed on the bottom of the closed-bottom lysimeter and caulked at the joint to make a water-tight seal as indicated in Figure 2.

Although 30 pressure sensor tubes were installed, the pneumatic scanner being considered will be capable of recording only 24 readings. The majority of these will most likely be in the open lysimeter since greater pressure changes are expected here. The final decision on which sensor tubes will be utilized on a full-time basis will be made after all sensor tubes have been tested and the effect of the closed bottom on pressure changes examined.

The tubes used for pressure sensors were of stainless steel. The tubes to a depth of 3 meters were 0.318-cm (0.125") o.d., and the remaining tubes were 0.635-cm (0.25") o.d. The end of the tube in the soil was enclosed inside a few layers of a cloth shield to prevent pluggage. The pressure sensor tubes exited the lysimeter at a depth of 3 meters, and entered the instrument room through the floor.

Thermocouple Psychrometers

Thermocouple psychrometers were installed axially at the following depths: 0.01, 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 18.1, and 18.3 meters as indicated in Figure 3. Three such sets were installed radially in each lysimeter at a radius of 75 centimeters. These were arranged in an equilateral triangle on the plan view as shown in Figure 1.

The psychrometers were assembled on the six cables required with calibrated thermocouple psychrometers located at the appropriate intervals. During installation a plastic tube was placed over the cable for placement in the lysimeters. This tube was removed as the lysimeter was filled, leaving the psychrometers implanted in soil. The tube expedited filling of the lysimeter and insured vertical alignment of the psychrometers.

Neutron Probe Tubes

Three 4.09-cm (1.61") i.d. aluminum pipes (1.5" nominal size) were installed to a depth of 18.3 m in each lysimeter to accommodate a Nuclear of Chicago Neutron Probe. These pipes were located at a radius of 0.5 m in an equilateral triangle plan. The plan of the axis of the neutron probe tubes was off-set 60° from the plan of the axis of the psychrometer sensors as indicated in Figure 2.

Temperature

Each thermocouple psychrometer has a "dry bulb" thermocouple for temperature measurement. These can be used to measure the temperatures for the soil moisture content computations.

Instrument Room

The room to house the recording instrumentation is below grade with the roof approximately 1 meter below ground level. This is to eliminate possible climatological influences, such as interfering wind patterns, casting shade, etc., that might be associated with an external structure. The room is large enough to accommodate three or four instrument banks and to permit easy access for repair work and collection of data.

The optimum conditions for instrumentation require that the room temperature be controlled at 25° C, with a maximum deviation of ± 2° C. This would necessitate air-conditioning and heating facilities which have not been installed for economic reasons.

The instrument room for the lysimeter program, as illustrated in Figures 4, 5, and 6, was constructed in the spring of 1974. The stainless steel tubing for the pressure sensing instrument has been brought into the instrument room from below the floor level and the bundles of tubing protrude through the floor grating as indicated in the elevation view, Figure 4. As shown in this Figure, the tube bundle for the closed-bottom lysimeter is on the right and that for the open-bottom lysimeter is on the left. The cables for the thermocouple psychrometer sensors have been brought into the instrument room and are coiled under the grating in the floor as indicated in Figure 4. The floor plan and the location of the grating are shown in Figure 5. The location of the entry and the pad for the motor-generator power source are indicated in the plan view of the surface area shown in Figure 6.

Soil Preparation

A decision was made that the soil used in filling the lysimeters must meet two criteria. First, it must be uniform in particle size distribution; and second, it must have a uniform moisture content.

After installation of the caissons there were two large piles of soil at the lysimeter site. Sand stored at the site from the core of nearby Wells 2B and 2D was added to the two piles to provide a sufficiency of soil to fill both lysimeters and provide an excess for use in testing. The soil was transported to the 200 Areas Batch Plant for mixing and then returned and stored at the site until filling.

There are five hoppers at the Batch Plant with individual capacities of 30 cubic yards. One is a loading hopper which feeds into four storage hoppers. The soil in the storage hoppers was fed in measured quantities into a mixer with a capacity of four cubic yards. The moisture content of the soil in the mixer was measured with a Chicago Nuclear Neutron Probe. No water was added as the soil was at the desired moisture content. The following procedure was used for soil preparation:[3]

> Soil stored in cans at the site from the core of Wells 2B and 2D was added equally to the two piles of soil already at the lysimeter site. Equal amounts of soil were removed from the two piles using horizontal cuts by a loader, transferred to dump trucks, and transported to the Batch Plant.
>
> Here two storage hoppers were filled via the loading hopper. Two cubic yards of soil from each hopper were fed into the mixer. The soil was then mixed for 1.5 minutes and fed into one of the empty hoppers. This process was repeated until the two hoppers that were initially full were empty and the other two were full. Then two-cubic-yard-batches of treated soil from each hopper were returned to the mixer. This charge was mixed again for 1.5 minutes to provide better uniformity, loaded into a cement truck, and transported to the lysimeter, into which it was placed as soon as possible to avoid change in moisture content. This entire process was repeated until all of the soil for the lysimeters had been mixed, brought to a uniform moisture content, and loaded beside each lysimeter.

INSTALLATION OF LYSIMETERS

Atlantic Richfield Hanford Company's Development Engineering supervised field installation of the lysimeters. Supervision of the calibration of Westcor Thermocouple Psychrometer Sensors; cable construction for the thermocouple psychrometers; and installation of sensors was performed by personnel of the Battelle Pacific Northwest Laboratories. Excavation commenced June 11, 1971, and was essentially completed by the end of the month with caissons installed. Insulation of the inside of the walls of both lysimeters was performed during July 1971 by spray application of polyurethane foam. During August 1971 the excavation for the underground instrument room to serve the two field lysimeters was completed. The dry, sandy texture of the soil resulted in an angle of repose of 45° or less. As a result the quantity of soil removed was large. Excavations also were made for the underground cables that run from each lysimeter to the instrument room at a depth of about 5 meters. This also added significantly to the total quantity of soil excavated.

During September 1971 the cables for the thermocouple psychrometer sensors were completed by Battelle Pacific Northwest Laboratories personnel. The stainless steel tubing used for pressure sensors was ordered, but delivery was late. This delay in receiving the stainless steel tubing held up back-filling until after the fall rains had increased the soil moisture in the mixed lysimeter soil stored on the surface adjacent to each lysimeter.

During October 1971 the three conduits for the thermocouple psychrometer sensor leads from each lysimeter were covered with sand. Work was held up temporarily because the stainless steel tubing for the pressure sensors had not yet been received. Plans for mixing the sand from the lysimeter were modified slightly in an effort to expedite the work without losing uniformity of the fill sand. No water was added at the Batch Plant because it was determined that the moisture content of the mixed sand was close to the average equilibrium value for soil from that area.[3]

During November 1971 the closed-bottom lysimeter was filled to within 5 meters of the surface. On November 24 a brief halt was made to shift the instrument cables and tubing leads to the conduits running horizontally to the site of the instrument room at a depth of 5 meters. Care was taken to mix the soil thoroughly as it was added to the hopper at the surface and to tamp the soil firmly as it refilled the lysimeter. Soil samples were obtained every 1.5 meters by coring down to the specified depths. The closed-bottom lysimeter was completely refilled with mixed soil during December 1971. The open-bottom lysimeter was not completely refilled until January 1972 and as a result the soil in the top section accumulated considerable moisture during the added exposure time to rain and snow. The psychrometer cables were found to be short after refilling the lysimeters. In order to bring the final surface elevation to the appropriate level to correspond with the desired spacing depths for the psychrometer and thermocouple sensors, some soil was removed from both the closed and open lysimeters and the area between and around the lysimeter was graded to correspond with the elevation within the lysimeters. Three 40.6-cm (16") levels of caisson rings were moved from the closed-bottom lysimeter bringing the top of the metal shell to an elevation just below that of the soil surface. Two levels of rings were removed from the open-bottom lysimeter leaving the top of the shell ring a few centimeters above the surface of the soil.

Soon after final filling and grading, an attempt was made to obtain a moisture content versus depth curve using the new neutron log in the open lysimeter. Difficulty was encountered when the neutron log sonde became stuck inside the aluminum pipe at about the 12-meter depth. A C-shaped "fishing" tool was constructed, attached to lengths of 0.32-cm (1/8") pipe, lowered in the well, and used to release and recover the sonde.

All three tubes, (#1, #2, and #3) in the open-bottom lysimeter were reamed successfully. Only two (#4 and #6) of the three tubes in the closed-bottom lysimeter were reamed. The reamer was lost in the third tube (#5) of the closed-bottom lysimeter and reaming operations were stopped when it was decided to discontinue further attempts at reaming the third tube and use only the two tubes that were successfully reamed for measurements to 18.3-meter depth.

EARLY MEASUREMENTS USING NEUTRON-LOG SONDE

In the soil moisture measurements, the zero point in the depth measurement is not the surface of the soil but a zero reference point on the top of the neutron probe shield as indicated in Figure 7. This zero depth reference is taken to be the distance A plus B above the soil surface. Distance A is a constant 27.5 cm, equal to the height of the zero reference above the bottom of the neutron shield. Distance B is the distance from the bottom of the neutron shield to the soil surface. Before November 1974 Distance B was different for the various access tubes ranging from 28 to 46 centimeters. Between November 1974 and January 1975 some soil was transferred from the top of the closed-bottom lysimeter to the open-bottom lysimeter in an attempt to bring the dimension B for each lysimeter to approximately the same value. The distance A + B is about 54 centimeters, using an average value of 36.5 cm for B after January 1975. The A + B distance should be subtracted from all depths which have been reported in previous tables and figures to give the actual depth below the surface where a measurement is made and reported.

Limitation of funds prevented construction of the instrumentation room during the 1972 Fiscal Year. Nearly consant temperature is required for accurate reading of the thermocouple psychrometers. Reading of these sensors in the lysimeters was attempted but proved impractical because of large temperature fluctuations. The decision was made to postpone these measurements and the pressure sensor measure-ents until a suitable room for instrumentation was available. This left the neutron-log probe as the only operational sensor for the two lysimeters during 1972 and 1973.

The first plots of soil moisture versus depth for the two ARHCO lysimeters were measured in March 1972 by personnel from Battelle Pacific Northwest Laboratories.[3] Figure 8 shows the water profile in the closed-bottom lysimeter determined March 14, 1972, as the average of two sets of values (from the two reamed survey tubes) reported from neutron log measurements. From a depth of about 1.2 meters to about 17.4 meters the moisture content held very constant at values between 5.4 to 6.4 vol% water. These values attest to the uniformity of mixing the soil and its return to the lysimeter before the onset of mid-winter weather. Above the 1.2-meter depth an increase in soil moisture to about 9 vol% is indicated and is attributed to winter precipitation.

A similar water profile for the open-bottom lysimeter is shown in Figure 9 as the average of three curves based on neutron log measurements made on March 13, 1972.

It should be noted that the return of soil to the open-bottom lysimeter was made after the filling of the closed-bottom lysimeter. Filling of the open-bottom lysimeter was interrupted at 4-meter intervals to permit cutting through the steel wall of the caisson and installation of psychrometer sensors in the virgin soil outside the open-bottom lysimeter. As a result of these and other delays caused by a cave-in outside the lysimeter and the on-set of bad weather in December, the upper 4.8 m of soil were not returned to the lysimeter until January 1972. During these delays the soil used for refilling was exposed to rain and snow and developed a higher moisture content and a lower temperature than the soil used to fill the closed-bottom lysimeter. The difference is indicated by the higher moisture contents shown in Figure 9 for the upper 4.8 m of soil. In Figure 9 the values of moisture content range from 5.4 to 7.3 vol% water from a depth of about 17.1 m to about 6 m. The moisture content increases closer to the surface to a maximum of about 13 vol% at a depth of 1.2 m.

Additional measurements of soil moisture content versus depth for the closed-bottom and open-bottom lysimeters were made by personnel of Battelle-Northwest on May 15, 26, 30, and June 14, 1972; and reported as graphs. The readings near the end of May were made after a record precipitation on May 21 of 3.53 cm (1.39"). Significant differences in soil moisture that can be attributed to percolation were evident at the 1.8-m depth and above for both lysimeters. Values in Tube #4 of the closed-bottom lysimeter showed a change from 5.0% water by volume on May 15 to 6.4% on May 30 and holding at 6.4% on June 13. Values in Tube #6 of the closed-bottom lysimeter showed less response to the record

May precipitation and indicated 6.0% on May 30 and again on June 14. Measurements at a depth of 0.75 m showed the influence of the heavy rainfall to a greater degree. On May 15 values in the closed-bottom lysimeter showed about 8.2% water which increased to a mean of about 11.0% by the end of the month. By June 14 these values had dropped back to about 9.5%.

Similar response was observed in the values for the open-bottom lysimeter. The maximum value at a depth of 1.2 m on May 15 was about 11.0%. After the heavy rain, this increased to a mean value of 13.0% measured on May 26 and dropped back to a mean of 11.4% on June 15. Percolation to the 1.8-m depth in the open-bottom lysimeter appeared to be delayed as compared with the closed-bottom lysimeter. This is indicated by the same mean value of 9.7% on May 15 and on May 26, increasing to 11.3% by June 13. The higher average moisture contents in the top of the open-bottom lysimeter as compared with the closed-bottom lysimeter were considered to be the result of the higher initial moisture content as a consequence of filling the open-bottom lysimeter in mid-winter during snow and rain.

At depths lower the 6 m, the moisture content of the soil in both lysimeters appeared to remain essentially constant as measured by neutron-log technique. At a depth of 4.8 m the mean value in the open-bottom lysimeter held constant during March, April, and May at 8.0% moisture but dropped slightly to 7.8% by June 13. This change at 4.8 m was not observed June 13 in the closed-bottom lysimeter.

During the period of July through September 1972 the neutron-log calibration used by BNW personnel was in error and the true values of moisture content in both lysimeters during this period are in question. This difficulty was overcome by October 1972.

The soil moisture profiles for the closed-bottom lysimeter for the springs of 1972, 1973, and 1974 are shown in Figure 10. The heavy line with the solid circles indicates the average of the values determined on March 21-22 in 1972. The line with open circles represents values determined a year later on April 5, 1973. A slight decrease in moisture content is developing in the lower portions from 4.5 m to the bottom at 18.3 m below the surface. This zone dropped from an average moisture value of 5.96% by volume in 1972 to an average value of 5.82% in 1973 and to an average value of 5.74% in 1974, or a decrease of about 0.1 vol% per year.

During the summer of 1972 the calibration of the neutron-log was in error and these data are not reported here. The higher moisture content in the upper 3 meters of soil during spring of 1973 as shown in Figure 10 was reduced during the hot, dry summer of 1973 as indicated in Figure 11 by the partial desiccation of the soil above the 3-meter depth. In general, early September is the period in which the soil is most dry as it follows July and August--usually the hottest months of the year. Autumn rains normally commence during the latter part of September and become more intense during November.

The surface elevation at the lysimeter site changed somewhat from its original configuration due to wind storms and landscaping attempts by personnel. This change in surface configuration modified the dimensions of the system (lysimeters and sensing equipment) on which all data measurements are based. Data obtained from thermocouple psychrometers measurements are interpreted on the basis of the surface elevation being the zero point. The thermocouple psychrometers are located at specified intervals along the instrument cables in each lysimeter. The reference point is taken as the first sensor beneath the surface and this characteristic length determines the exact depth of the lower sensors. This fixes the origin of the coordinates for each set of data collected.

The elevation view as of November 1974 for the open-bottom lysimeter is shown in Figure 12. It shows that periodic wind storms piled up soil at the lysimeter sites which has changed the relative position of the sensors. The elevation view shows that the top sensor on the Number 2 cable then was located 13 cm below the surface. The sensor positions for the Numbers 4 and 6 cables are also shown in the Figure.

The same situation developed for the closed-bottom lysimeter as shown in Figure 13. Soil piled up around the lysimeter changing its configuration in relation to the surface. The soil was leveled off and the Figure shows the elevation view as of January 1975. The distance from the surface to the top sensor on the west cable is shown as 16.5 cm with the dimensions for the north and south cables pictured similarly. Any subsequent psychrometer measurements should be correlated with these basic dimensions to ensure accurate data representation.

THE RISE AND FALL OF SOIL MOISTURE IN THE CLOSED-BOTTOM LYSIMETER DURING THE 1973-1974 WATER YEAR

MONTH-TO-MONTH CHANGES, 1973-1974

The closed-bottom lysimeter has undergone a complete annual cycle of partial desiccation, heavy precipitation during the 1973-1974 fall and winter, movement of a percolation front downward to a depth of 4 m, followed by the complete removal of the percolation envelope by October 1974 and the renewal of a partly desiccated zone in the top 4 m of the lysimeter. No water moved to the closed bottom of the lysimeter. This cycle is believed to be a classic example of the fate of meteoric precipitation on the Hanford Reservation at sites high above the deep water table where water accumulation by surface run-off does not exist. These are the first known data that illustrate this phenomenon. Moisture profiles have been selected to illustrate the various sequences in the annual cycle of the phenomenon. The cycle commences with the water year usually taken as September 1 to September 1 in two consecutive years.

The moisture profile in the closed-bottom lysimeter as of September 6, 1973, after the 1973 summer desiccation, is described in Table I and Figure 14. The moisture content is the average of neutron probe measurements in Tubes #4 and #6 of the closed-bottom lysimeter. The third tube, #5, is not used because a tube reamer was lost near the bottom.

The soil moisture profile in the closed-bottom lysimeter as of January 24, 1974, is described in Table II and Figure 15. The percolation front is taken arbitrarily as the lower depth at which the moisture content is 10% by volume. This front has a maximum moisture content of 13.75% by volume in both lysimeters at a depth of 1.7 m as shown in Table II. The 10% value occurs at a depth of 2.3 m as indicated in Figure 15. During the early part of the calendar year percolation may move water downward rapidly. This is illustrated by the data of February 6, 1974, in Table III, and plotted in Figure 16. The percolation front, as defined by the 10% moisture line, moved downward from 2.3 m to 3.5 m in the 13-day period between measurements.

TABLE I

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN SEPTEMBER 1973

Depth		Open-Bottom Lysimeter			Closed-Bottom Lysimeter		
Meters	Feet	Tube #1 9/6/73	Average	Tube #2 9/6/73	Tube #4 9/6/73	Average	Tube #6 9/6/73
0.79	2' 7"	2.6%	2.85	3.1%	3.6%	3.35	3.1%
0.89	2' 11"	3.8	4.35	4.9	4.6	4.5	4.4
1.19	3' 11"	5.3	5.95	6.6	4.9	4.9	4.9
1.70	5' 7"	6.2	6.5	6.8	5.2	5.3	5.4
2.72	8' 11"	8.4	8.65	8.9	5.1	5.55	6.0
4.85	15' 11"	8.0	8.0	8.0	6.0	5.95	5.9
6.70	22'	6.8	6.8	6.8	5.8	5.8	5.8
8.69	29' 6"	6.4	6.5	6.6	5.5	5.6	5.7
10.67	35'	6.9	6.65	6.4	6.1	6.05	6.0
12.70	41' 8"	5.6	6.7	5.8	5.8	5.85	5.9
14.68	48' 2"	6.2	6.15	6.1	5.7	5.75	5.8
16.69	54' 9"	6.1	6.05	6.0	6.2	6.1	6.0
17.68	58'	6.2	6.25	6.3	5.6	5.65	5.7
18.67	61' 3"	5.6	5.5	5.4	4.6	4.5	4.4

TABLE II

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN JANUARY 1974

Depth		Open-Bottom Lysimeter			Closed-Bottom Lysimeter		
Meters	Feet	Tube #1 1/23/74	Average	Tube #2 1/23/74	Tube #4 1/24/74	Average	Tube #6 1/29/74
0.79	2' 7"	10.6%	10.8	11.0%	11.1%	11.2	11.3%
0.89	2' 11"	11.5	12.1	12.7	12.1	12.35	12.6
1.19	3' 11"	11.9	12.74	13.5	13.3	12.75	12.2
1.70	5' 7"	13.9	13.75	13.6	14.1	13.75	13.4
2.72	8' 11"	12.5	12.4	12.3	6.4	6.85	7.3
4.85	15' 4"	8.0	8.05	8.1	5.8	5.9	6.0
6.70	22'	6.9	6.95	7.0	5.9	5.9	5.9
8.69	28' 6"	6.6	6.75	6.9	5.9	5.85	5.8
10.67	35'	7.2	6.95	6.7	6.1	6.2	6.3
12.70	41' 8"	5.9	6.05	6.2	6.0	6.2	6.4
14.68	48' 2"	6.3	6.25	6.2	6.1	6.1	6.1
16.69	54' 9"	6.4	6.2	6.0	6.6	6.65	6.7
17.68	58'	6.5	6.55	6.6	6.3	6.2	6.1
18.67	61' 3"	5.6	5.6	5.6	5.1	5.15	5.2

TABLE III

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN FEBRUARY 1974

Depth		Open-Bottom Lysimeter			Closed-Bottom Lysimeter		
Meters	Feet	Tube #1 2/5/74	Average	Tube #2 2/5/74	Tube #4 2/6/74	Average	Tube #6 2/6/74
0.79	2' 7"	8.7%	8.4	8.1%	10.4%	11.15	11.9%
0.89	2' 11"	10.1	10.3	10.5	10.8	11.5	12.2
1.19	3' 11"	10.4	11.2	12.0	11.8	11.9	12.0
1.70	5' 7"	12.3	12.45	12.6	13.2	13.2	13.2
2.72	8' 11"	13.1	12.95	12.8	12.4	11.95	10.5
4.85	15' 11"	8.1	8.15	8.2	6.2	6.35	6.5
6.70	22'	6.8	6.9	7.0	6.8	6.7	6.6
8.69	28' 6"	6.5	6.7	6.9	6.1	6.25	6.4
10.67	35'	7.2	7.0	6.8	6.7	6.85	7.0
12.70	41' 8"	5.9	6.35	6.6	6.5	6.7	6.9
14.68	48' 2"	6.4	6.5	6.6	6.6	6.7	6.8
16.69	54' 9"	6.5	6.5	6.6	7.0	7.1	7.2
17.68	58'	6.5	6.85	7.2	6.5	6.7	6.9
18.67	61' 3"	5.5	5.9	6.3	5.4	5.6	5.8

During this period of rapid percolation the moisture content may be in the range of 13 to 15% water by volume. As the percolation front moves downward it travels into a previously partly desiccated zone where it must raise the moisture content at the expense of the maximum value of the percolation envelope. As a result, the velocity of percolation decreases exponentially with the moisture content, expressed as fraction saturation. This reduction in velocity serves to brake the downward percolation.

Additional precipitation during the spring season adds meteoric water to the percolation zone. Also the warmer weather in early summer evaporates the water from the surface. The net result is the development of an envelope of higher moisture content moving slowly downward by percolation. The thickness of the percolation envelope may reach a maximum in June at about the beginning of the summer season. This is shown by the data in Table IV and plotted in Figure 17. During the period from February 6, 1974, to June 24, 1974, the percolation front (10% moisture) moved down only 30 cm from 3.5 to 3.8 m as indicated in Figure 17. The percolation envelope of 6% and higher moisture content extended 3.5 m from 1.0 to 4.5 m depth.

During the hot weather of July an increasing amount of water is evaporated from the surface. This developed a zone of partial desiccation (5.7% moisture) in the top 1.5 m of the closed-bottom lysimeter as listed in Table V and shown in Figure 18 for August 8, 1974. During August the thickness and size of the percolation envelope shrank considerably more as a result of upward transport of the moisture in the percolation envelope. Data in Table VI for moisture content as of August 29, 1974, in the closed-bottom lysimeter, are plotted in Figure 19. The percolation envelope shrank to a

TABLE IV

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN JUNE 1974

Depth		Open-Bottom Lysimeter			Closed-Bottom Lysimeter		
Meters	Feet	Tube #1 6/24/74	Average	Tube #2 6/26/74	Tube #4 6/26/74	Average	Tube #6 6/27/74
0.79	2' 7"	2.9%	2.75	2.6%	4.7%	5.25	5.8%
0.89	2' 11"	4.6	5.1	5.6	5.5	5.85	6.2
1.19	3' 11"	5.5	7.0	8.5	5.7	5.9	6.1
1.70	5' 7"	8.4	8.95	9.5	8.2	8.7	9.2
2.72	8' 11"	10.5	10.5	10.5	10.1	10.25	10.4
3.05	10'				11.5	11.3	10.7
3.35	11'				11.0	10.65	10.3
3.66	12'				11.9	11.15	10.4
3.81	12' 6"				11.0	10.05	9.1
3.96	13'				10.4	9.25	8.1
4.11	13' 6"				8.3	7.55	6.8
4.19	13' 9"				6.9	6.6	6.3
4.27	14'				5.9	6.0	6.1
4.42	15' 6"	12.4					
4.49	15' 9"	12.0					
4.85	15' 11"	12.8	12.8	12.8	5.9	5.9	5.9
4.88	16'	11.8	12.05	12.3			
4.98	16' 4"	11.7					
5.01	16' 5"			11.9			
5.19	17'	11.7	11.5	11.3			
5.24	17' 2"	11.0					
5.29	17' 4"			10.8			
5.31	17' 5"	10.4					
5.39	17' 8"	9.6					
5.49	18'	8.1	8.5	8.9			
5.79	19'			6.8			
6.70	22'	7.0	7.0	7.0	5.9	5.75	5.6
8.69	28' 6"	6.5	6.6	6.7	5.9	5.75	5.6
10.67	35'	7.0	6.8	6.6	6.0	6.05	6.1
12.70	41' 8"	5.8	6.05	6.3	6.3	6.1	5.9
14.68	48' 2"	6.3	6.2	6.1	6.1	5.9	5.7
16.69	54' 9"	6.2	6.15	6.1	6.1	6.15	6.0
17.68	58'	6.3	6.45	6.6	5.7	5.8	5.9
18.67	61' 3"	5.7	5.6	5.5	4.6	4.65	4.7

TABLE V

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN EARLY AUGUST 1974

Depth		Open-Bottom Lysimeter			Closed-Bottom Lysimeter		
Meters	Feet	Tube #1 8/06/74	Average	Tube #2 8/07/74	Tube #4 8/07/74	Average	Tube #6 8/08/74
0.79	2' 7"	2.4%	2.15	1.9%	4.4%	4.6	4.8%
0.89	2' 11"	4.1	4.1	4.1	5.0	5.15	5.3
1.19	3' 11"	4.9	5.15	5.4	5.3	5.1	4.9
1.70	5' 7"	4.9	5.05	5.2	5.8	5.7	5.6
2.72	8' 11"	6.0	6.3	6.6	6.6	6.9	7.2
2.90	9' 6"				6.4	7.1	8.8
3.05	10'	8.6	8.4	8.2	7.7	8.4	9.1
	10' 6"	10.4					
3.35	11'	10.3	10.15	10.0	7.3	8.55	8.8
3.66	12'	11.7	11.7	11.7	9.7	10.1	10.5
	12' 6"	11.6					
3.96	13'	11.1	11.05	11.0	10.7	10.2	9.8
4.11	13' 6"						9.7
4.27	14'	12.2	12.4	12.6	8.1	7.6	7.1
4.42	14' 6"				6.3		
4.07	15' 9"	12.0					
4.85	15' 11"	12.5	12.65	12.8	5.8	5.8	5.8
4.88	16'	11.4	12.0	12.6			
4.98	16' 4"	11.7					
5.19	17'	12.0	11.8	11.6			
5.24	17' 2"	11.8					
5.31	17' 8"	11.7					
5.49	18' 6"	11.7	11.5	11.3			
5.64	18' 6"	9.6	9.9	10.2			
5.79	19'	7.1	7.6	7.9			
6.70	22'	6.7	6.65	6.6	5.8	5.7	5.6
8.69	28' 6"	6.4	6.4	6.4	5.8	5.85	5.9
10.67	35'	7.1	6.8	6.5	6.0	6.1	6.2
12.70	41' 8"	5.8	6.1	6.4	6.1	6.15	6.2
14.68	48' 2"	6.3	6.15	6.0	6.0	5.95	5.9
16.69	54' 9"	6.3	6.15	6.0	6.1	6.15	6.2
17.68	58'	6.3	6.4	6.5	6.1	5.85	5.6
18.67	61' 3"	5.4	5.45	5.5	4.7	4.65	4.6
18.97	62' 3"	5.5	5.4	5.3	5.6	5.5	5.4
19.20	63'	5.4	5.4	5.4	5.7		

thickness of about one meter with a maximum moisture content of 8.1% by volume at a depth of 4.0 m. The movement of the percolation envelope downward had been halted and the envelope was rapidly consumed by evaporation at the surface and the upward transport of water by both liquid and vapor transport.

By September 12, 1974, the percolation envelope in the closed-bottom lysimeter shrank further as shown by the data in Table VII and plotted in Figure 20. The maximum moisture content dropped to 7.15% and the desiccation penetrated to a depth of 3.5 m. The percolation envelope was believed to have been consumed by the desiccation front later in September but no additional measurements were available until October 11 and 18. By this time the percolation front in the closed-bottom lysimeter had completely disappeared as shown by data in Table VIII and average values plotted in Figure 21.

From September 1, 1973, to September 1, 1974, the precipitation totaled 10.21" or 25.93 cm based on measurements at the Hanford Meteorology Station as listed in Table IX. This is 158% of the normal precipitation and is considered to be a rather moist water year. In spite of this greater-than-normal rainfall, percolation in the closed-bottom lysimeter penetrated only to a depth of 4.0 m and then it was completely removed by desiccation from the surface at the end of the summer before the first measurable precipitation in the 1974-1975 water year.

TABLE VI

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN LATE AUGUST 1974

Depth Meters	Open-Bottom Lysimeter Tube #1 8/27/74	Open-Bottom Lysimeter Average	Open-Bottom Lysimeter Tube #2 8/28/74	Closed-Bottom Lysimeter Tube #4 8/29/74	Closed-Bottom Lysimeter Average	Closed-Bottom Lysimeter Tube #6 8/29/74
1.0	3.8%	3.95	4.1%	5.1%	5.05	5.0%
1.5	5.0	5.2	5.4	5.1	5.15	5.2
2.0	4.4	4.55	4.7	5.0	5.0	5.0
2.5	4.8	4.85	4.9	5.2	5.3	5.4
3.0	5.5	5.3	5.1	5.7	5.85	6.0
3.5	5.7	6.45	7.2	5.4	5.8	6.2
3.75				6.6	7.35	8.1
4.0	9.1	9.35	9.6	7.0	8.1	9.2
4.25				6.9	7.5	8.1
4.5	11.6	11.45	11.3	6.2	6.1	6.0
5.0	11.3	11.7	12.1	6.0	5.45	5.9
5.5	11.9	11.55	11.2	6.1	6.1	6.1
6.0	7.4	7.65	7.9	5.8	6.0	6.2
6.5	6.5	6.35	6.2	6.2	5.9	5.6
7.0	6.4	6.7	7.0	6.0	5.8	5.6
7.5	6.4	6.5	6.6	6.0	5.85	5.7
8.0	6.0	6.1	6.2	6.0	5.95	5.9
8.5	6.0	6.15	6.3	6.0	5.85	5.7
9.0	6.2	6.2	6.2	5.6	5.7	5.8
9.5	6.1	6.15	6.2	5.8	5.85	5.9
10.0	6.6	6.75	6.9	6.2	6.05	5.9
10.5	7.1	6.7	6.3	5.8	5.75	5.7
11.0	5.8	5.95	6.1	6.1	5.9	5.7
11.5	6.0	6.05	6.1	5.8	6.0	6.4
12.0	5.8	5.75	5.7	5.9	5.8	5.7
12.5	5.7	5.85	6.0	5.8	5.85	5.9
13.0	6.1	6.15	6.2	5.6	6.0	6.4
13.5	6.1	6.1	6.1	5.6	5.75	5.9
14.0	5.8	6.1	6.4	6.1	6.0	5.9
14.5	5.8	5.95	6.1	5.7	5.75	5.8
15.0	6.0	6.0	6.0	5.6	5.5	5.4
15.5	5.7	5.85	6.0	5.7	5.6	5.5
16.0	5.9	6.0	6.1	6.0	6.0	6.0
16.5	6.0	6.0	6.0	5.9	5.95	6.0
17.0	6.0	5.8	5.6	6.1	5.95	5.8
17.5	6.6	6.55	6.5	5.9	5.95	6.0
18.0	6.1	6.15	6.2	5.5	5.55	5.6
18.5	5.7	5.75	5.8	6.6	6.15	5.7
19.0	5.1	5.25	5.4	5.9	5.65	5.4
19.21	5.0	5.15	5.3	5.7	5.34	
Average		6.54%				

TABLE VII

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN SEPTEMBER 1974

Depth Meters	Open-Bottom Lysimeter Tube #1 9/09/74	Open-Bottom Lysimeter Tube #2 9/10/74	Open-Bottom Lysimeter Average	Closed-Bottom Lysimeter Tube #4 9/10/74	Closed-Bottom Lysimeter Tube #6 9/13/74	Closed-Bottom Lysimeter Average
0	2.0	2.0	2.0	2.0	2.0	2.0
0.5	2.5	2.5	2.5	2.5	2.5	2.5
1.0	3.8	4.1	3.95	5.0	5.0	5.0
1.5	5.0	5.2	5.1	5.3	5.1	5.2
2.0	4.4	4.7	4.55	5.3	5.1	5.2
2.5	4.7	5.0	4.85	5.1	5.2	5.15
3.0	5.2	5.2	5.2	5.3	5.5	5.4
3.5	5.3	5.8	5.55	5.1	6.1	5.6
4.0	6.9	7.5	7.2	6.2	8.0	7.1
4.5	10.9	10.5	10.7	6.0	6.2	6.1
5.0	11.2	11.8	11.5	6.1	5.9	6.0
5.5	11.8	11.4	11.6	6.1	6.1	6.1
6.0	7.4	8.5	7.95	5.9	6.2	6.05
6.5	6.4	6.5	6.45	6.4	5.8	6.1
7.0	6.5	6.9	6.7	6.0	5.7	5.85
7.5		(6.43)*			(5.93)*	
8.0	5.9	6.4	6.15	6.1	5.9	6.0
8.5		(6.28)			(5.9)	
9.0	6.3	6.5	6.4	5.7	5.9	6.8
9.5		(6.55)			(6.0)	
10.0	6.5	6.9	6.7	6.2	6.2	6.2
10.5		(6.33)			(6.15)	
11.0	5.7	6.2	5.95	6.2	6.0	6.1
11.5		(5.90)			(5.95)	
12.0	5.7	6.0	5.85	5.8	5.8	5.8
12.5		(6.1)			(5.9)	
13.0	6.2	6.5	6.35	5.7	6.3	6.0
13.5		(6.23)			(6.08)	
14.0	5.6	6.6	6.1	6.3	6.0	6.15
14.5		(5.95)			(5.85)	
15.0	5.8	5.8	5.8	5.5	5.6	5.55
15.5		(5.93)			(5.85)	
16.0	5.9	6.2	6.05	6.2	6.1	6.15
16.5		(5.9)			(6.18)	
17.0	5.8	5.7	5.75	6.3	6.1	6.2
17.5		(5.95)			(5.9)	
18.0	6.2	6.1	6.15	5.7	5.5	5.6
Average			6.28			5.63

*Parens indicate a value from a previous measurement included to provide 37 values required for computer average program.

TABLE VIII

NEUTRON LOG OF WATER IN PERCENT BY VOLUME IN LYSIMETER SOIL IN OCTOBER 1974

Depth Meters	Open-Bottom Lysimeter Tube #1 10/18/74	Tube #2 10/11/74	Tube #3 10/18/74	Average #1 + #2	Closed-Bottom Lysimeter Tube #4 10/18/74	Tube #6 10/11/74	Average #4 + #6
0	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)
0.5	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)
1.0	3.7	3.8	3.7	3.75	4.8	4.9	4.85
1.5	4.8	5.3	5.1	5.05	4.9	4.9	4.9
2.0	4.4	4.6	4.8	4.6	5.1	5.1	5.1
2.5	4.7	4.9	4.9	4.8	4.8	5.2	5.0
3.0	5.1	5.0	5.1	5.05	5.2	5.3	5.25
3.5	5.1	5.2	5.2	5.15	5.4	5.4	5.4
4.0	5.4	5.8	5.6	5.6	5.2	6.9	6.05
4.5	9.3	8.5	9.1	8.9	5.7	6.4	6.05
5.0	10.4	11.0	11.1	10.7	5.8	6.2	6.0
5.5	11.7	10.9	12.2	11.2	6.2	6.1	6.15
6.0	8.8	10.0	8.5	9.4	6.3	6.2	6.25
6.5	6.6	6.5	6.7	6.55	6.3	5.9	6.05
7.0	6.6	7.0	6.6	6.8	6.1	5.8	6.05
7.5	(6.4)	6.6		(6.5)	(6.0)	(5.7)	(5.85)
8.0	6.2	6.4	6.3	6.3	6.0	6.1	6.05
8.8	(6.0)	(6.3)		(6.15)	(6.0)	(5.7)	(5.85)
9.0	6.4	6.6	6.3	6.5	5.6	5.9	5.75
9.5	(6.1)	(6.2)		(6.15)	(5.8)	(5.9)	(5.85)
10.0	6.8	6.9	6.5	6.85	6.3	6.1	6.2
10.5	(7.1)	(6.3)		(6.7)	(5.8)	(5.7)	(5.75)
11.0	5.9	6.2	6.1	6.05	6.1	5.9	6.0
11.5	(6.0)	(6.1)		(6.05)	(5.8)	(6.4)	(6.1)
12.0	6.0	6.0	6.1	6.0	6.0	5.8	5.9
12.5	(5.7)	(6.0)		(5.85)	(5.8)	(5.9)	(5.85)
13.0	6.4	6.5	6.4	6.45	5.8	6.3	6.05
13.5	(6.1)	(6.1)		(6.1)	(5.6)	(5.9)	(5.75)
14.0	5.9	6.6	6.5	6.25	6.3	6.0	6.15
14.5	(5.8)	(6.1)		(5.95)	(5.7)	(5.8)	(5.75)
15.0	6.0	5.9	6.4	5.95	5.5	5.8	5.65
15.5	(5.7)	(6.0)		(5.85)	(5.7)	(5.5)	(5.6)
16.0	6.0	6.3	6.1	6.15	5.9	6.1	6.0
16.5	(6.0)	(6.0)		(6.0)	(5.9)	(6.0)	(5.95)
17.0	6.1	5.8	6.0	5.95	6.5	6.2	6.35
17.5	(6.6)	(6.5)		(6.55)	(5.9)	(6.0)	(5.95)
18.0	6.4	6.3	6.5	6.35	5.7	5.8	5.75
Average				6.24			5.66

*Parens indicate a value from a previous measurement included to provide 37 values required for computer average program.

TABLE IX

PRECIPITATION DURING 1973-1974 WATER YEAR

Month	Precipitation Inches	Departure from Normal Inches
1973		
September	0.43	+0.13
October	1.72	+1.11
November	2.64	+1.84
December	2.02	+1.21
1974		
January	0.90	-0.07
February	0.41	-0.17
March	0.52	+0.14
April	0.46	+0.02
May	0.28	-0.25
June	0.12	-0.58
July	0.71	+0.56
August	-	-0.21
	10.21	+3.73
	- 3.73	
	6.48 Normal	

$$\frac{10.21}{6.48} \times 100\% = 158\% \text{ average}$$

SUMMARY OF ANNUAL BEHAVIOR OF METEORIC WATER IN CLOSED-BOTTOM LYSIMETER

The water year 1973-1974 began with a partly desiccated zone in the upper 2.5 m of soil in the closed-bottom lysimeter in September 1973. The 15.5 m of soil between this partly desiccated top and the closed-bottom had a moisture content of about 6% by volume, considered to be approximately equal to the residual saturation of the soil. No drainage with moisture accumulation at the bottom closure was observed over the annual cycle.

Greater-than-normal precipitation fell during the autumn of 1973 and a percolation front with a moisture content over 13% by volume penetrated to a depth of 1 m by November 14, 1973. By January 24, 1974, the percolation front of almost 14% moisture had moved down to about 1.8 m. The percolation front continued to move slowly downward during the spring and early summer. The envelope of the zone with a moisture content greater than 6% increased to a maximum thickness of about 3 m by June 24, 1974. The maximum moisture content decreased to about 11% by volume. During the hot weather in July and August the percolation envelope shrank in size to about 2 m thickness by August 8, 1974, and to about 1 m thickness by August 29, 1974. The average of the peak moisture content in the closed-bottom lysimeter dropped to 10.2 on August 8 and 8.1% on August 28, 1974. Inspection of the plots for the soil moisure profiles indicated that the moisture was being removed by upward transport rather than by downward percolation. This is shown by the constancy of the profile below a depth of 4 m and the shrinking curve above this depth.

A small spike of higher moisture (7.1%) existed at the 4.0-m depth with lesser amounts downward to the bottom of the closed-bottom lysimeter. Thus, although the precipitation was 158% of normal, percolation did not progress below a 4-m depth. The dry summer and autumn of 1974 not only wiped out the percolation envelope from the heavy precipitation from the early part of the water year, but also partly desiccated the soil to a depth of 4 m.

A general conclusion concerning the absence of percolation to the underground water cannot be made based on these data alone. A percolation envelope with moisture content up to 11.2% by volume existed in the open-bottom lysimeter with a maximum peak at depth of 5.5 m. Downward movement of the percolation envelope continued through autumn of 1974 at a rate of about 20 cm per month in the open-bottom lysimeter and will be studied in greater detail during the following months.

SUMMARY OF ANNUAL BEHAVIOR OF METEORIC WATER IN OPEN-BOTTOM LYSIMETER

The annual behavior of meteoric water in the open-bottom lysimeter differed from that in the closed-bottom lysimeter in that the percolation envelope did not disappear by October 14, 1974. For purpose of comparison, the soil moisture profiles of the open-bottom lysimeter are shown in Figures 22 through 30. These profiles may be compared with those for the closed-bottom lysimeter shown in Figures 14 through 21.

The soil moisture profile for the open-bottom lysimeter as of September 6, 1973, just after the beginning of the 1973-1974 water year, is shown in Figure 22. The curve dif-siderably from that for the closed-bottom lysimeter for this date in that a significant percolation envelope already existed with a moisture content greater than 6% by volume. This is believed to be the result of residual moisture accumulated in the backfill of this lysimeter. Note further that the partly desiccated zone existed only to a depth of about 1 m as compared with 2.5 m for the closed-bottom lysimeter. Moisture content greater than 6.5% existed from a depth of 1.7 to 10.7 m as listed in Table I.

Heavy precipitation during autumn of 1973 wiped out the shallow, partly desiccated zone near the surface. The new percolation front merged with the residual moisture envelope and by October 1973 produced a percolation envelope with a moisture content in excess of 13% by volume. By January 24, 1974, the peak of this envelope increased to 13.75% and descended to a depth of 1.7 m as listed in Table II and plotted in Figure 23. Down to a depth of 1.7 m the moisture content in both lysimeters was essentially the same. However at a depth of 2.7 m, the moisture content in the open-bottom lysimeter was about twice that in the closed-bottom lysimeter--12.4% as compared with 6.85% from Table II. As of February 5, 1974, and thereafter the maximum moisture content in the percolation envelope was at a lower depth in the open-bottom lysimeter than in the closed-bottom lysimeter as shown in Table III and Figure 24. It was about 13% by volume and had percolated to a depth of 2.72 m in the open-bottom lysimeter. During the spring of 1974 this front continued to move downward slowly. By June 24, 1974, the peak of 12.8% had reached a depth of 4.85 m as indicated in Table IV and Figure 25. The percolation envelope then reached its maximum thickness of about 5 m and was quite asymmetrical in late June (see Figure 25). The asymmetry is believed to be caused by drainage and liquid two-phase flow downward which bends the distribution curve downward. The hot weather during July and August removed moisture primarily from the top of the percolation envelope as indicated by Table V and Figure 26 for measurements made August 7, 1974. The thickness of the percolation envelope decreased from 5 to 4 m between June and August 1974.

By September, and the end of the water year, a percolation envelope of about 3-m thickness still existed between the 3.6- and 6.6-m depths as shown in Table VI and Figure 27. This envelope had a peak moisture content of about 11.6% at the 5.5-m depth. In spite of the lack of significant rain during October 1974, the percolation envelope was not eliminated by mid-October as in the case of the closed-bottom lysimeter. The envelope had a thickness of about 2.5 m as of October 14, 1974, as shown in Figure 28 (see Table VIII) with a peak of 11.2% at 5.5 m. Note that the envelope is much more symmetrical than in June. This is considered to be the result of removal of about half of the upper part of the percolation envelope. Further, this is believed to indicate upward transport of water from the 5.5-m depth during summer and autumn. The soil above the 4-m depth becomes partly desiccated with less than 6% water by volume. The change in slope of the moisture profile curves is shown in both Figures 27 and 28 with the break in slope at about 5.7% moisture in both and at 3.5-m depth in Figure 27 and 4.0-m depth in Figure 28. The change in depth is considered to show the progress in partial desiccation from September to October 1974. The depth of the partly desiccated zone remained at about 4 m into November as shown in Figure 29 (see Table XI for data). This is considered to be indicative of the cooling trend in late autumn and the termination of the period of rapid upward transport of water that occurs at the end of summer at the lysimeter site.

A comparison of the soil moisture profiles of the open-bottom lysimeter for June 24 and November 14, 1974, is shown in Figure 30. During the first five months of this period the percolation envelope decreased to less than half its volume and moved downward 0.5 m or about 12 cm per month. There was little percolation movement after October 14, 1974, as may be observed by comparison of Figures 28 and 30. During the six-month period two opposing temperature-related driving forces acted on the percolation envelope in addition to the gravitational force responsible for percolation. These were the moisture gradient driving upward and the temperature gradient driving downward. Water removed during the shrinkage of the percolation envelope is considered to be removed primarily by upward transport because of the change in the upper profile of the envelope. By material balance this indicates that the moisture gradient driving force upward is significantly greater than the combination of moisture gradient downward, temperature gradient downward, and gravity. The soil water potential in negative bars versus soil moisture in volume percent is shown in Figure 31. Note that water at the November 14 peak has a moisture content of 11.5% and can move either upward toward a moisture content of 5.4% or downward toward a moisture content of 6.8%. The difference in terms of moisture content is not great but in terms of water potential there is a major difference favoring upward transport. Note that the driving force upward is (15 - 0.002) or 14.998 bars and that downward is (1.0 - 0.002) or 0.998 bar. In comparison, the gravitational potential at 20° C is only 0.098 bar per meter. The upward two-phase flow zone is from 5.5- up to the 3.5-m depth. Thus the net upward potential (isothermal) is [(14.998 - 2(0.098)] or 14.802 bars. The downward gravitational force operates on the water in the envelope from 5.5- down to the 6.5-m depth. The net downward isothermal potential is [0.998 + 1.0(0.098)] = 1.096 bars. Thus the ratio of the isothermal upward force to the isothermal downward force is:

$$\frac{14.802 \text{ bars}}{1.096 \text{ bars}} \text{ or } 13.51.$$

A moisture transport depth-time phase diagram is shown in Figure 32. The purpose of the Figure is to provide an overall concept of the direction and magnitude of the thermal driving force as a function of time and depth. Table X lists the relative values in Figure 32 and their corresponding thermal driving force.

The temperature wave from the past summer's heat moves

TABLE X

VALUES SHOWN IN FIGURE 32 AND CORRESPONDING DRIVING FORCE

Number	Thermal Driving Force °C/Meter
9	6.0 (upward)
8	2.0
7	1.4
6	1.0
5	0.6
4	0.2
3	0.12
2	0.06
1	0.02
0	-
-1	-0.02 (downward)
-2	-0.06
-3	-0.12
-4	-0.2
-5	-0.6
-6	-1.0
-7	-1.4
-8	-2.0
-9	-6.0

Depth variations were chosen to be 0.25 meters and the time increments were four per month. The magnitudes of the driving force were determined by calculating the temperatures at 0.25 meters above and below the selected depth.

downward in November at depths of 3 to 9 meters as indicated in Figure 32. Water tends to be transported from a zone of higher to a zone of lower temperature. As a result there is a small temperature gradient driving force downward. This decreases the ratio of 13.6 slightly but not significantly.

DISCUSSION OF LYSIMETER EXPERIMENT

The behavior of the meteoric precipition percolating into both the closed-bottom and open-bottom lysimeters has been reviewed for the 1973-1974 water year. The behavior was different in the two lysimeters--not because one was closed at the bottom and the other open, but rather because the open-bottom unit had a residual envelope of water from the previous year whereas the closed-bottom unit did not.

The moisture content of the soil and its distribution at the beginning of the water year had a pronounced influence on the disposition of the precipitation during the water year. If the top 2.5 m of soil are partly desiccated at the beginning of the water year, the onset of percolation to a lower depth will be delayed. This was demonstrated in the closed-bottom lysimeter review earlier in this report. Here, although the precipitation for the 1973-1974 water year was 158% of normal, the percolation front penetrated to a depth of only 4 m and then was removed by evaporation at the surface. If the soil is partly desiccated to a depth of only about 1 m and if the soil below has a residual envelope of moisture from previous history that has a moisture content signficantly greater than that of the residual saturation, percolation of the precipitation will be favored as demonstrated by the open-bottom lysimeter. Here the partly desiccated zone was eliminated by October and the new envelope of percolation joined the residual envelope by January with a front peaking at about 2-m depth and about 14% peak moisture content. This percolation front moved slowly down to a depth of about 6 m by June 1974. The residual envelope of moisture apparently had two major effects. First, it tended to eliminate the delaying action of the partly desiccated zone left from last summer. Second, the high moisture content in the envelope raises the relative permeability of the soil to the wetting-phase, water. This permits penetration of the percolation to a depth of 6 m for the open-bottom lysimeter during the 1973-1974 water year.

What will become of this residual envelope of higher moisture? This is one of the principal questions remaining to be answered. If a succession of wet years follow, this envelope of higher moisture can be anticipated to increase in volume through combination with the new percolation envelope and move to a greater depth. However if a succession of normal or dryer-than-normal years follow, the volume of the envelope should shrink at the end of each summer until it eventually disappears. The time required for either outcome will depend upon the relative volume of the initial envelope, the magnitude of the annual precipitation, and the duration of hot, dry periods causing partial desiccation. With known values of these variables from previous records, and known characteristics for the soil such as porosity, permeability, residual saturation, diffusivity, etc., the anticipated change in the position and size of an envelope of higher moisture should be predictable using computer calculations for the case of unstratified soil. After this has been accomplished, the program may be modified to include the added variable of stratification.

THE THERMOCOUPLE PSYCHROMETER EXPERIMENT

According to the first law of thermodynamics, water will migrate from a site of higher water potential to a site of lower water potential. Under isothermal conditions the water potential gradient determines both the direction and magnitude of forces causing such migration. If the water potential profile is determined for a soil site from the surface to the underground water, the potential gradient and therefore the direction of moisture movement can be determined at any depth.[6]

The water potential as measured by thermocouple psychrometers is defined as the difference between the free energy of pure, free water and the free energy of the water in the system studied, at the same temperature and pressure. Two assumptions usually are made in using a thermocouple psychrometer: (1) water vapor and liquid water are in equilibrium, and (2) water vapor behaves as an ideal gas. The derivation of water potential relationships based on relative humidity assumes that the vapor pressure of the soil water varies with the temperature only according to the ideal gas law. This is recognized as an approximation. The temperature of the soil at the site varies both with the depth (as a result of the geothermal gradient), and with the season (because of the sinusoidal temperature vacillations between summer and winter in the seasonal zone). Personnel of Battelle Pacific Northwest Laboratories used Equation 1 to obtain an approximate correction in matric potential for temperature.[6]

$$\frac{(P_2 - P_1)}{0.47} \frac{40}{T+20} = \psi \tag{1}$$

where ψ = matric potential, negative bars

T = temperature at the psychrometer, °C

P_1 = the first voltage measurement prior to cooling

P_2 = the voltage measurement after cooling.

Equation 1 was used to correct the matric potential, ψ, for the geothermal gradient given by Equation 2 for the depths between 7.5 and 93 meters. Equation 2 is based upon a least square fit to data for temperature measurements at the 32-49D site.[6]

$$T = 16.986 + (0.0572)D \quad (2)$$

where T = temperature at any depth D*, °C

D = depth below surface, meters.

MATRIC POTENTIAL GRADIENT AND THE PARTLY DESICCATED ZONE

The average monthly matric potential for the 32-49D site is shown from September 1973 through September 1974 in Figures 33 through 45. All the profiles can be divided into three zones: the seasonal zone from the surface to a depth of about 4 m, the partly desiccated zone from a depth of about 5 to 18 m, and the upward gradient zone from about 24 to 93 m. These three zones are apparent in all 12 figures.

THE LOWER ZONE

For easier discussion the lower zone will be considered first. Inspection of Figures 33 through 45 shows a gradual gradient upward in the matric potential from the 93- to 24-m depths. At the lower depth the matric potential is less than one negative bar, averaging about -0.3 to -0.5 bars. At the 24-m depth the average matric potential is about -2.0 bars. Thus there is a gradient favoring upward transport of about -1.6 bars per 70 m. The upward gradient is the summation of three major driving forces: (1) the downward gravitational force, (2) the upward concentration gradient resulting from saturation at the water table and partial desiccation in the 5- to 18-m depth-zone, and (3) the geothermal gradient upward of 4.7° C for a 93-m depth. The net

*At depths from 7.5 meters to the surface, the temperature is influenced by the season and the climate. In this depth range the observed temperature at the time and location was used in Equation 1 to correct the matric potential for temperature.

sum of these three forces is upward, favoring water transport from the water table to the partly desiccated zone.

Richards has reported[7] on the equilibrium suction profile beneath a structure (road) in the arid areas of Australia as shown in Figure 46 (his Figure 6). This Figure shows water moving upward from a a deep water table in the liquid phase with a water potential of about -10 bars below the partly desiccated zone and a water potential of more than -100 bars in the desiccated zone. These water potentials are significantly less than those shown in Figures 33 through 45 but are computed values rather than measured values. The upward transport of water in the liquid phase is considered to terminate at the lower limit of the desiccated zone. This occurs at a depth of only 4.27 m (14') in the clay soil reported by Richards but occurs at a greater depth of about 18 m at the 32-49D site.

THE PARTLY DESICCATED ZONE

The partly desiccated zone appears to be the key to the upward transport of water and to the inhibition of percolation of meteoric water from the surface to the water table in arid and semi-arid vadose zones. This partly desiccated zone is believed to have developed over a period of many years, possibly centuries, and appears to be a feature of arid and semi-arid sites previously overlooked or not fully appreciated. This zone is an important feature with regard to the management of radioactive waste on arid and semi-arid sites. The partly desiccated zone can be eliminated as a result of dumping process water or irrigation water on the surface. However if this is avoided the partly desiccated zone behaves like a sponge; it soaks up and holds water or solutions that commence to percolate downward from the surface. Summer heat with partial desiccation of the soil down to 4 m as reported in "The Lysimeter Experiment" tends to eliminate water and solutions from small spills. Virgin soil in the 32-49 Hanford coordinates must receive excess water sufficient to percolate to a depth of 18 to 24 meters before it is free to percolate to the water table. The upward slope of the water potential gradient is only about 0.0225 bar per meter in the lower zone (93 to 24 m) but is much greater in the partly desiccated zone. In Figure 33 the matric potential at 18-m depth is -4.0 bars. This drops to -7.0 bars at 15-m depth giving a gradient of -3.0 bars/ 3 m or -1.0 bar per meter or about 45-fold greater than the slope in the lower zone. Water cannot migrate from a depth of 18 m downward with this opposing potential. Instead, it must migrate from a depth of 15 m upward, possibly to a depth of 10.5 m where the potential has dropped to about -8.2 bars.

The subsurface matric potential shown in Figure 33 is most negative at the 10.1-m depth and water will tend to migrate to this depth from below and from above. However near the surface at the uppermost measurement the matric potential was about -11.5 bars during September 1973. It is this low because the desiccation during the hot month of August 1973 caused the surface to become very dry. Plots of data for August 1974 are shown in Figure 44. Note that in August 1974 the percolation front had reached a depth of 4.5 m.

THEORY FOR PARTLY DESICCATED ZONE DEVELOPMENT FROM PERIODIC DRY SEASONS

The presence of the partly desiccated zone at depths of 6 to 18 m is one of the more significant factors in soil moisture phenomena in the vadose zone above deep water tables of the 200 Areas plateau on the Hanford Reservation. The steps leading to the development of this phenomenon are important. A number of mechanisms are recognized that are capable of contributing to the removal of water from this zone as shown in Figure 47. In this Figure the diurnal cycle and the annual cycle have been indicated as influencing the temperature, moisture content, and water potential. The diurnal cycle of 24 hours has an influence down into the soil to a distance measured in centimeters.

The annual cycle has an influence at the 32-49 coordinate site down to a depth of about 6 m maximum and probably to a depth of only 2 to 4 m for a normal or drier than normal year. But Figures 33 through 44 indicate a partly desiccated zone to a depth of 18 m, 3 to 9 times the depth of the influence of the annual cycle. One possible prediction from this observation is that there is a periodic dry cycle occurring every 3 to 9 years that influences the partly desiccated zone.

The water potential profile at the 32-49D site shown in Figure 48 for September 1972 developed from the rather dry 1971-1972 water year. Above the 18-m depth the water potential is -4.5 bars or less. It is about -6.2 bars at the 15-m depth. In this dry zone the maximum water potential of -4.5 bars occurs at a depth of about 4 m, the maximum depth of percolation for the 1971-1972 water year. If this water year has been a little drier and hotter, this residue of the annual percolation front might have disappeared altogether; producing a profile similar to that indicated by dashed line in Figure 48. This profile as indicated by the dashed line slopes continuously upward to the right from the 15-m depth to the surface. This is the condition required for upward transport of water from the 15-m depth to the surface. Such transport tends to increase the degree of desiccation in the partly desiccated zone and is one of the possible mechanisms for creation of the zone. Another mechanism yet to be studied is the "barometric pressure-induced air flow," also termed "soil breathing," resulting from changes in barometric pressure and ingress of relatively dry air from the atmosphere followed by egress of nearly saturated air from the soil. A preliminary computation was made based on annual average temperature and humidities for the atmospheric air and air in the soil voids. This computation was based on 30 major pressure cycles per year reaching to an estimated depth of 4.5 m. The computation showed a loss of only 128 grams of water per year per lysimeter. This estimate of loss is considered to be low because of the closeness of the annual average air and soil temperatures (12.2° C for air and 15° C for soil.). Studies with the lysimeters indicate that the major portion of the water evaporated from the percolation front is removed during July, August, and early September when the temperature and humidity differences between the atmospheric air and the soil are are much greater. The depth of soil breathing must be measured with pressure tubing installed in the lysimeters and which must yet be connected to suitable instrumentation. The instrumentation has been specified but is not yet available.

Another mode of transport of water upward is by thermal gradients. Annual sinusoidal-shaped waves describe the temperature versus time curves for each depth in the upper 10 m of soil at which measurements are made. These sinusoidal waves were identified and described by equations in the previons report on "Soil Moisture Transport in Arid Site Vadose Zones, I".[1] The curves for the 2.7- and 4.0- m depths are reproduced here in Figure 49. During July, August, September, and October the thermal driving force is downward because the temperature at the upper (2.7 m) horizon is greater than the temperature at the lower (4.0 m) horizon. During this period the soil in this region is partly desiccated and there is little moisture to be moved downward by the thermal driving force. During winter and early spring the direction of the thermal driving force reverses and is upward. This tends to prevent moisture from autumn and winter precipitation from percolation downward and may move some moisture from the 4-m depth upward.

The sinusoidal oscillation of the temperature at each depth creates a parametric pump tending to "yo-yo" moisture up and down in the top 6 m of soil. However because there is little moisture in the upper zone during the summer months this pump tends to move water in one direction only. This direction is upward and effective transport occurs only during the winter months. Therefore this mechanism cannot explain the rapid upward transport during July, August, and September, as shown in Reference 1, for desiccation down to 4-m depth in the closed-bottom lysimeter. By elimination, the mechanism most likely to account for this desiccation must be the concentration difference in moisture content from the 4.5- to the 3.5-m depths.

CHANGES IN MATRIC POTENTIAL WITH TIME

In the deep well experiment, from early 1971 until the summer of 1974 water (matric) potential has been measured as a function of time. Values for 18-, 63- and 93-m depths for the 1971-1972 water year are shown in Figure 50 as a function of time. The 93-m depth is near the water table and the matric potential was -0.75 bars in September 1971. At the 63-m depth on this date the water potential was more negative with a value of -1.50 bars. The value at the 18-m depth on his date was also more negative at -1.78 bars. By the end of the water year in September 1972 these values were -0.20, -1.70, and -2.13 bars, respectively. At the end of the following water year in September 1973 the respective values were -0.20, -1.70, and -4.0 bars as shown in Figure 51. Comparison indicates that the water potentials were approaching constant values at the two lower depths of 93 and 63 m but the soil was becoming drier at the 18-m depth as indicated by the more negative water potential. During the next year there was little change in these values as shown in Figure 52. The 18-m depth is near the bottom of the partly desiccated zone as indicated in the earlier figures. Apparently the soil returned to the well pipe at the time of sensor installation was not in equilibrium with the *in situ* soil at the 18-m depth and about two years were required for equilibration.

Values for three successive years and depths of 78, 42, and 6 m are shown in Figures 53, 54, and 55. The 6-m depth is near the top of the partly desiccated zone. The water potential at this depth was -5.5 bars in September 1971, decreased to -6.3 bars in September 1972, to -7.5 bars in September 1973, and was -6.3 bars in 1974. At the last measurement in June 1974 the two lower depths had approached nearly constant values of -0.90 and -1.70 bars as shown in Figure 55. Measurements made at depths closer to the surface show the effects of seasonal vacillations as indicated in Figures 56 to 59. The first three of these figures are for three successive years for the 72-, 36-, and 3-m depths. The 3-m depth is in the seasonal zone as indicated in Figure 56 by the drop in water potential from about -0.7 bar in June 1972 to -7.5 bars in August 1972. The 36-m depth is near the partly desiccated zone as indicated in Figure 56 by the more negative water potential of -4.62 bars in September

1971. The 72-m depth is below the partly desiccated zone with a water potential of about -1.5 bars. The seasonal vacillation in the water potential is more apparent for the 3-m depth for the 1972-1973 water year as shown in Figure 57. The soil was quite dry in September and October 1972, and reached a water year minimum water potential of -9.2 bars. During the spring of 1973 the water potential rose to about -0.8 bar in March 1973 and held at this value until July 1973. The soil at this 3-m depth became increasingly drier during July, August, and September 1973 as indicated by the increasing negativeness of the water potential reaching -4.37 bars in September 1973. The sensor at the 36-m depth failed in March 1973 at a water potential of -5.2 bars.

The 1973-1974 water year was wetter than the previous year with greater precipitation during autumn and the end of the calendar year. The results are shown in Figure 58 for the 3- and 72-m depths and the 1973-1974 water year. Note that the water potential rose continually from September 1973 to January 1974. Percolation to 3 m and below probably occurred during January, February, and March 1974. The curve begins to reverse its direction beginning with April 1974. The water potential at the 3-m depth never rose to zero but approaches a maximum of about -0.3 bar in March 1974. A similar but more symmetrical vacillation is shown in Figure 59 for the 1.5-m depth for the 1972-1973 water year. The curve peaks to the right at -9.3 bars for October 1972. It reaches zero bars in March 1973 which is its peak to the left. Percolation probably occurred here and the moisture content was higher than at any other time but saturation was not complete. The water potential may rise to zero at moisture contents less than saturation. Both the 27-m and the 69-m depths are below the partly desiccated zone and the water potential curves for these depths hold quite constant at -2.0 bars for the upper depth and -1.5 bars for the lower depth. In addition to Figures 50 through 59 showing the change in matric potential with time since September 1971 there are 17 figures (60 through 76) for 51 additional depths showing similar data.

THE 1.52-METER DEPTH MEASUREMENTS

TEMPERATURE SINUSOIDAL CURVES

At the 32-49 Hanford site, instruments were installed by personnel from Battelle Pacific Northwest Laboratories to a depth of 1.52 m (5') to supplement the instrumentation in the 94-m (310') site reaching to the water table. Temperature sensors were of the diode-type with good calibration. These were installed at 0.076-, 0.152-, 0.229-, 0.305-, 0.38-, 0.46-, 0.61-, 0.76-, 0.92-, 1.07-, 1.22-, 1.37-, and 1.52-meter (3-, 6-, 9-, 12-, 15-, 18-, 24-, 30-, 36-, 42-, 48-, 54-, and 60-inch) depths. Temperature data at these depths were plotted on computer printout as a function of time as shown in Figures 77 through 85 for the 1971-1972, 1972-1973, and 1973-1974 water years. The sinusoidal shape of the curves is particularly apparent in Figure 79 for the 1973-1974 water year and 36- to 60-inch depths. The curves for the individual depths of 0.91, 1.07, 1.22, 1.37, and 1.52 meters (36, 42, 48, 54, and 60 inches) crossed about the first week in October 1973 and again about the first week in April 1974. These crossings are considered to be indicative of reversal of the thermal driving force that influences water transport in the vadose zone. During the 1971-1972 and 1973-1974 water years the spring cross-over dates occurred about one week earlier than in 1974, causing a slight upward deviation from a perfect sinusoidal shape as shown in Figures 77 and 78.

At the depth range of 0.91 to 1.52 meters (36 to 60 inches) the maximum temperature gradient between measurement horizons occurs during the peaking and bottoming of the sinusoidal curves. Although this varies slightly from year to year, the maximum usually occurs about the third week in August and the minimum about the first week in February. The gradient at these times averages about 0.23° C per centimeter of depth.

TEMPERATURE PROFILES

Profiles of the temperature as a function of depth and time are shown in Figures 86 through 121 for consecutive months since August 1971. These data are to be used later for improvement of the relationships such as equations used to describe the temperature-time-depth system at the 32-49 coordinate site.

The temperature profiles oscillate from left to right with the change in date because of seasonal and climatic temperature changes. During the month of March the temperature profiles are nearly vertical because the warming spring temperatures counteract the previous cold gradient developed during the winter months. An example of a nearly vertical temperature profile is illustrated in Figure 105 which shows temperature profiles to the 1.52-m depth at 32-49 Hanford coordinates for March 1973. The parameters are the date of measurement. Temperatures go from a low of about 7° C on March 2, 1973, to a high of about 11° C on March 30, 1973, in nearly parallel vertical lines. This corresponds to an average temperature rise of about 4° C per 28 days, or 0.143° C/day.

The steepest slope for temperature gradient upward occurs in July as exemplified by Figure 109 which shows the temperature profiles to the 1.52-meter depth at 32-49 Hanford coordinates for July 1973. On July 3, 1973, the temperature increased nearly in a linear manner from 20.2° C at the 1.52-m depth to 26.5° C at the 0.254-m depth or at a gradient of about 5.0° C/meter (1.51° C/ft). The temperature increased 1° C in 10 days at the 1.52-m depth and 1.8° C in 10 days at the 0.254-m depth. In both 1971 and 1973 the temperature at the 1.52-m depth reached a maximum of 24.5° C near the end of August as shown in Figures 86 and 110.

In mid-September the temperature profiles again became nearly vertical at depths from 0.5-m (20") to 1.52-m (60") as shown in Figures 87 and 99. This represents the autumn crossing of the sinusoidal temperature versus time curves as shown in Figures 77 to 79 for 1971 through 1973. Between the dates of September 7, 1971, and September 17, 1971, at the 1.52-m depth the temperature decreased about 1° C over the 10-day period or about 0.1° C per day as shown in Figure 87; whereas in 1972 for a similar time period and depth there was little change in temperature.

The temperature profiles slope with a maximum decrease in temperature in January as is shown in Figures 91, 103, and 115 for January in 1972, 1973, and 1974, respectively. In 1972 the temperature at the 1.52-m depth dropped from about 9° C (in mid-January) to about 0° C at a depth of 0.23 m (9"). In 1973 the temperature at the 1.52-m depth was about the same as in 1972 (about 9° C) for the 1.52-m depth but the 0° C depth dropped to about 0.44 m (17.5") on January 12, 1973. The 1974 January was warmer than during the two previous years and the 0° C range is shown only for January 7, 1974, at a depth of 0.20 to 0.25 m.

MATRIC POTENTIAL SINUSOIDAL CURVES

The 1.52-m depth site at 32-49 coordinates is equipped with thermocouple pyschrometer sensors at the same depths as the temperature sensors. As with the data on temperature, the measurements on matric potential are plotted as a function of time and depth in Figures 122 through 130 for 1971-1972, 1972-1973, and 1973-1974 water years.

At depths from 0.91 to 1.52 m all sensors indicated a water potential of only a few negative bars, zero or close to zero, from September 1971 until June 1972 as shown in Figure 122. During June and July 1972 the water potential at all depths between 0.91 and 1.52 m dropped to a matric potential of -15 to -18 bars, indicating a significant desiccation of the upper 1.52 m of soil during this period.

By September 1972 the matric potential rose to about -10 to -15 bars, the lowest for the 1972-1973 water year for this depth range, as shown in Figure 123. By the end of January 1973 the water potential for this depth range had risen to less than one negative bar and remained close to zero until the end of April 1973. During the next three months the matric potential dropped to about -5 to -8 bars as a result of summer desiccation but never reached as low values in the late summer as reached in late summers of 1972 or 1974 (Figures 122 and 124). The Figures show an approximate sinusoidal shape similar to the temperature versus time curves but with much greater variation from the average sinusoidal shape.

Matric potential values for the 0.305- to 0.76-m (12 to 30") depth range and for the same three water years are shown in Figures 125 to 127. At this closer-to-the-surface depth range, the data tend to be divided into two ranges of matric potential: (1) values near zero during the winter months, November through May; and (2) values more negative from -8 to -30 or less bars during the summer months, June through September. Measurements nearest the surface, 0.229- to 0.076-m depths, follow this pattern to even a greater extent as shown in Figures 128 to 130. In this near-surface zone the soil is either involved in percolation with the matric potential near zero during the winter months, or is partly desiccated with a negative water potential during the summer months.

MATRIC POTENTIAL PROFILES

As with the temperature data, the profiles of the matric potential values were plotted versus depths and date of measurement as shown in Figures 131 through 167. During the winter and early spring months percolation occurs and usually extends to a depth greater than 1.52 m. As a result, during the winter months the matric potential profile usually is close to zero or shows a water potential of only a few negative bars as shown in Figure 136 for December 1971. The more negative potential at 0.305-m (12") depth is considered to be a malfunction of the sensor at the depth as this sensor repeatedly shows a discrepancy with other sensors in measurements made on other dates. In May the evaporation from the surface reduced the moisture content and caused the matric potential to drop to a more negative value. This is exemplified in Figure 141 for May 1972. From the early part of the month, May 2, to May 26 the matric potential at depths below 0.38 m (15") held at about -1 to -5 bars. Four days later, on May 30, the matric potential dropped to -5 to -25 bars over the depth range as a result of warmer and drier conditions with the approach of June. After June 2 through June 30, 1972, the matric potential for the lower 0.75 of the 1.52-m depth site dropped an additional -5 or more negative bars as shown in Figure 142. A drop of another -5 or more bars for the lower 0.75 of the 1.52-m depth site continued during July 1972 as shown in Figure 143. In 1972, by August the trend in change in matric potential had reversed and the matric potential was increasing by about -5 to -10 bars during the month as shown by Figure 144.

The trend of rising matric potential below 25 cm continued during September and October, 1972; and is shown in Figures 145 and 146. The lower half of the matric potential profile is essentially a series of vertical lines with increasing matric potential with time. The temperature profiles follow the same pattern, a series of vertical lines, moving to the left to lower temperatures with time.

Values in the very dry zone of the upper 25 cm (Figures 142 through 146) are extremely erratic because, with very dry soil and the wet junction readout procedure, the duration of the signal for the wet junction plateau is too short to be read by the instrument used. As a result the readout may show incorrect values between zero and -30 bars and should be ignored. Use of the dew-point junction procedure should give significant values in such dry soil. This procedure will be used in the instrumentation planned for the lysimeter instrument room.

The flatter slope in matric potential shown in Figure 141 between 30.50 and 15.25 cm (12 to 6"), in Figure 143 between 71.1 and 40.6 cm (28 to 16"), and in Figure 144 between 91.4 and 76.2 cm (36 and 30") is believed to be due in part to the upward transport and concentration of dissolved salts in the soil water and the resulting increase in the osmotic potential. The water evaporates from below the soil surface at the terminus of the liquid water transport zone. Here the remaining soil water becomes more concentrated in dissolved salts which precipitate out.

Thus, concentrated solutions of precipitating soil salts exist during the upward transport of soil water at the end of a hot, dry summer. Under these conditions the osmotic effect on water potential can become significant.

Compared with 1972 and 1974, the summer of 1973 was much cooler and wetter. For example, in the lower 1.2 m of the 1.52-m depth site the matric potential did not drop lower than -10 bars during July and August of 1973 (Figures 155 and 156). Because of this, the data for the summer of 1974 are of greater interest than the data for 1973.

The 1973-1974 year began in September 1973 with early and greater-than-average precipitation but ended with the hot, dry summer of 1974. As a result, the matric potential values for the summer of 1974 are of special interest. Desiccation of the top 1.52 m of soil began as early as May 1974 as shown in Figure 165. The matric potential at 1-m depth (39.37") was about -4.5 bars as of May 24 and dropped to about -8 bars by May 28 and to -10 bars by May 31, 1974. Thus the 1973-1974 desiccation front was below the 1.52-m depth in May 1974. The slopes of the matric potential curves are nearly identical for these three dates and correspond to a potential gradient of about 7 bars per meter. This is about 70 times the gravitational gradient downward of 0.098 bars per meter and is the chief reason for the transport of water to the surface rather than continuance of downward percolation. As may be observed in Figure 166 for June of 1974, the potential gradient increased to about -18 bars per meter at depths between 1.52 and 0.25 m and all values were -10 to -30 bars or less. At depths of 0.25 m and above the matric potential was -30 bars or less. [Any value less than -30 is printed as -30 bars.] The sensor at a depth of 0.305 m (12") is considered to be defective and should be ignored. In July of 1974 only one series of measurements was made--on July 2. The gradient is less, being about -14 bars per meter, and the values below 0.25 m range from -13 to -30 bars as shown in Figure 167.

DISCUSSION

Water potential is influenced by dissolved solids such as salts in the soil water. The total water potential equals the matric potential plus osmotic potential. B. G. Richards of Australia[7] gives some examples of the influence of concentration of total soluble salts on water potential for soils with different moisture contents. In one of his examples, a soil with 5 wt% soil moisture and 0.02 wt% total soluble salts gave an osmotic suction of 3.16×10^3 cm H_2O (about -3 bars). If the dissolved salt is increased four-fold to 0.08 wt%, the osmotic potential also is increased four-fold to 12.64×10^3 cm H_2O (about -12.6 bars). Richards points out that if the osmotic suction completely dominates, the mean atmospheric humidity controls the total suction with approximately zero matric potential component. As a result, it is possible to have, in arid areas, soils fully saturated without the presence of a water table near the surface. In the less extreme case, the osmotic suction may appreciably depress the matric suction with an increase in the moisture content.

SUMMARY

Measurements for the Lysimeter Experiment and the Thermocouple Psychrometer Experiment have been continued. A new series of measurements have been made on closely spaced sensors in a 1.52-meter depth installation at 32-49 Hanford coordinates.

In the closed-bottom lysimeter during the 1973-1974 water year, meteoric precipitation percolated to a depth of about 4 meters and then the envelope of higher moisture was dissipated by upward transport of moisture and evaporation during the hot, dry autumn of 1974. In the open-bottom lysimeter a residual envelope of higher moisture content from the 1972-1973 water year caused the precipitation for the 1973-1974 water year to percolate to a depth of about 6 meters.

The greater depth of percolation plus the greater moisture content in the envelope of higher moisture in the open-bottom lysimeter resulted in a residual envelope of "perched" water at a depth of 4 to 7 meters below the surface. An unanswered question for the 1974-1975 water year is whether or not the new envelope of percolation will overtake the perched envelope, combine with it, and move down to a greater depth.

If the 1974-1975 percolation does not overtake the perched envelope another question to be answered is whether or not a portion of the perched envelope will move upward during the summer period of partial desiccation.

In the thermocouple psychrometer experiment the sensors have nearly equilibrated with the surrounding soil at each depth in the back-filled 32-49D well. A partly desiccated zone is observed to exist below the seasonal zone down to a

depth of about 18 meters. This zone has a higher negative matric potential, about -10 bars with a gradient upward in the range of -1 bar per meter. The gravitational gradient is 0.098 bars per meter downward and is insufficient to overcome this strong upward gradient. Thus this partly desiccated zone can act as a barrier to percolation of meteoric precipitation from the surface to the water table.

Measurements were made every 7.6 to 15.2 centimeters (3 to 6") every two to four days at the 32-49D coordinate site for a period of two water years, 1972-1973 and 1973-1974. These data will permit a better definition of the temperature and matric potential relationships with time, depth, season, and climatic variations.

CONCLUSIONS

This report contains the soil moisture data obtained from early 1971 until September 1974 for both the lysimeter experiment and the thermocouple psychrometer experiment. Possible mechanisms involved in the process of moisture transport in arid and semi-arid climates are being studied. The results obtained confirm earlier concepts of the authors regarding the advantages of Hanford as a site for a national repository for radioactive waste.

The justification in favoring Hanford as a waste repository site is based on the unique features of the dry Hanford soils which have been previously overlooked by various advisory committees. The Hanford Reservation is on a semi-arid (desert) site with a high solar heat input. This results in the development of a partly desiccated zone in the Hanford soil, which prevents the percolation of meteoric water down to the water table at sites high above the water table and free of ponding of surface runoff.

The problem of long-term storage of radioactive wastes and the analysis of feasible solutions are based on one governing focal point: the prevention of dispersal of radioactive material in natural water supplies; *i.e.*, ground water, water courses, and the oceans. Should interaction occur between the radioactive waste and any large body of water, the process is in practice irreversible and it is impossible to regain control of the radioactive substances dissolved or suspended in the water.

The basic criterion of maintaining a separation between radionuclides and natural water supplies indicates the advantage of storage above the water table in the partly desiccated vadose zone of an area where percolation to the water table does not exist. The nature of the Hanford soil complies with this requirement by blocking the percolation of water down to the water table. The opinion of the former NAS-NRC Advisory Committee that Hanford might not be suitable as a site for a national repository for radioactive waste is believed to be incorrect if the points presented in this report are considered and if the present understanding of the Hanford site is correct. Taken in this light, Hanford should be reconsidered and possibly preferred as probably one of the best sites in the Country for a national repository.

ACKNOWLEDGMENTS

The authors are indebted to many members of Battelle Pacific Northwest Laboratories' Water and Land Resources Department for measurements made for the Thermocouple Psychrometer Experiment and 1.52-Meter Depth Measurements sections of this report. Messrs. A. E. Reisenauer, J.J.C. Hsieh, and H. H. Hoober were especially helpful.

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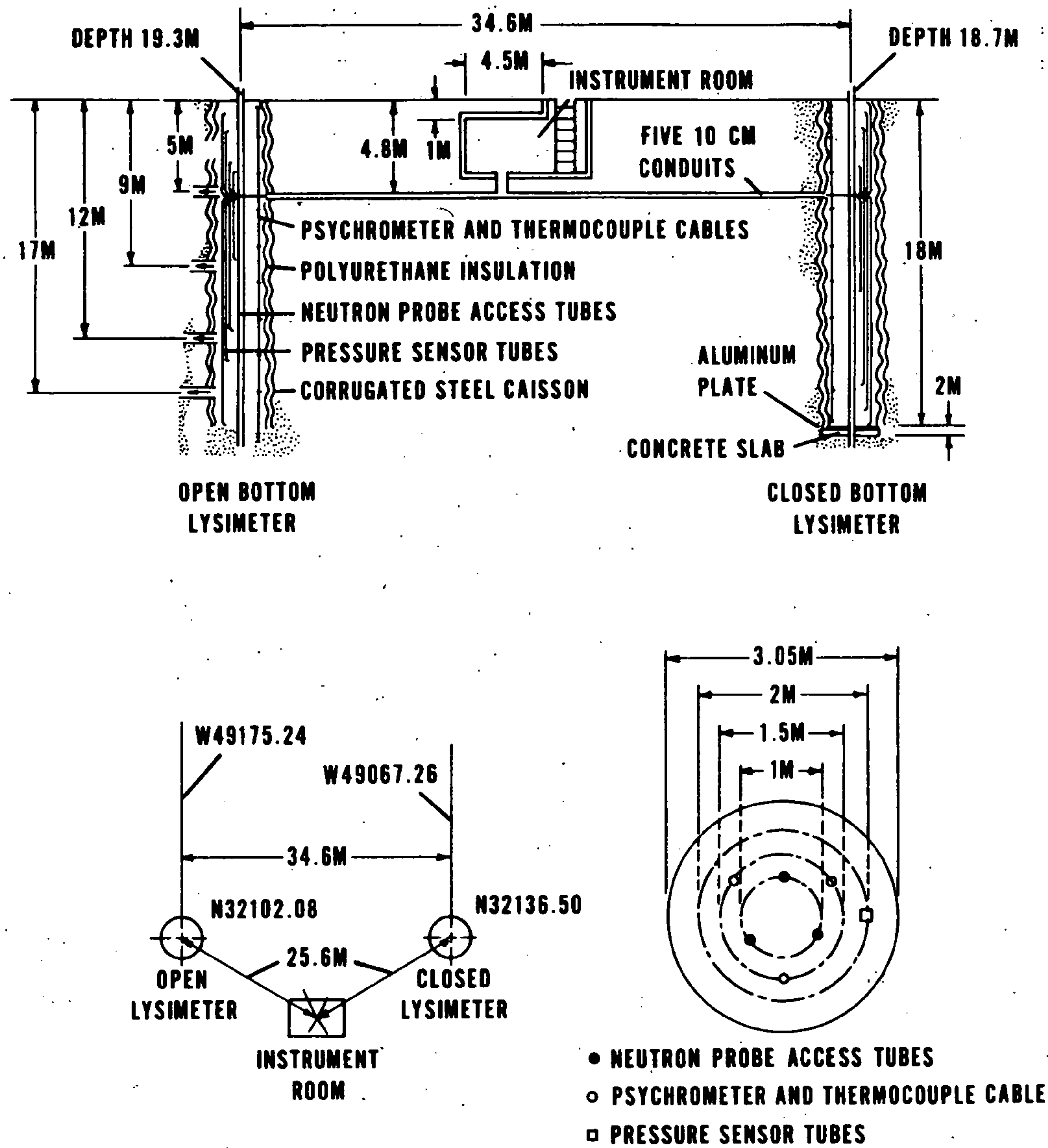


FIGURE 1

ELEVATION AND PLAN VIEWS OF LYSIMETERS
(As Planned)

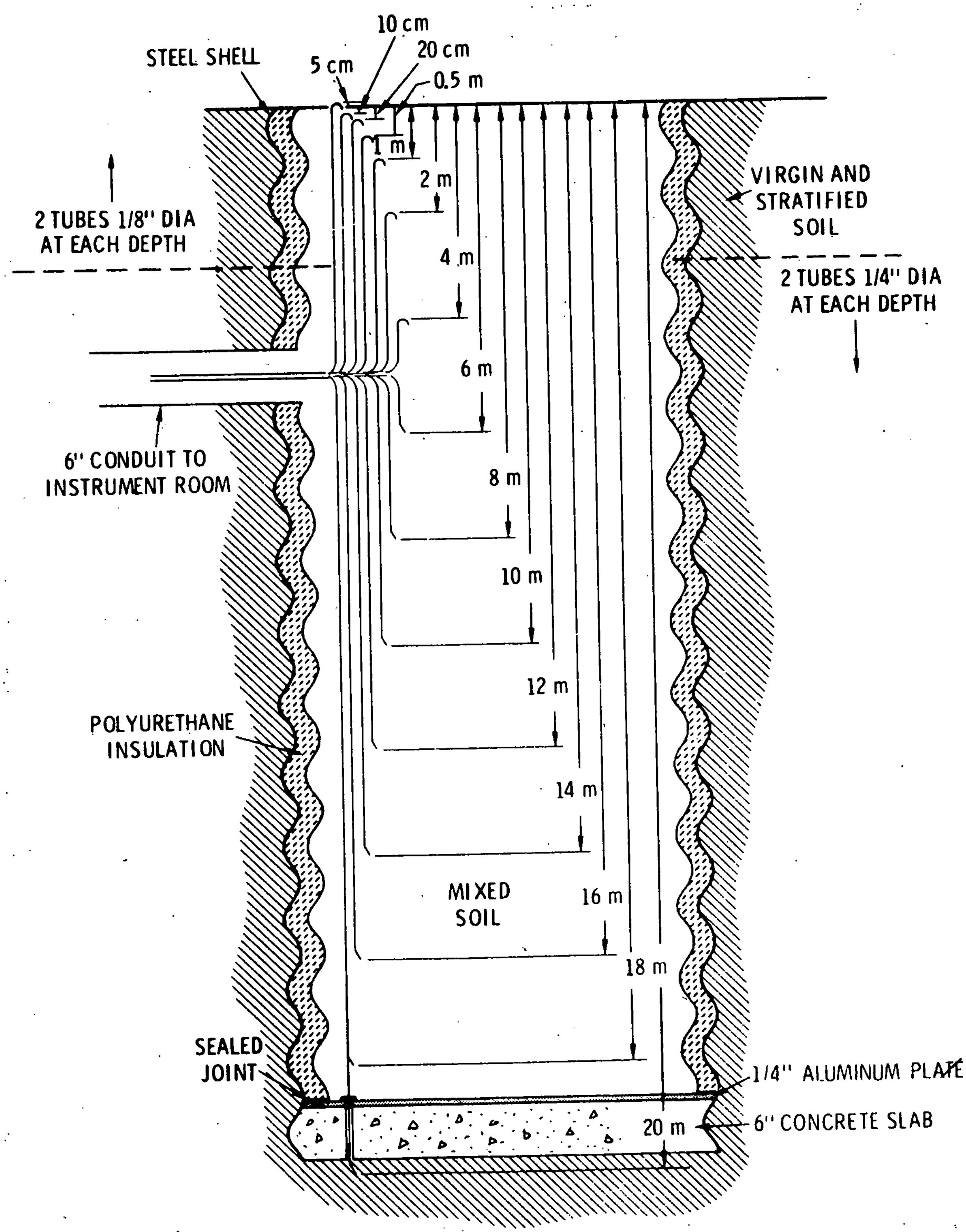


FIGURE 2

DETAIL OF PRESSURE SENSOR TUBE INSTALLATION IN CLOSED LYSIMETER (As Planned)

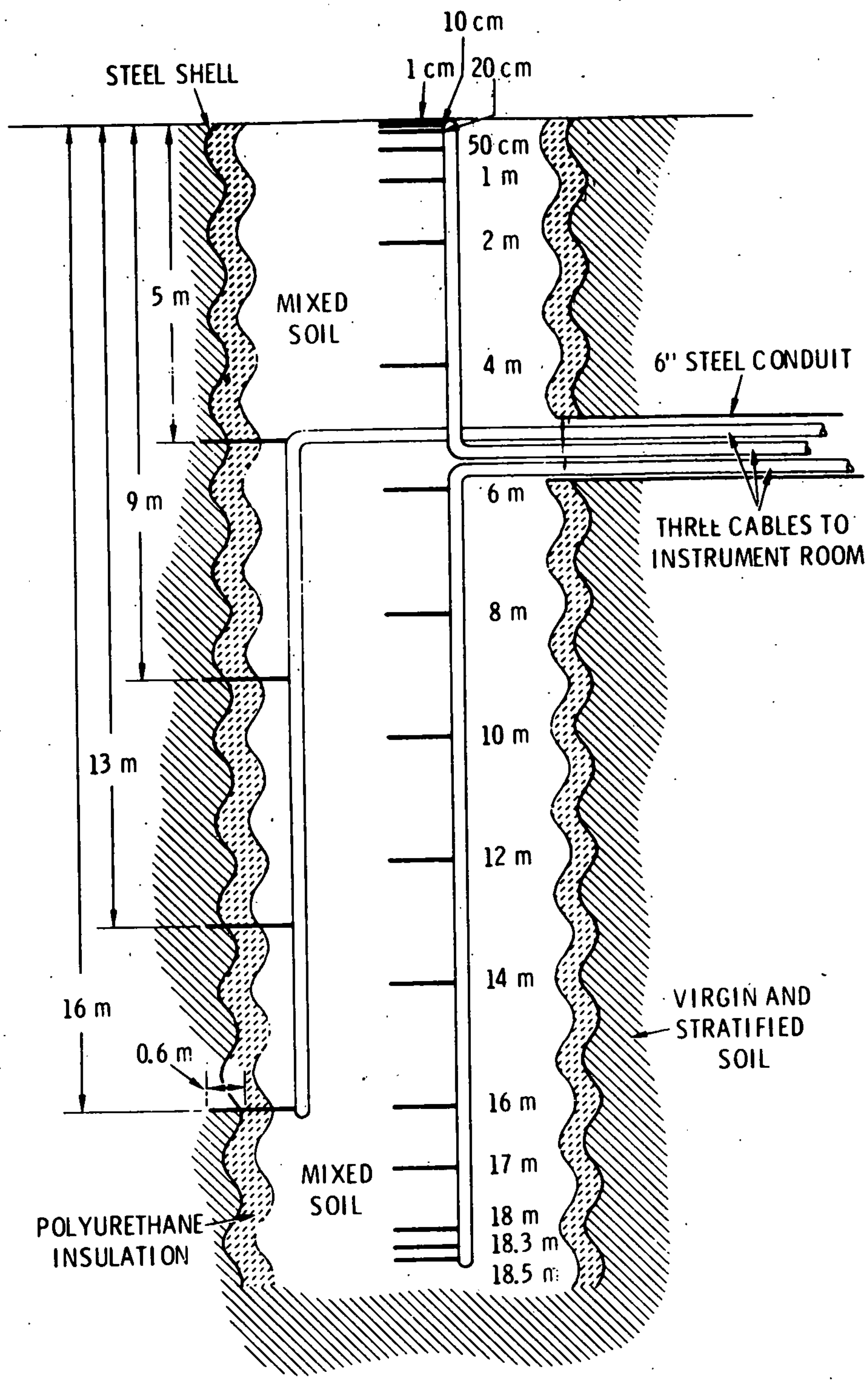


FIGURE 3

DETAIL OF PSYCHROMETER AND THERMOCOUPLE CABLE INSTALLATION IN OPEN LYSIMETER (As Planned)

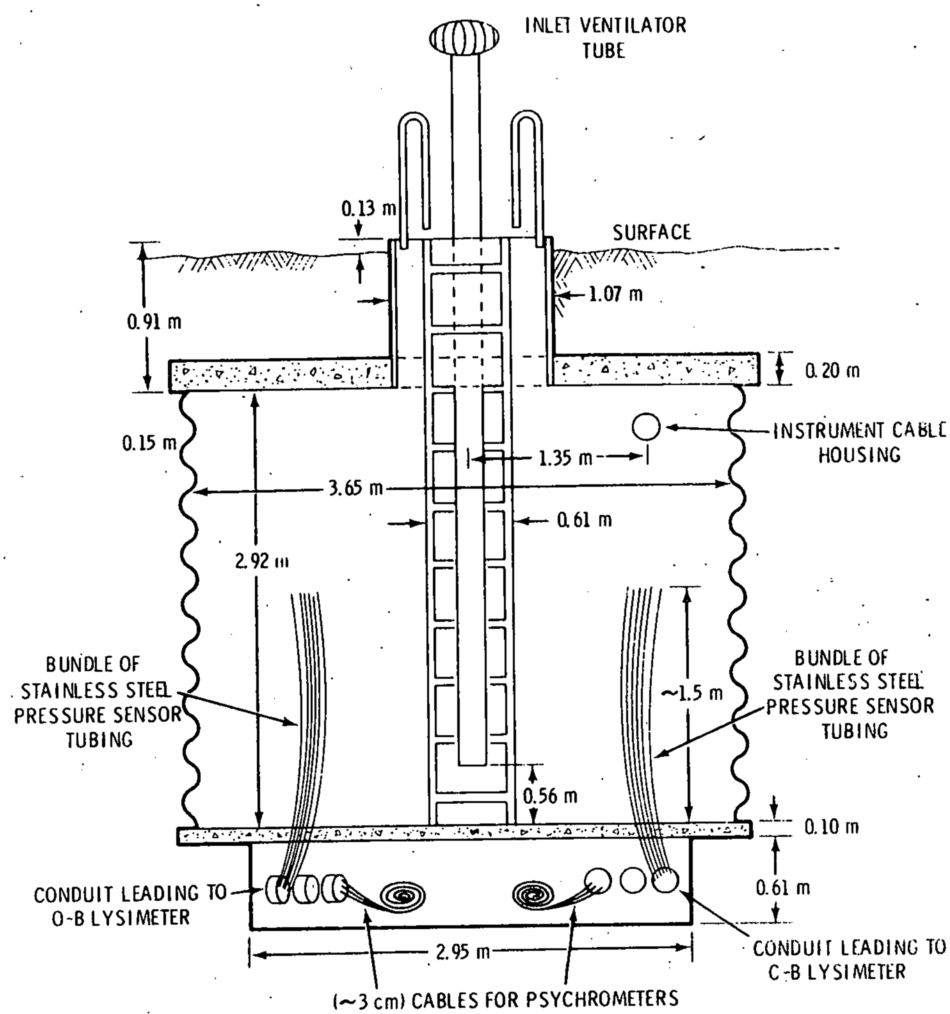


FIGURE 4

ELEVATION VIEW OF INSTRUMENT ROOM AT LYSIMETER SITE 32-49 HANFORD COORDINATES

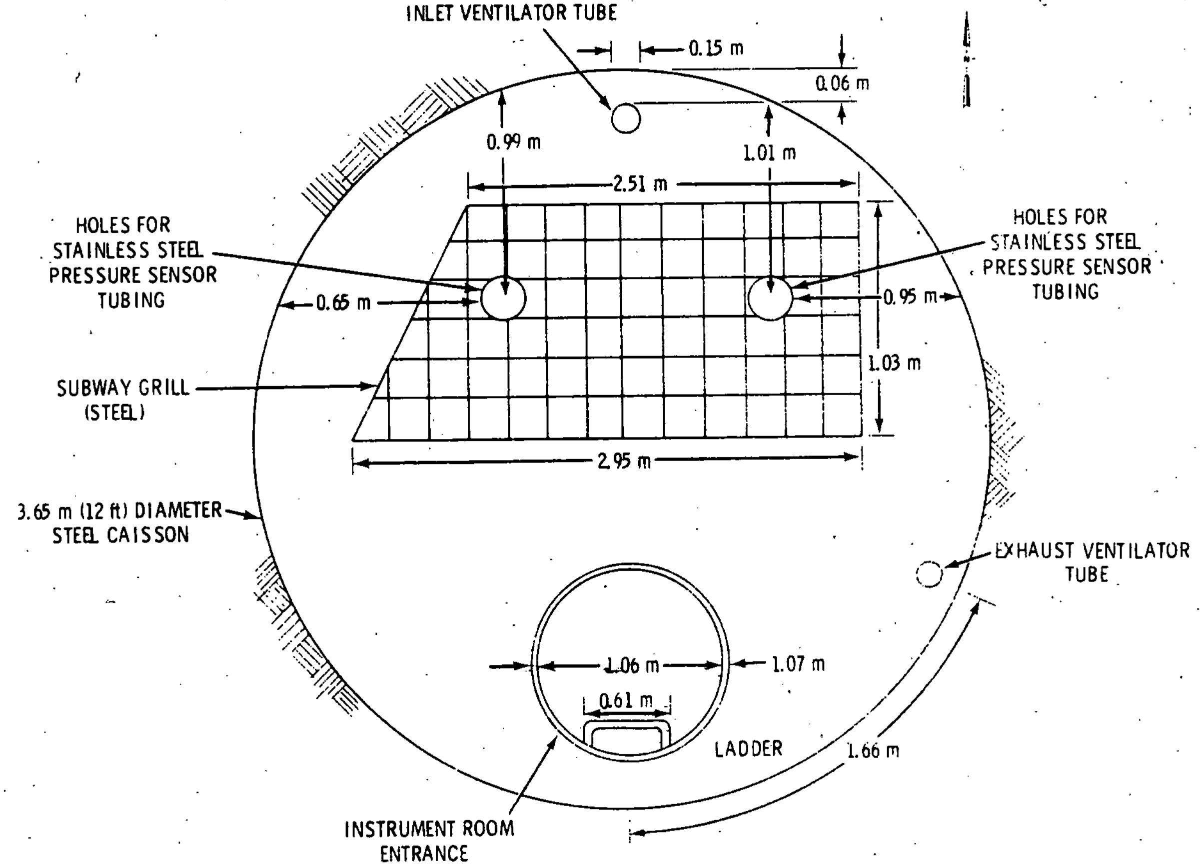


FIGURE 5

PLAN VIEW OF SECTION OF INSTRUMENT ROOM AT LYSIMETER SITE

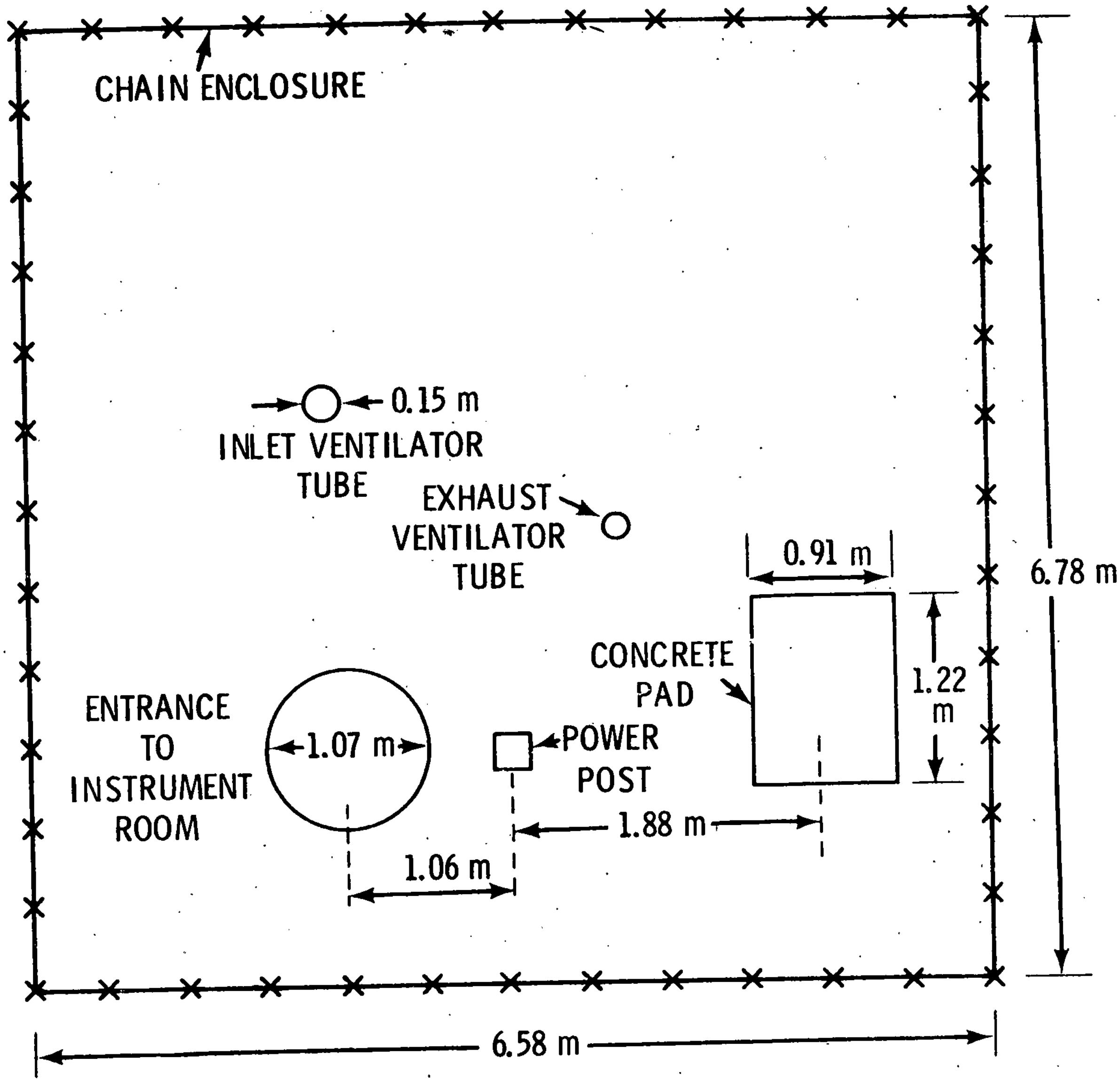


FIGURE 6

PLAN VIEW OF SURFACE ABOVE INSTRUMENT ROOM AT LYSIMETER SITE

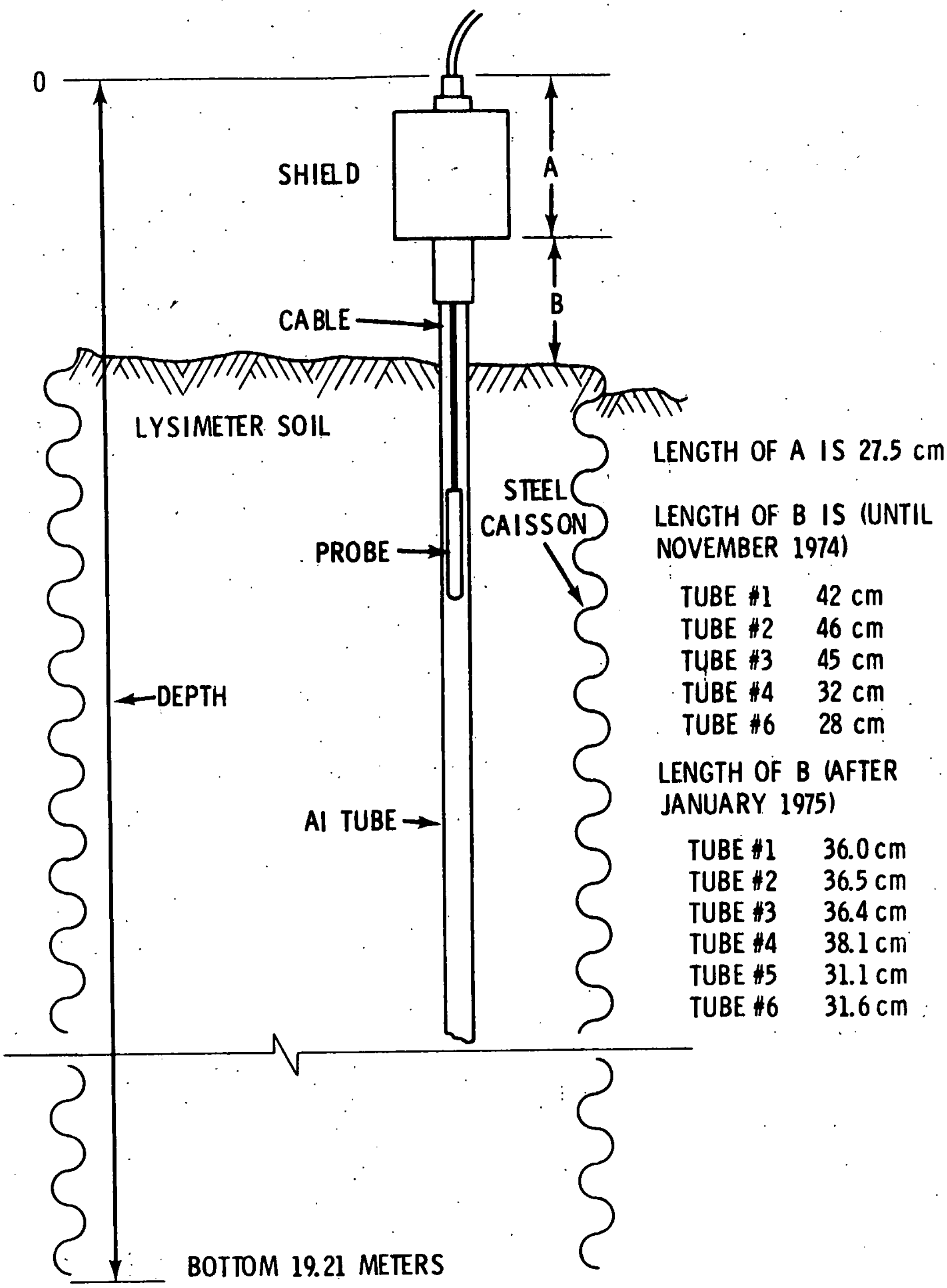


FIGURE 7

DEFINITION OF ZERO DEPTH REFERENCE FOR NEUTRON PROBE

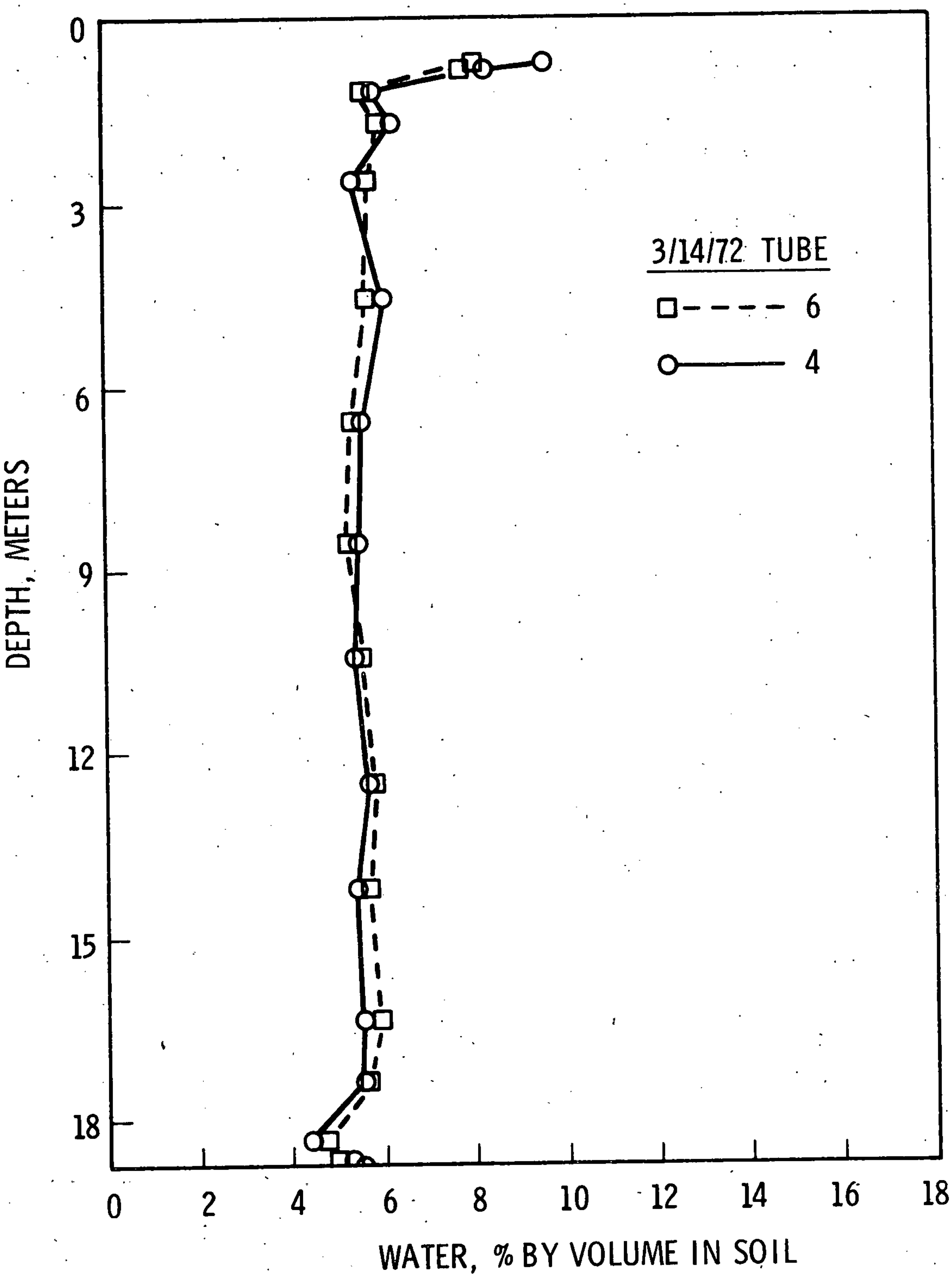


FIGURE 8

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AS OF MARCH 14, 1972

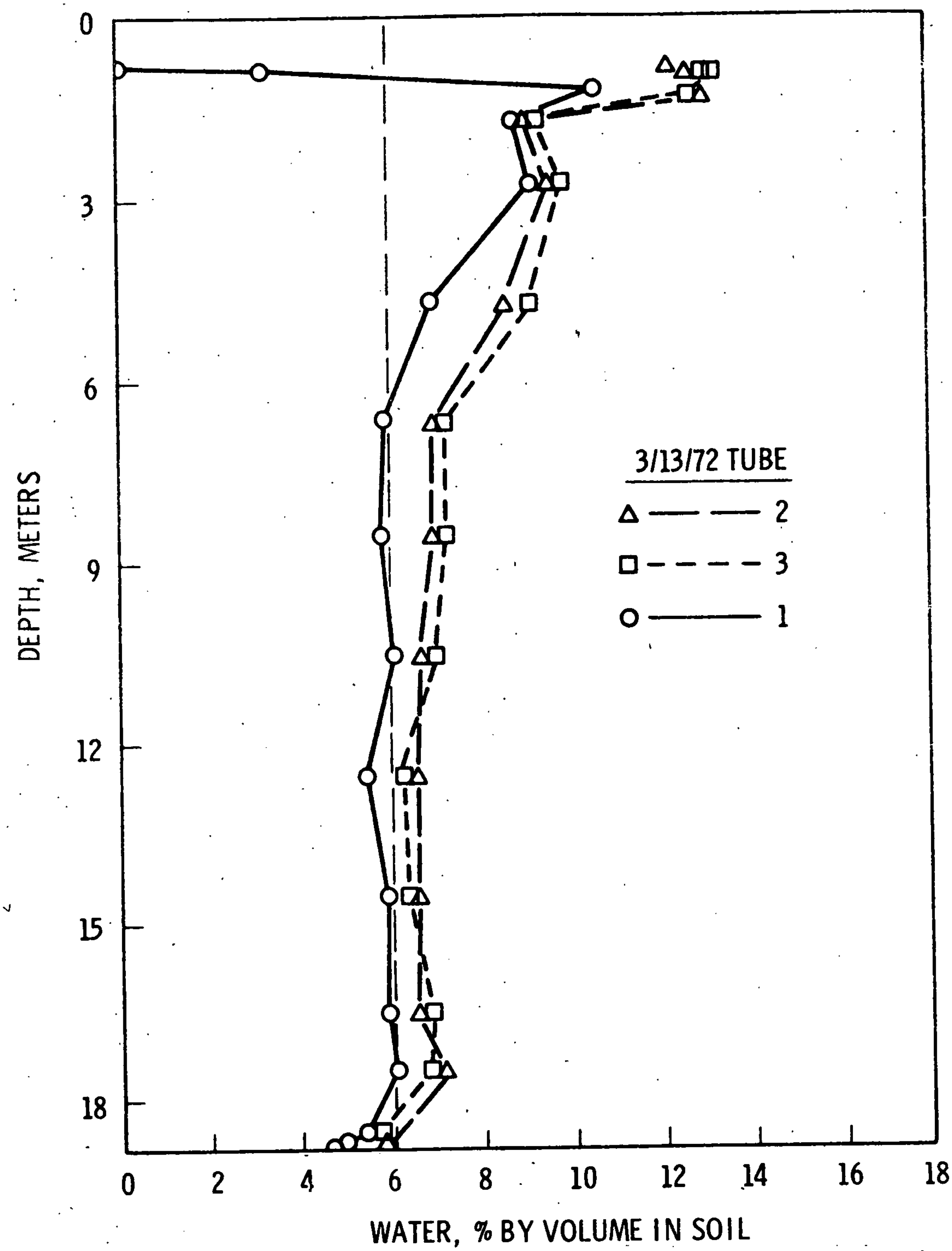


FIGURE 9

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
AS OF MARCH 13, 1972

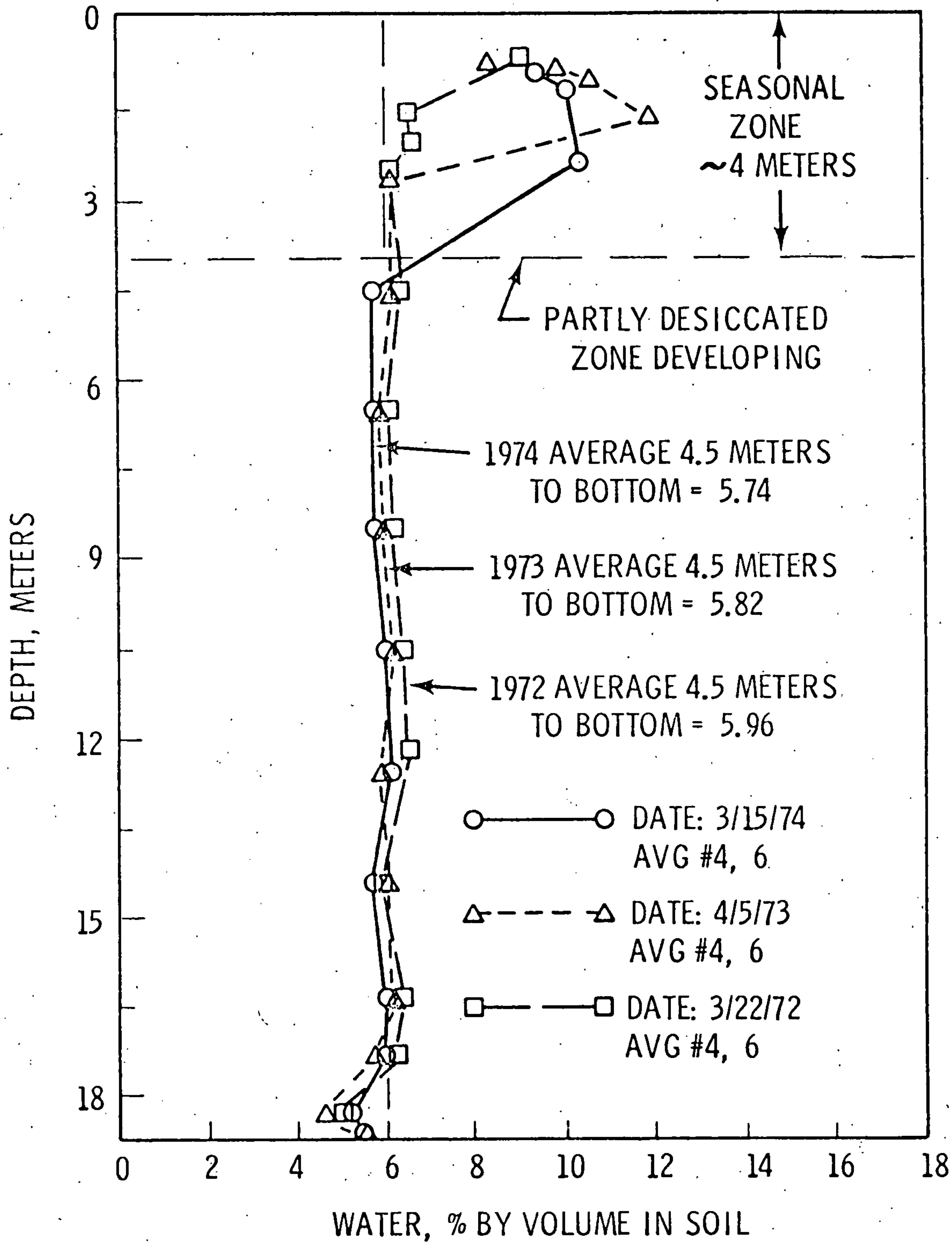


FIGURE 10

SOIL-MOISTURE PROFILES IN CLOSED-BOTTOM LYSIMETER FOR SPRINGS OF 1972, 1973, AND 1974

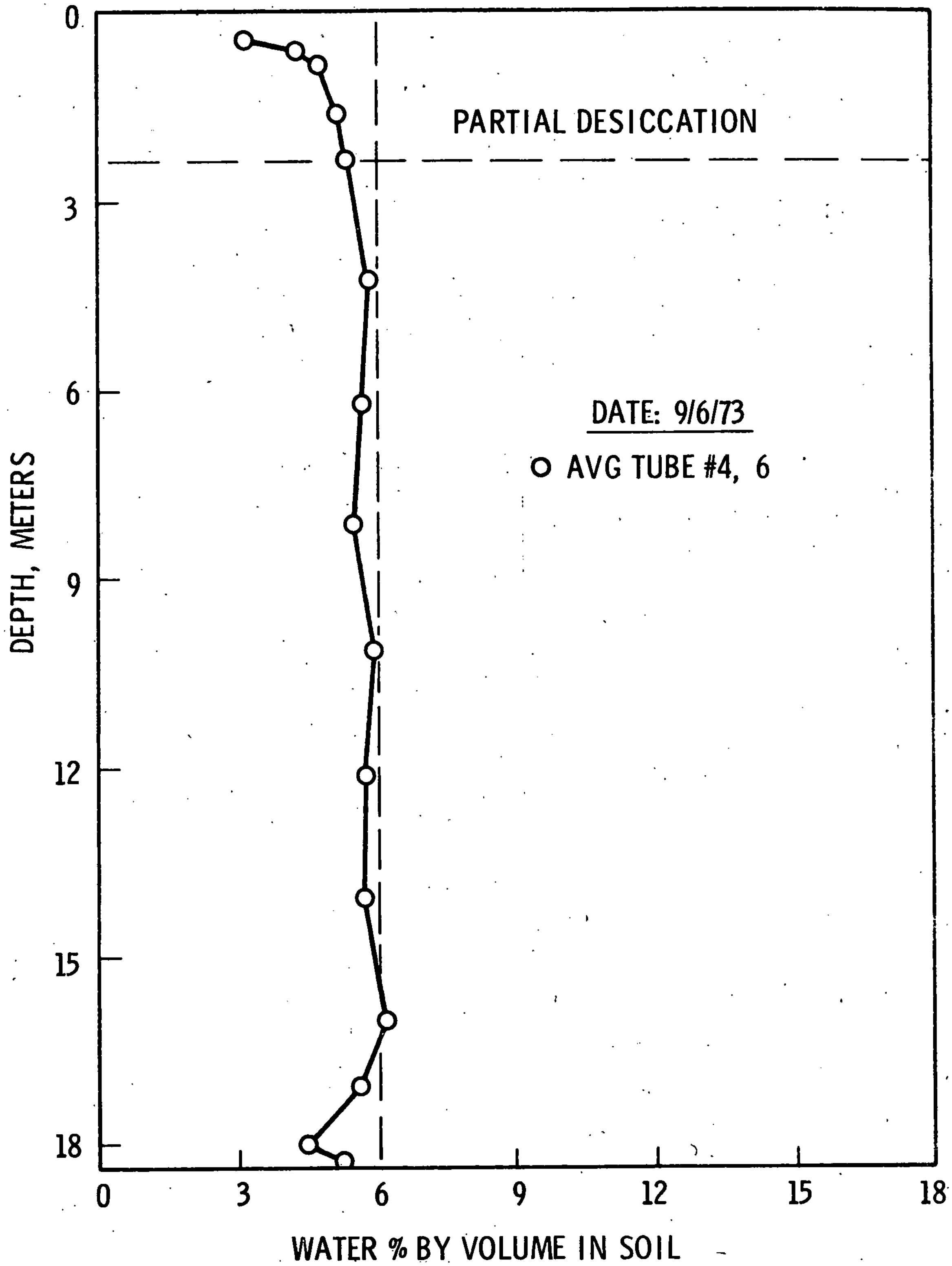


FIGURE 11

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AS OF SEPTEMBER 6, 1973

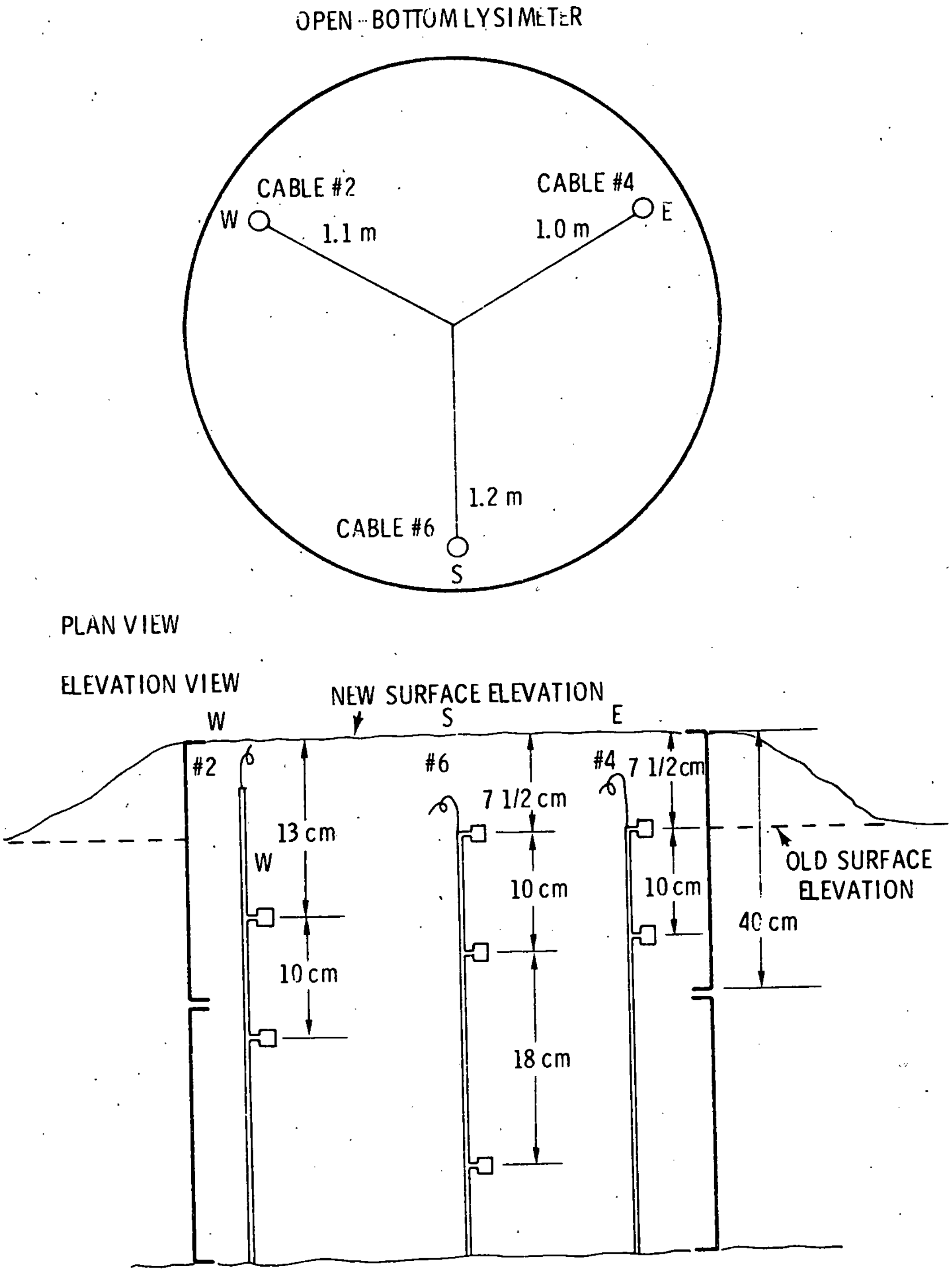


FIGURE 12

NEW SURFACE SECTION AT OPEN-LYSIMETER SITE, NOVEMBER 1974

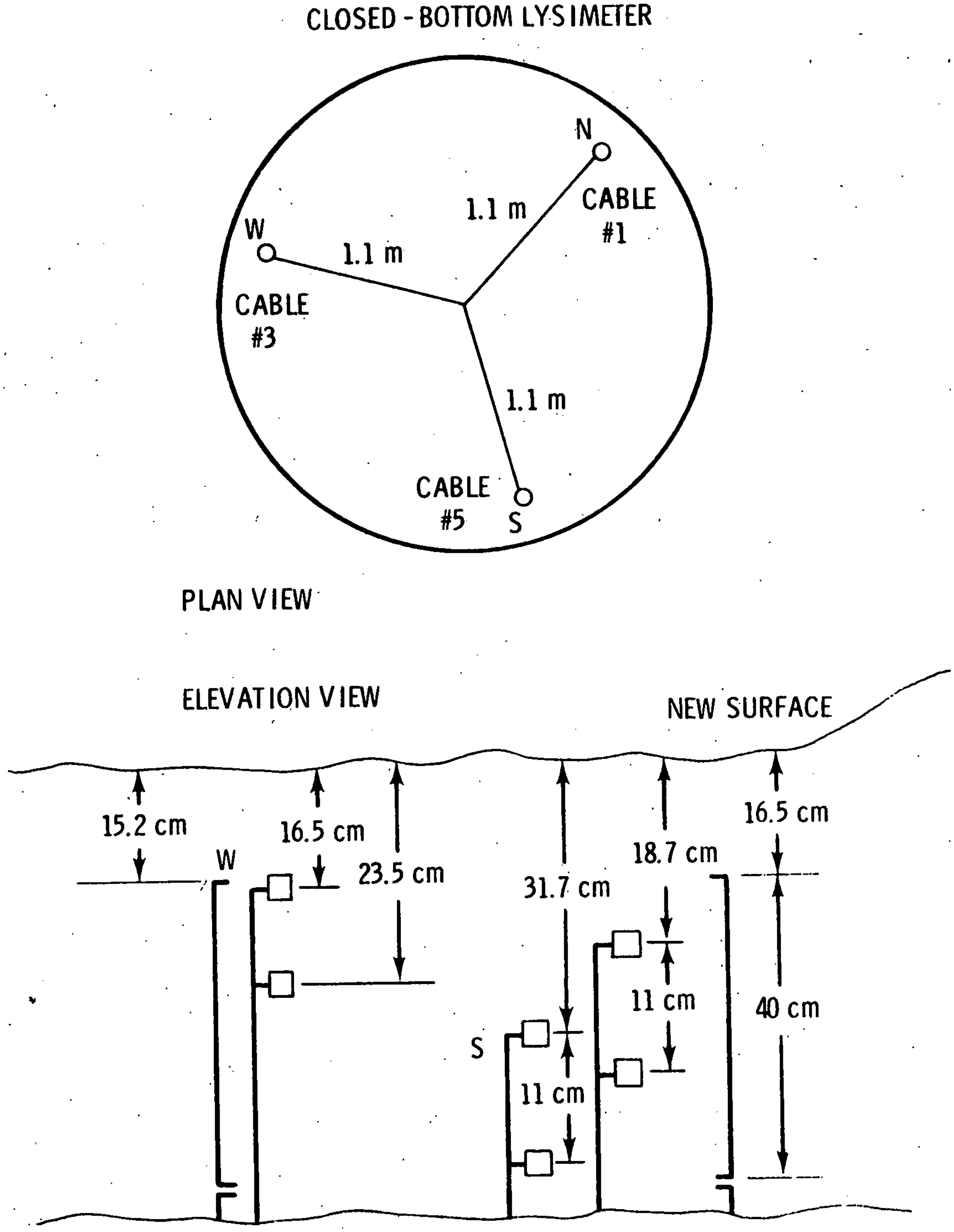


FIGURE 13

NEW CONDITION OF SURFACE AT CLOSED-BOTTOM LYSIMETER SITE, JANUARY 1975

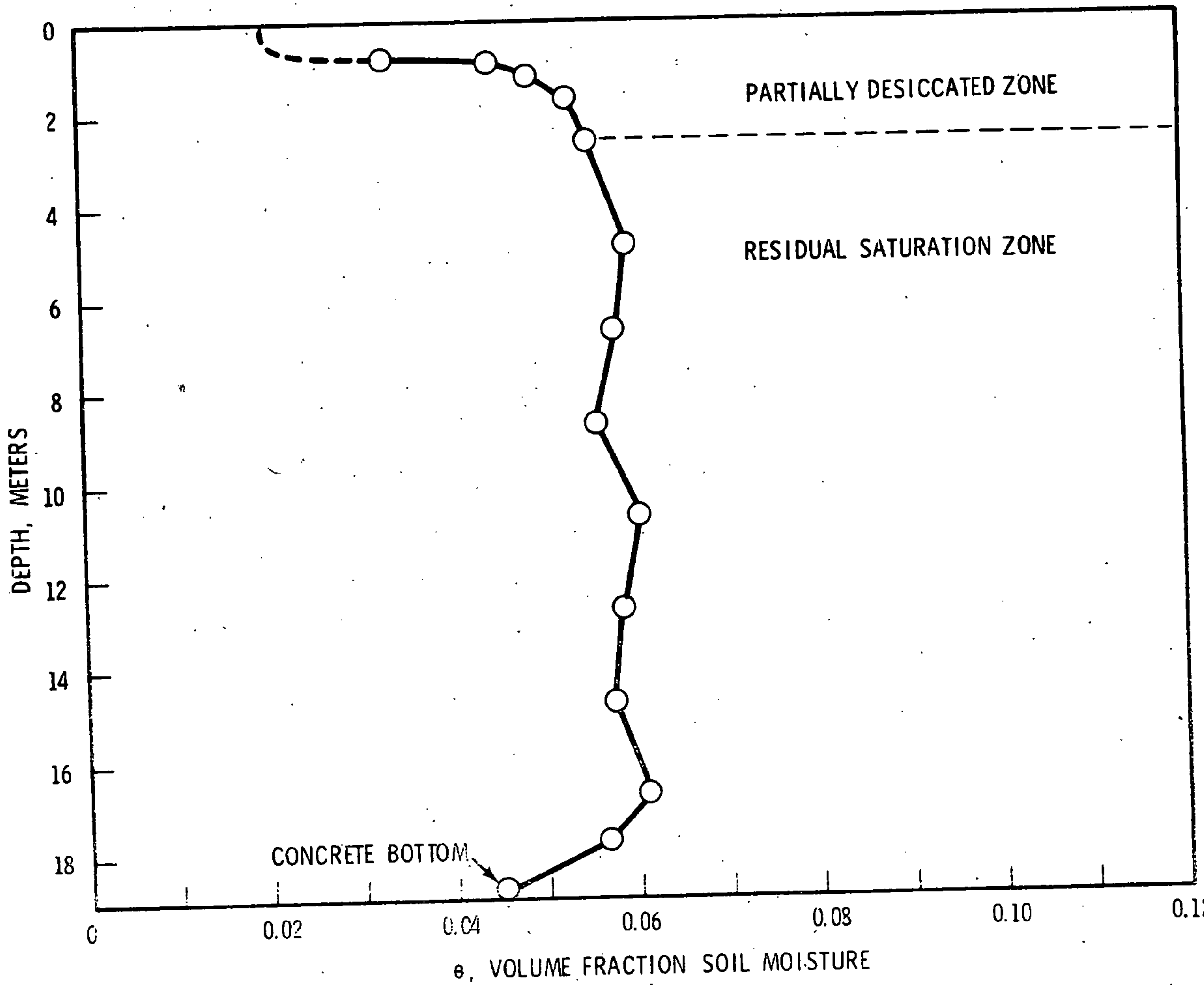


FIGURE 14

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AFTER 1973 SUMMER DESSICATION
(As of September 6, 1973, for Average of Tubes Numbers 4 and 6)

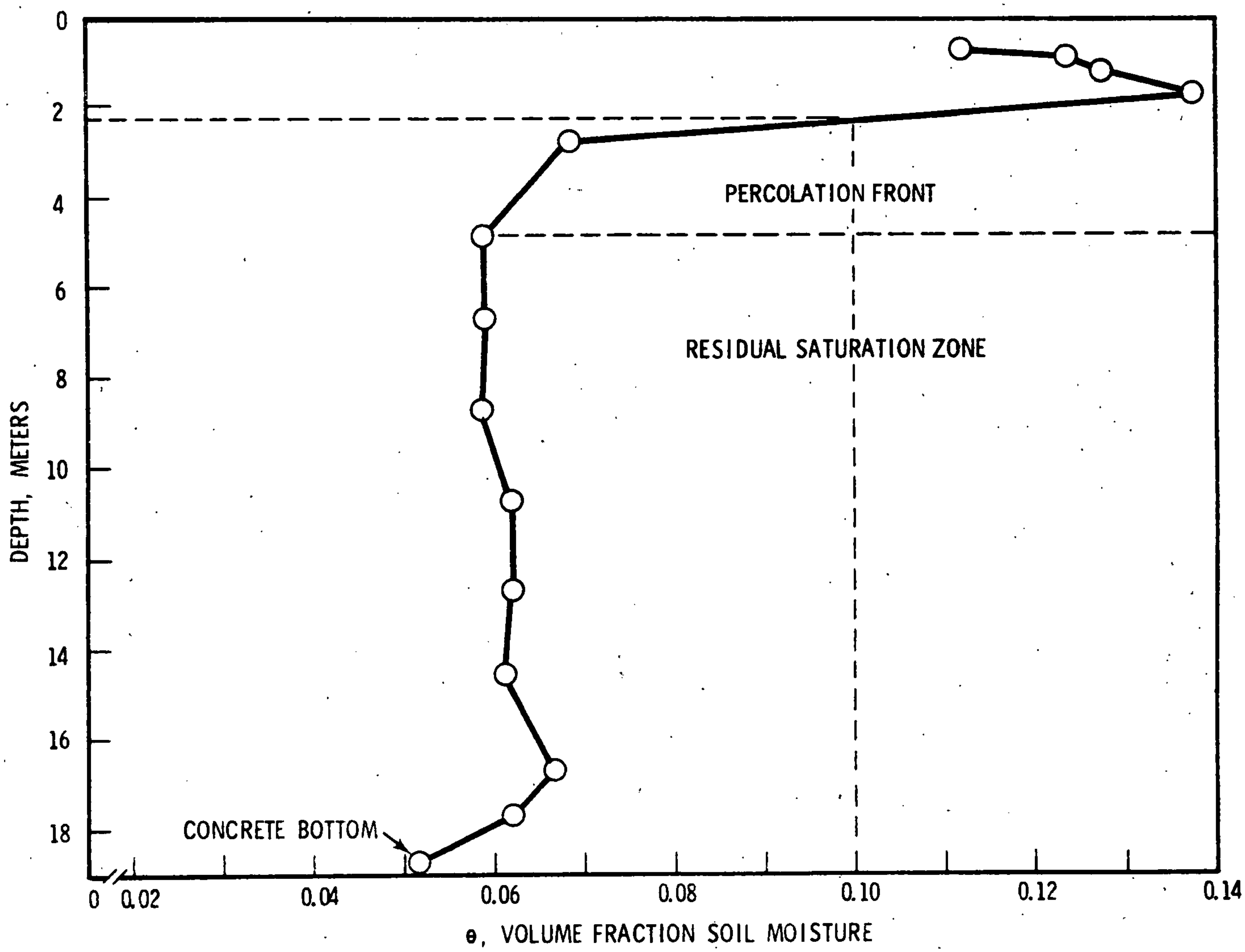


FIGURE 15

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AFTER EARLY WINTER PRECIPITATION
(As of January 24, 1974, for Average of Tubes Numbers 4 and 6)

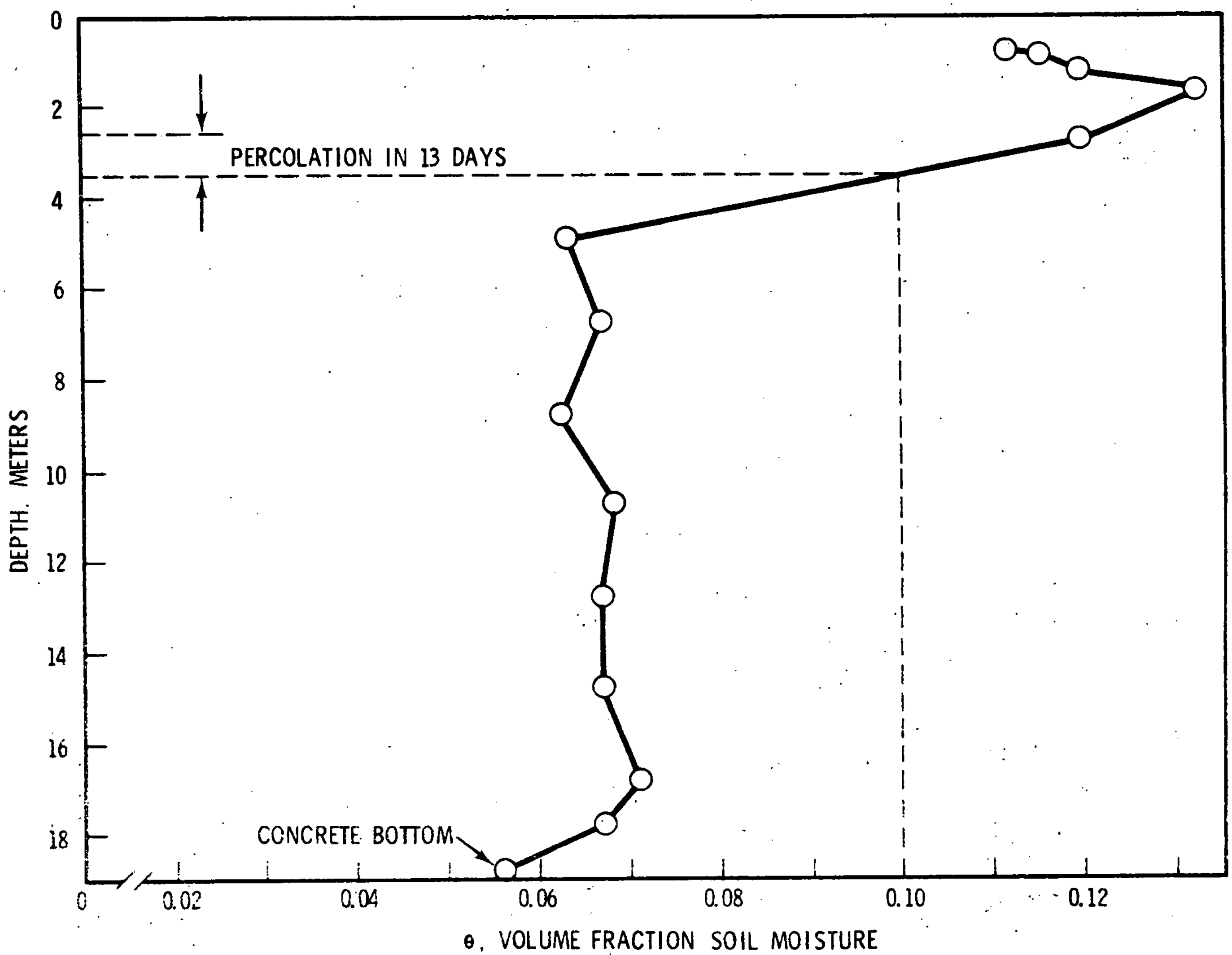


FIGURE 16

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AFTER RAPID PERCOLATION IN EARLY FEBRUARY (As of February 6, 1974, for Average of Tubes Numbers 4 and 6)

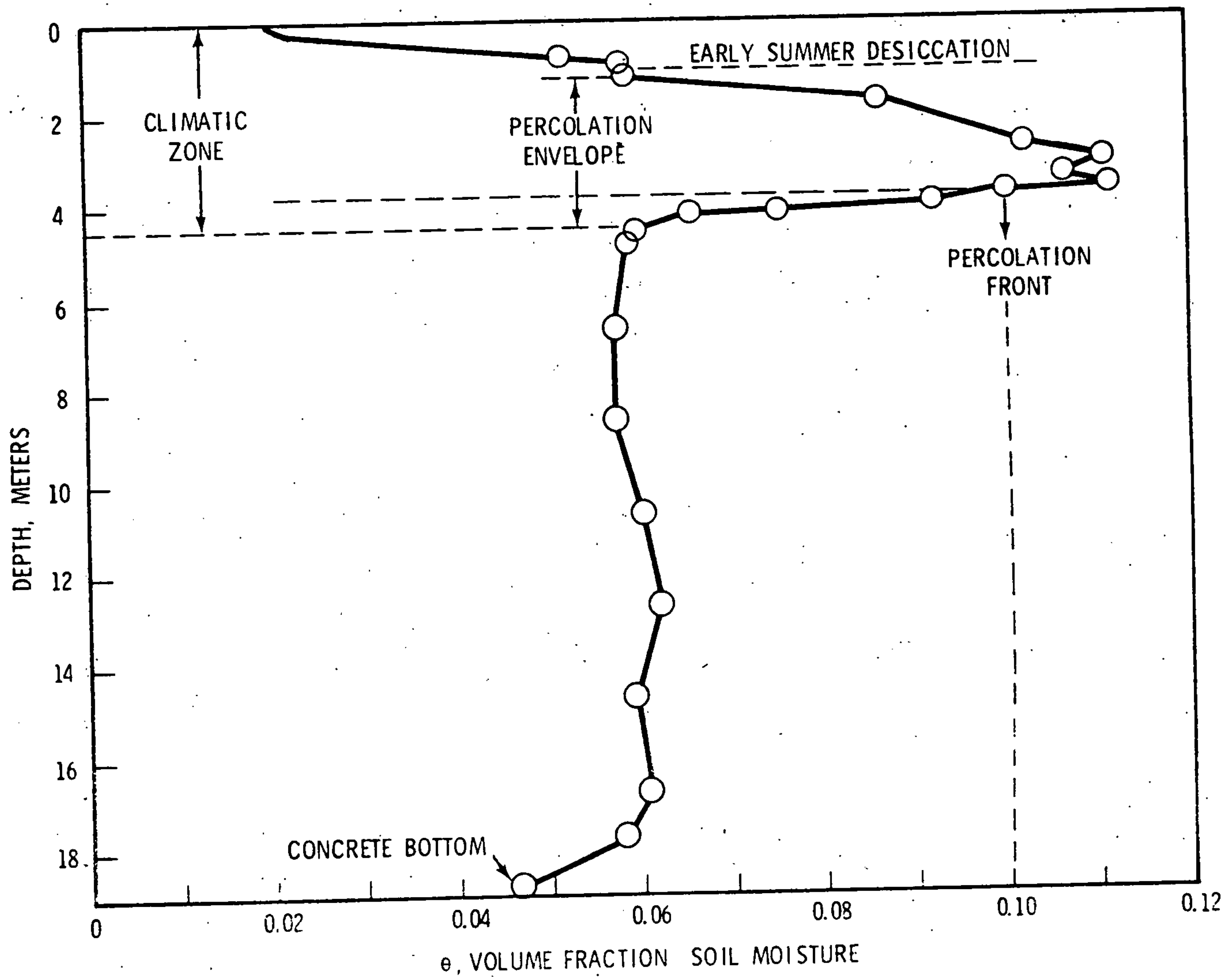


FIGURE 17

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER SHOWING PERCOLATION ENVELOPE AT ITS MAXIMUM (as of June 24, 1974, for Average of Tubes Numbers 4 and 6)

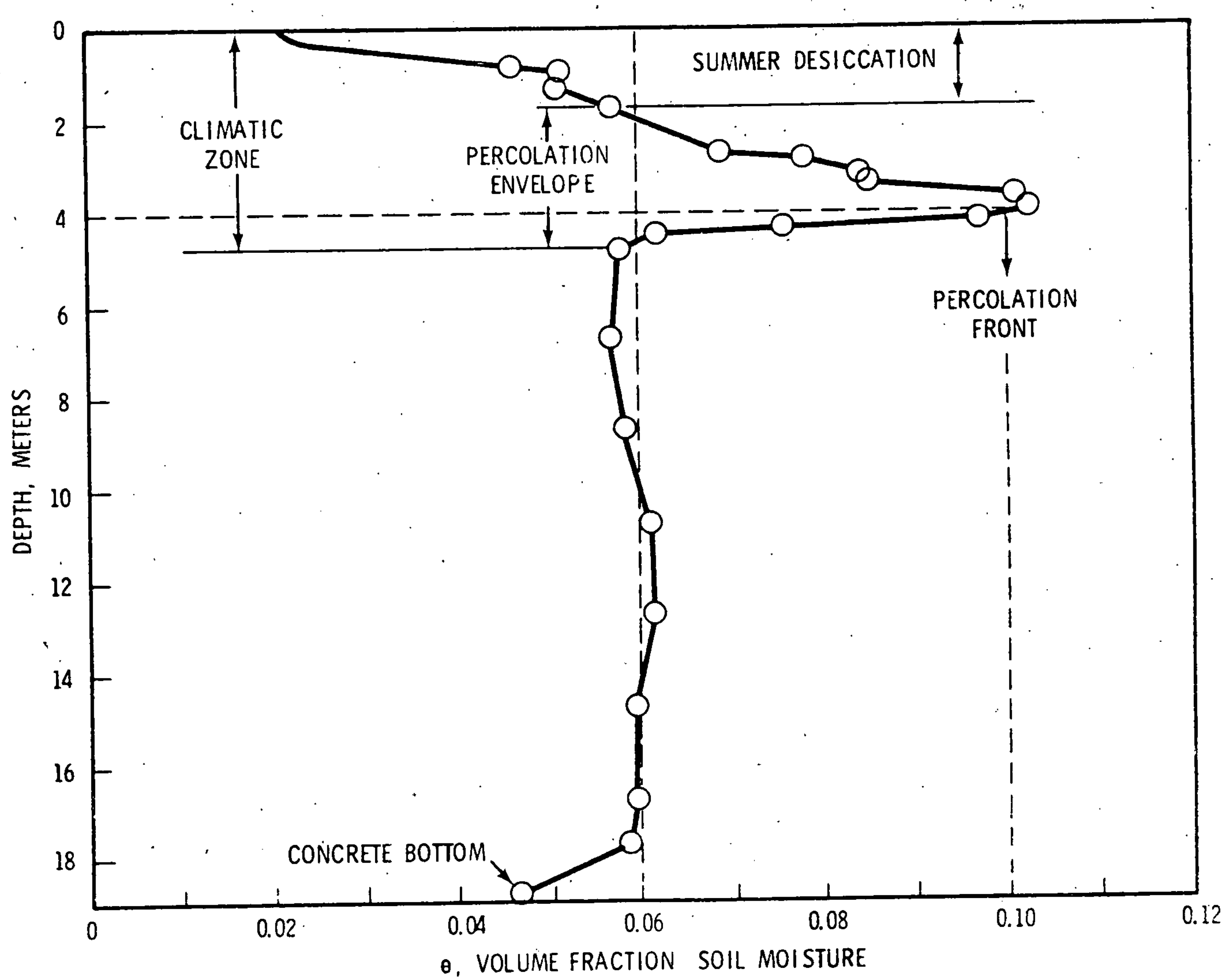


FIGURE 18

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER AFTER PARTIAL ATTENUATION OF PERCOLATION ENVELOPE (As Of August 8, 1974, for Average of Tubes Numbers 4 and 6)

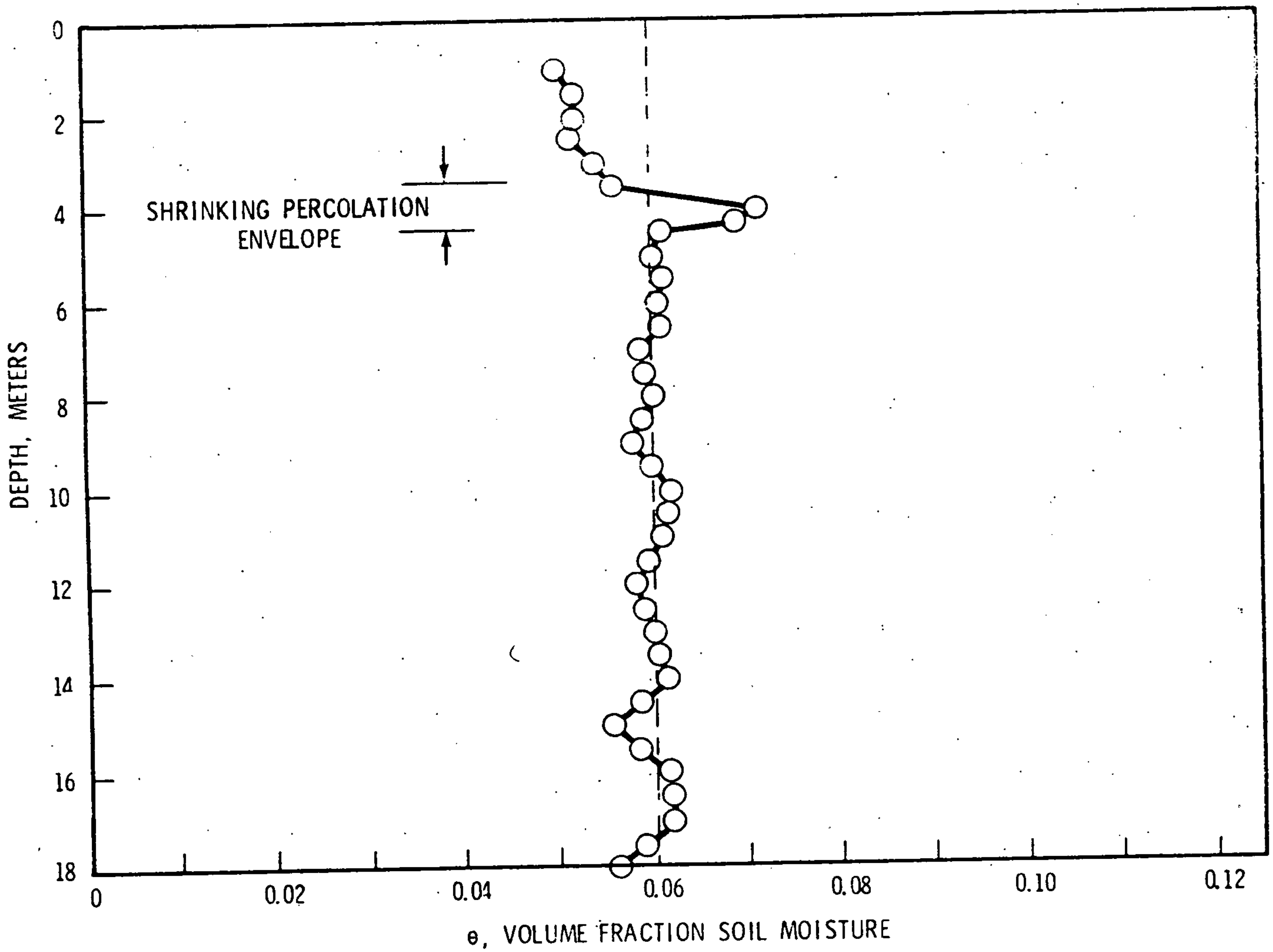


FIGURE 19

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER
(As of August 29, 1974, for Average of Tubes Numbers 4 and 6)

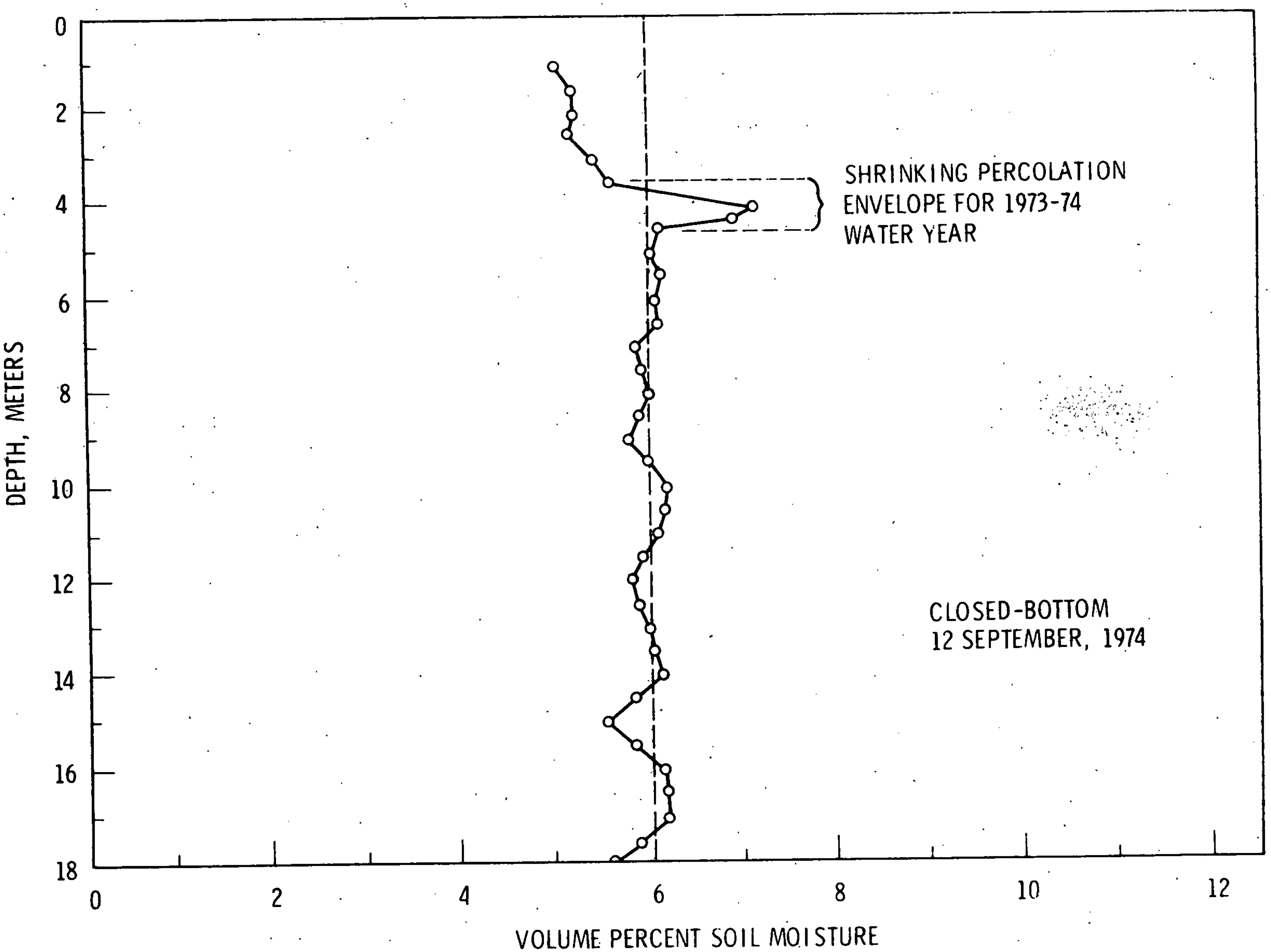


FIGURE 20

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER
(As of September 12, 1974, for Average of Tubes Numbers 4 and 6)

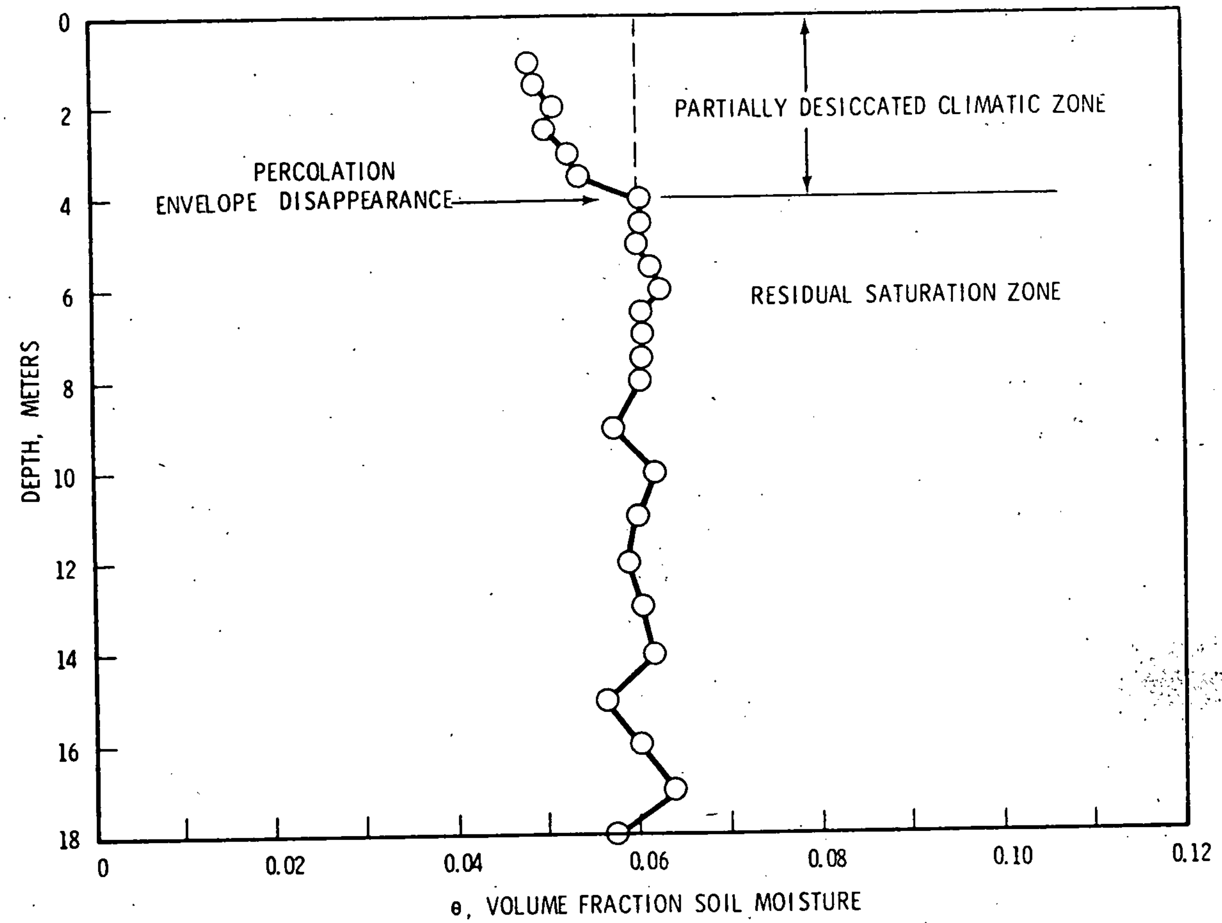


FIGURE 21

SOIL-MOISTURE PROFILE IN CLOSED-BOTTOM LYSIMETER WITH DESICCATION TO FOUR METERS
(As of October 18, 1974, for Average of Tubes Numbers 4 and 6)

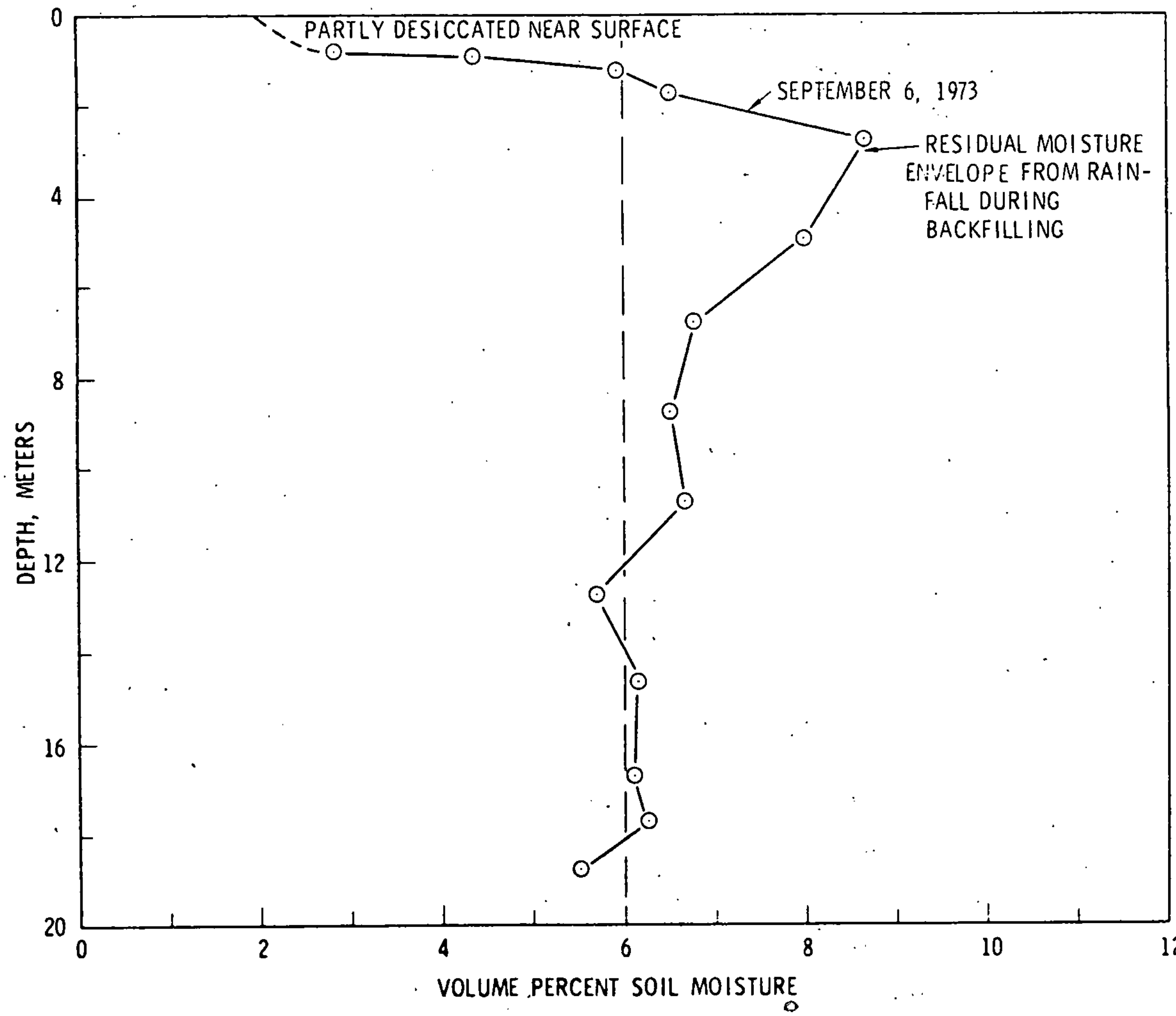


FIGURE 22

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of September 6, 1973, for Average of Tubes Numbers 1 and 2)

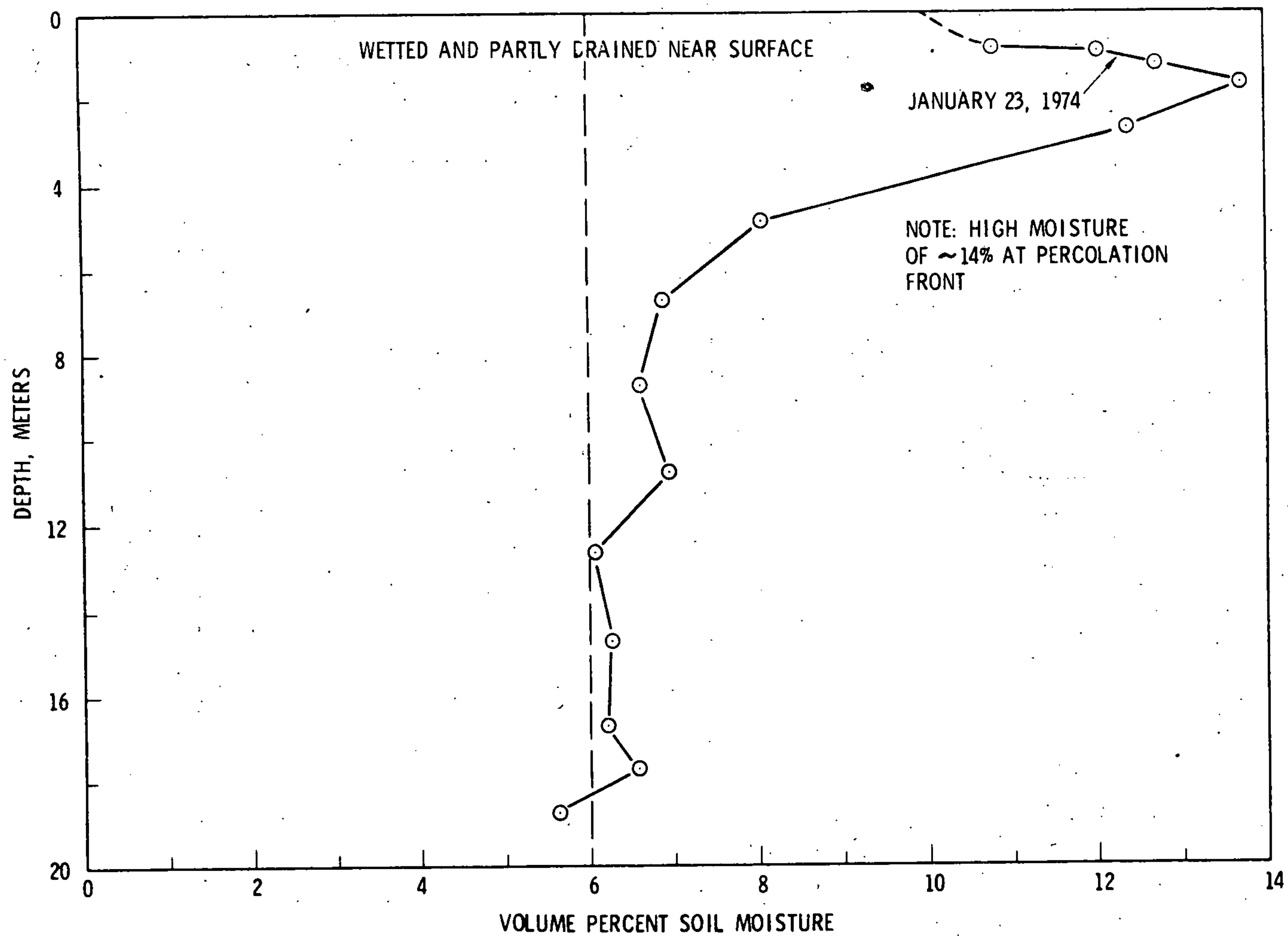


FIGURE 23

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of February 5, 1974, for Average of Tubes Numbers 1 and 2)

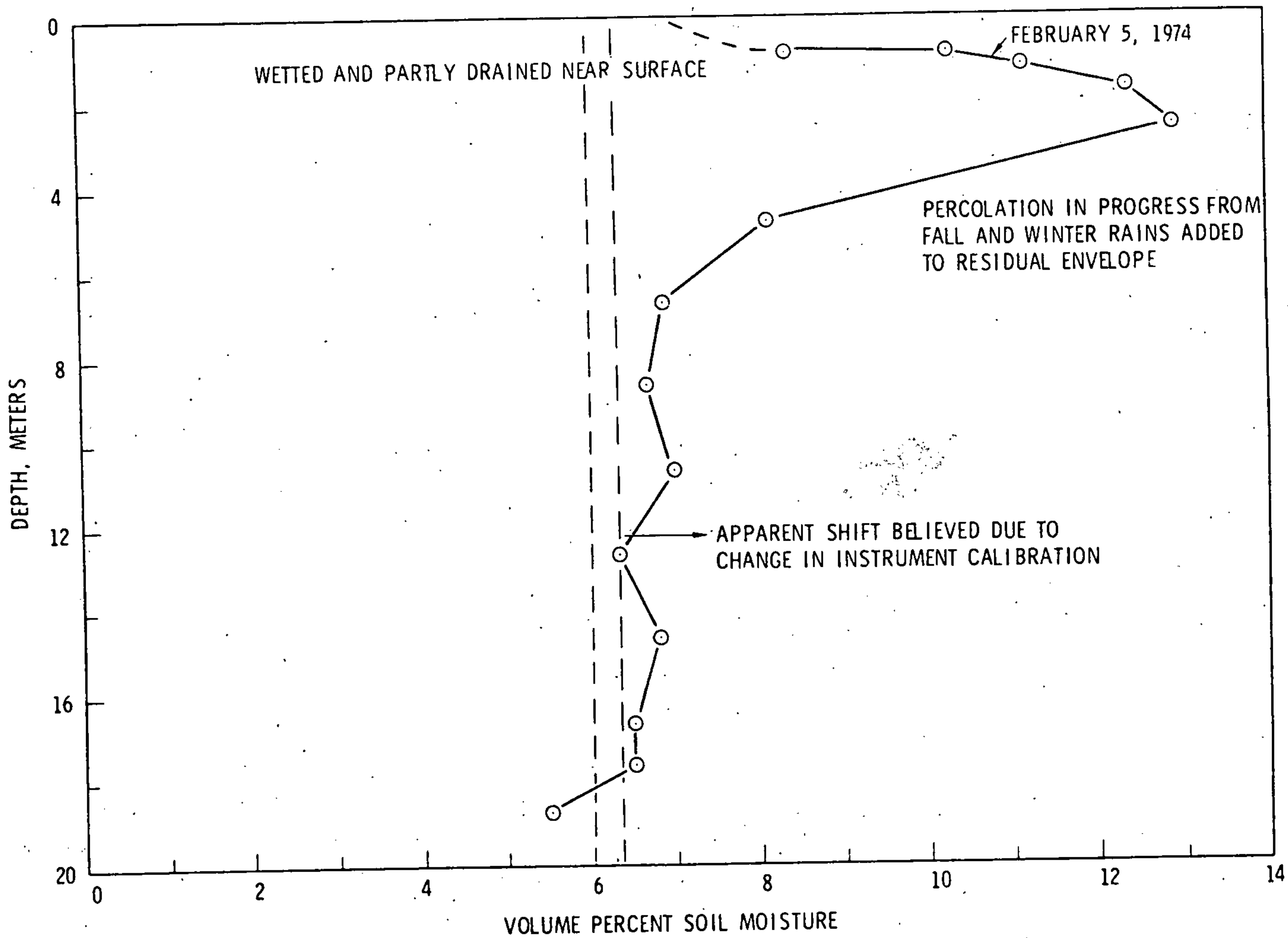


FIGURE 24

SOIL-MOSTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of February 5, 1975, for Average of Tubes Numbers 1 and 2)

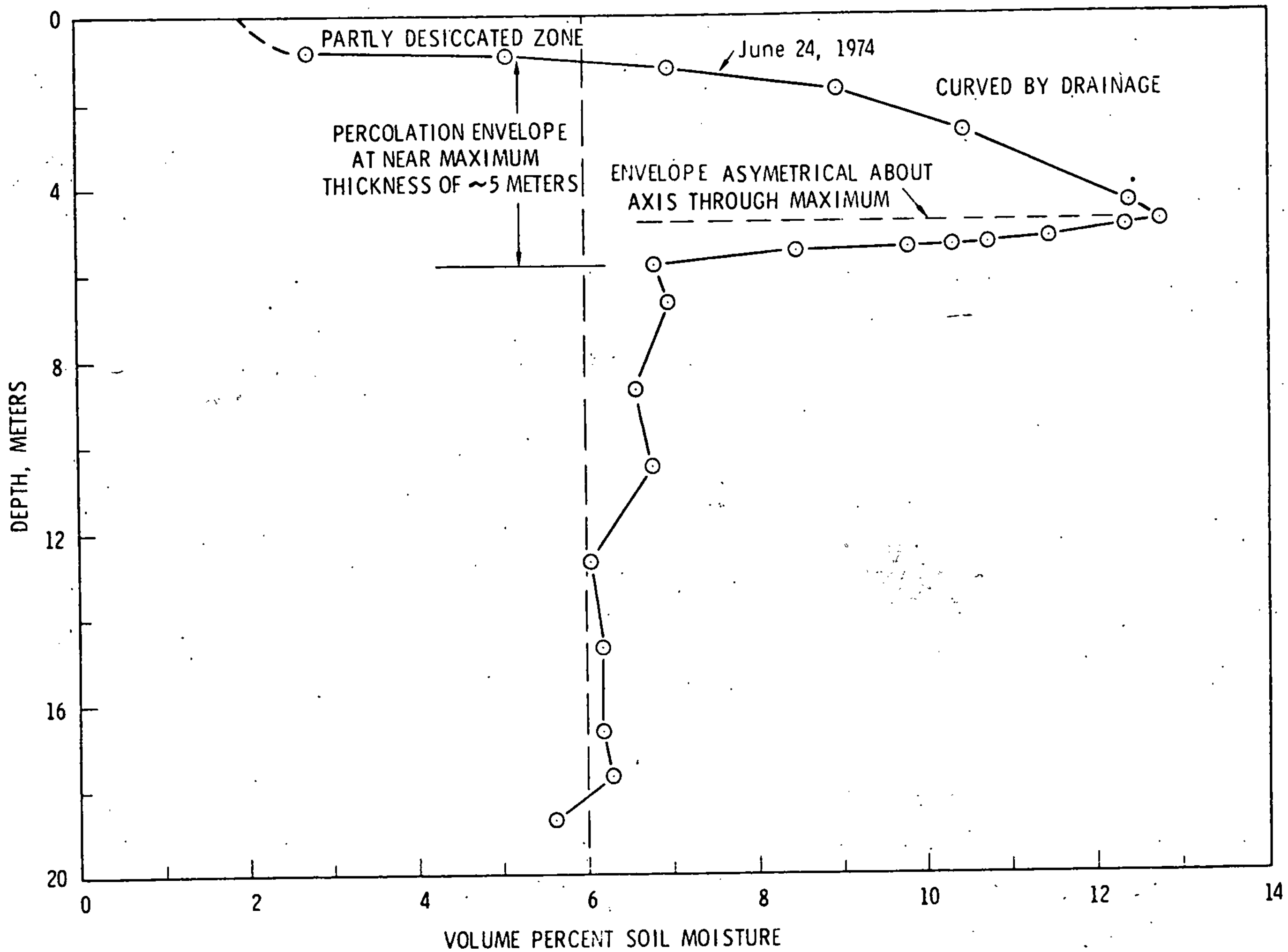


FIGURE 25

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of June 24, 1974, for Average of Tubes Numbers 1 and 2)

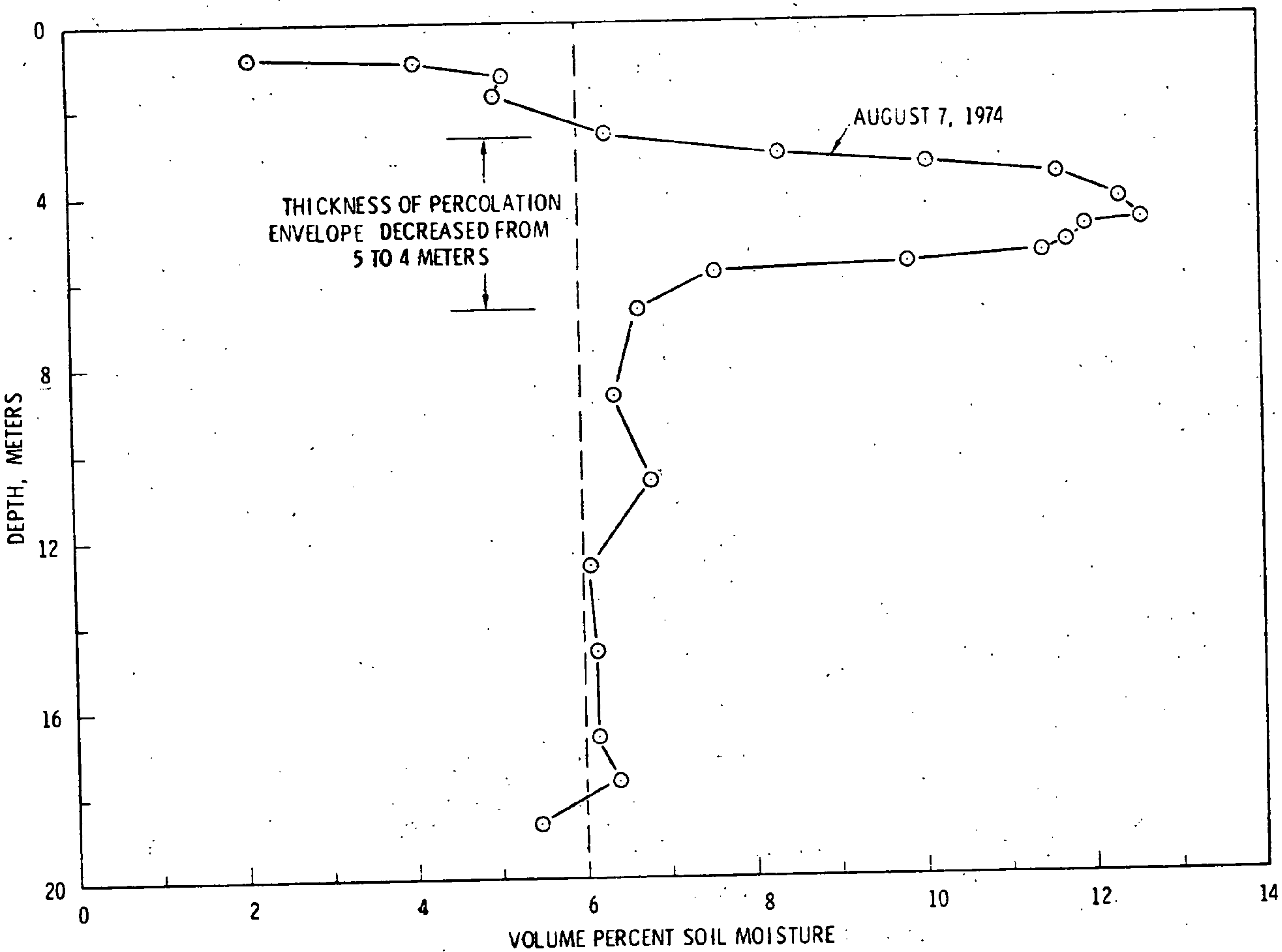


FIGURE 26

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of August 7, 1974, for Average of Tubes Numbers 1 and 2)

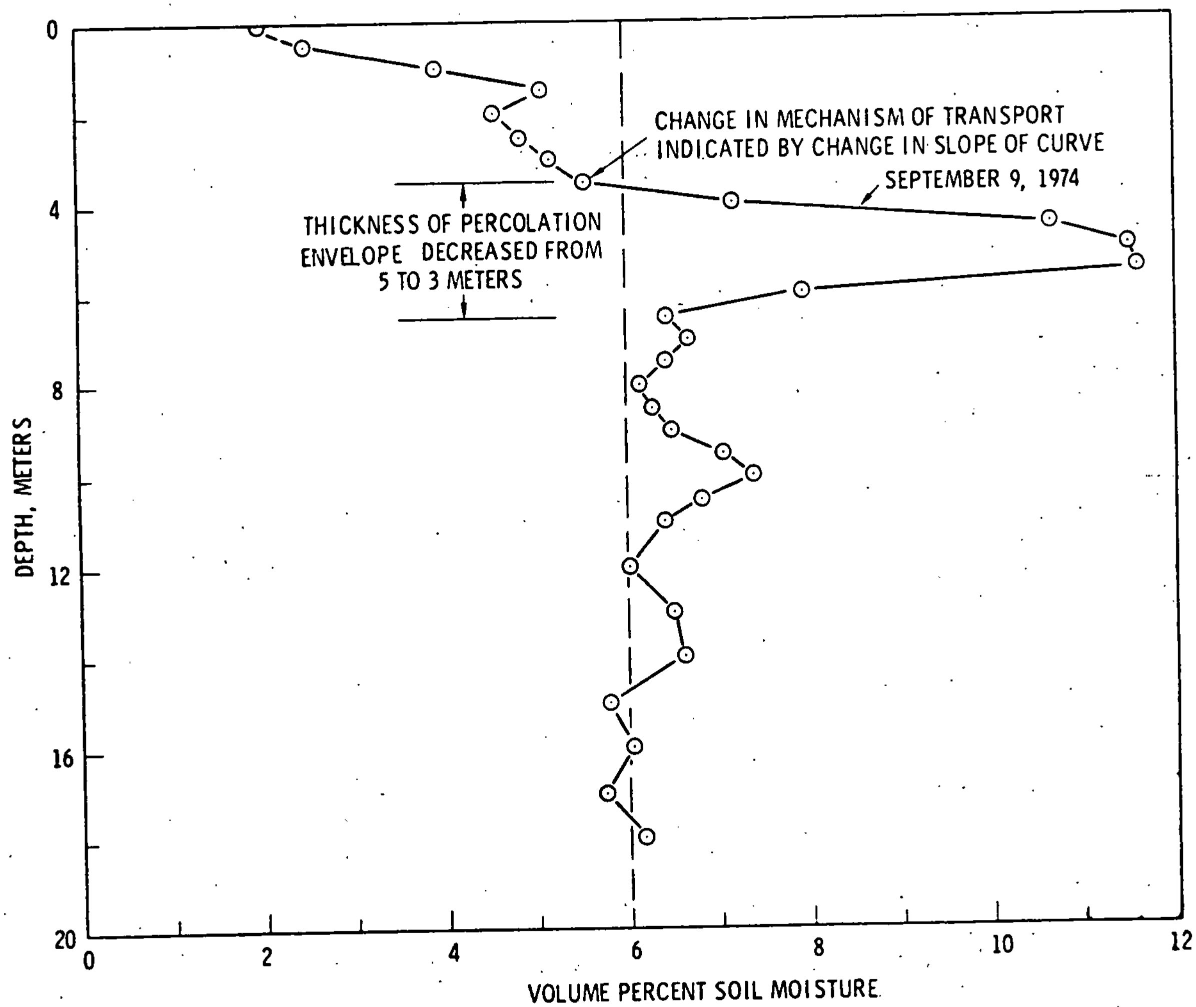


FIGURE 27

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of September 9, 1974, for Average of Tubes Numbers 1 and 2)

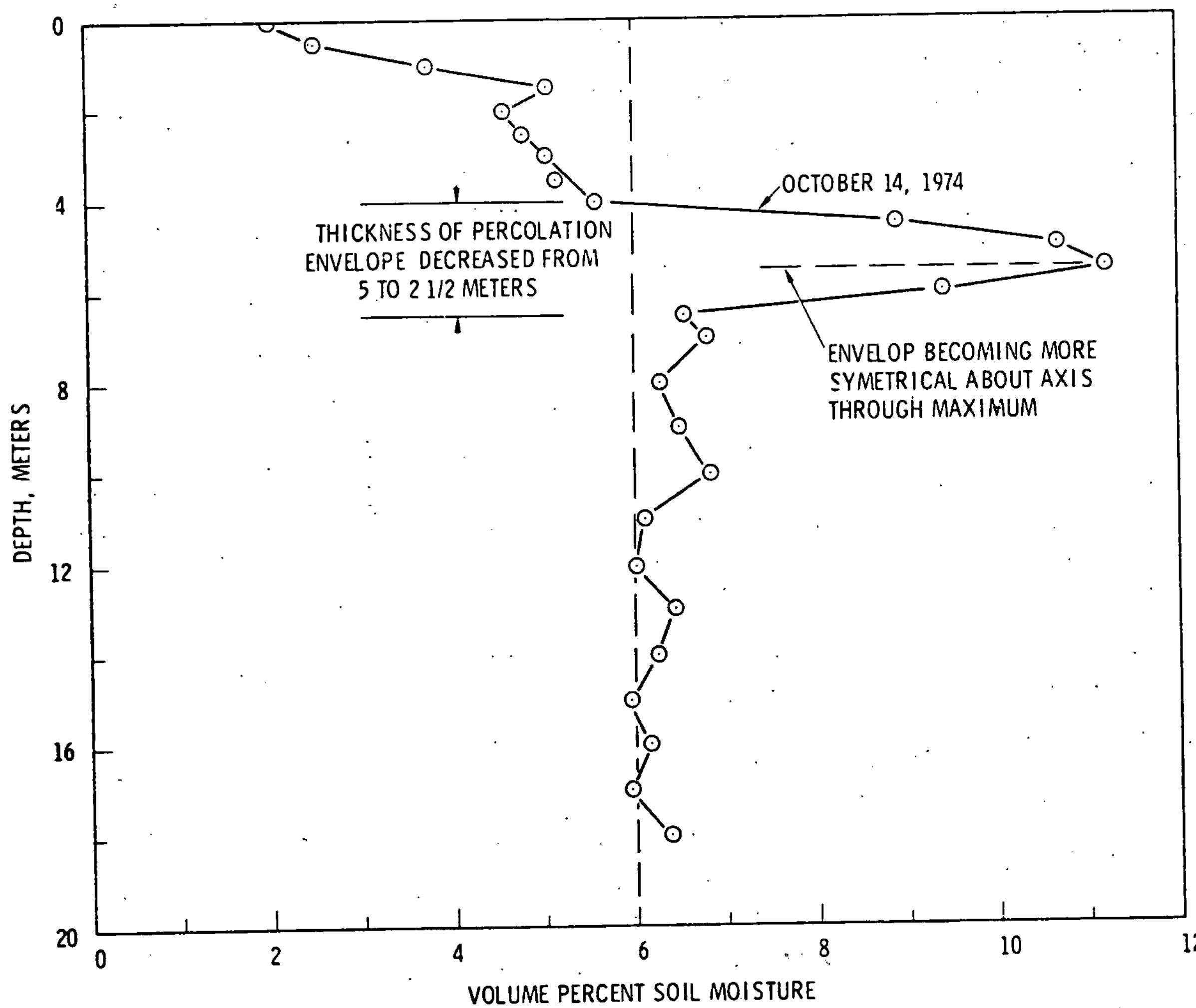


FIGURE 28

SELF-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of October 24, 1974, for Average of Tubes Numbers 1 and 2)

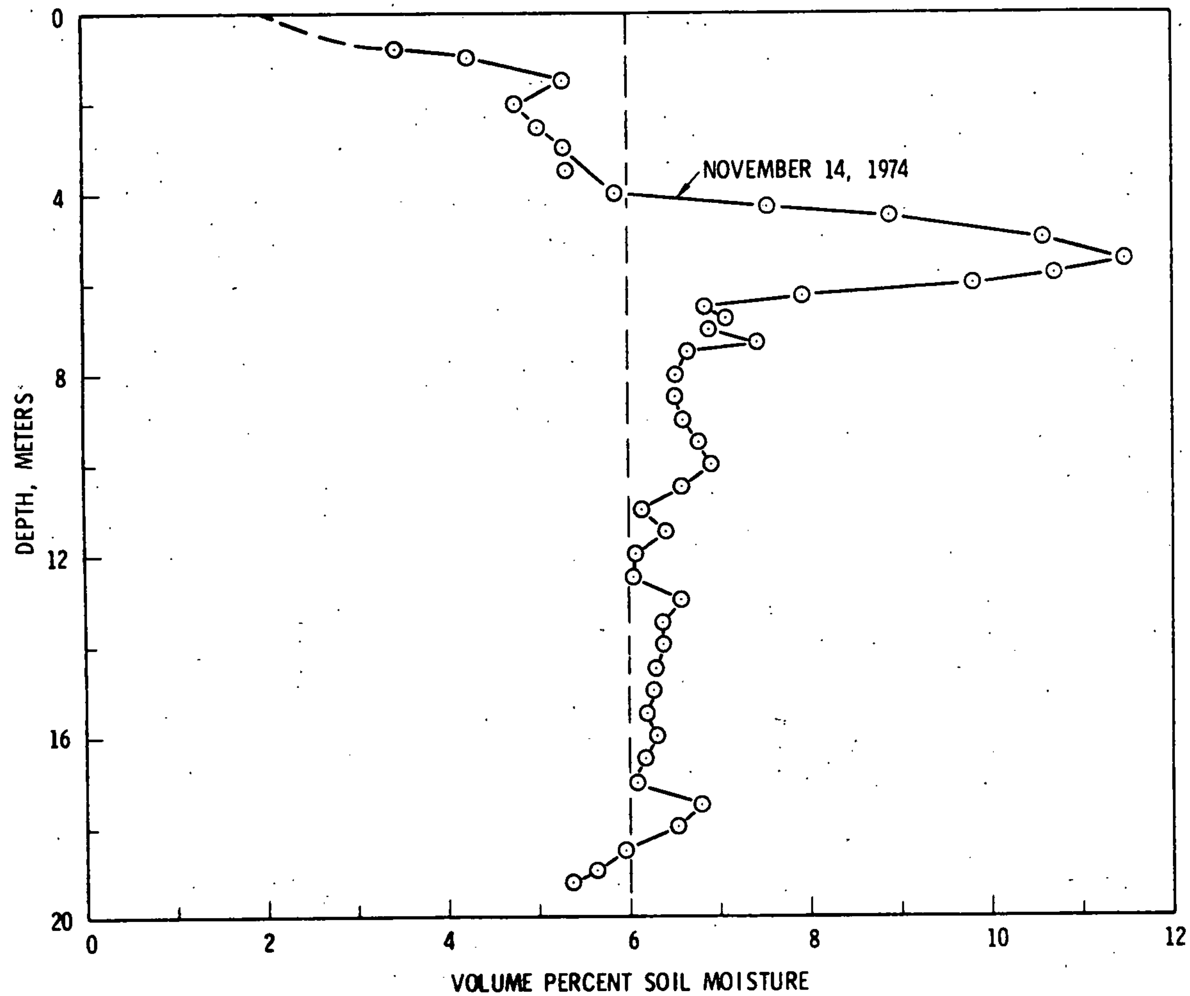


FIGURE 29

SOIL-MOISTURE PROFILE IN OPEN-BOTTOM LYSIMETER
(As of November 14, 1974, for Average of Tubes Numbers 1 and 2)

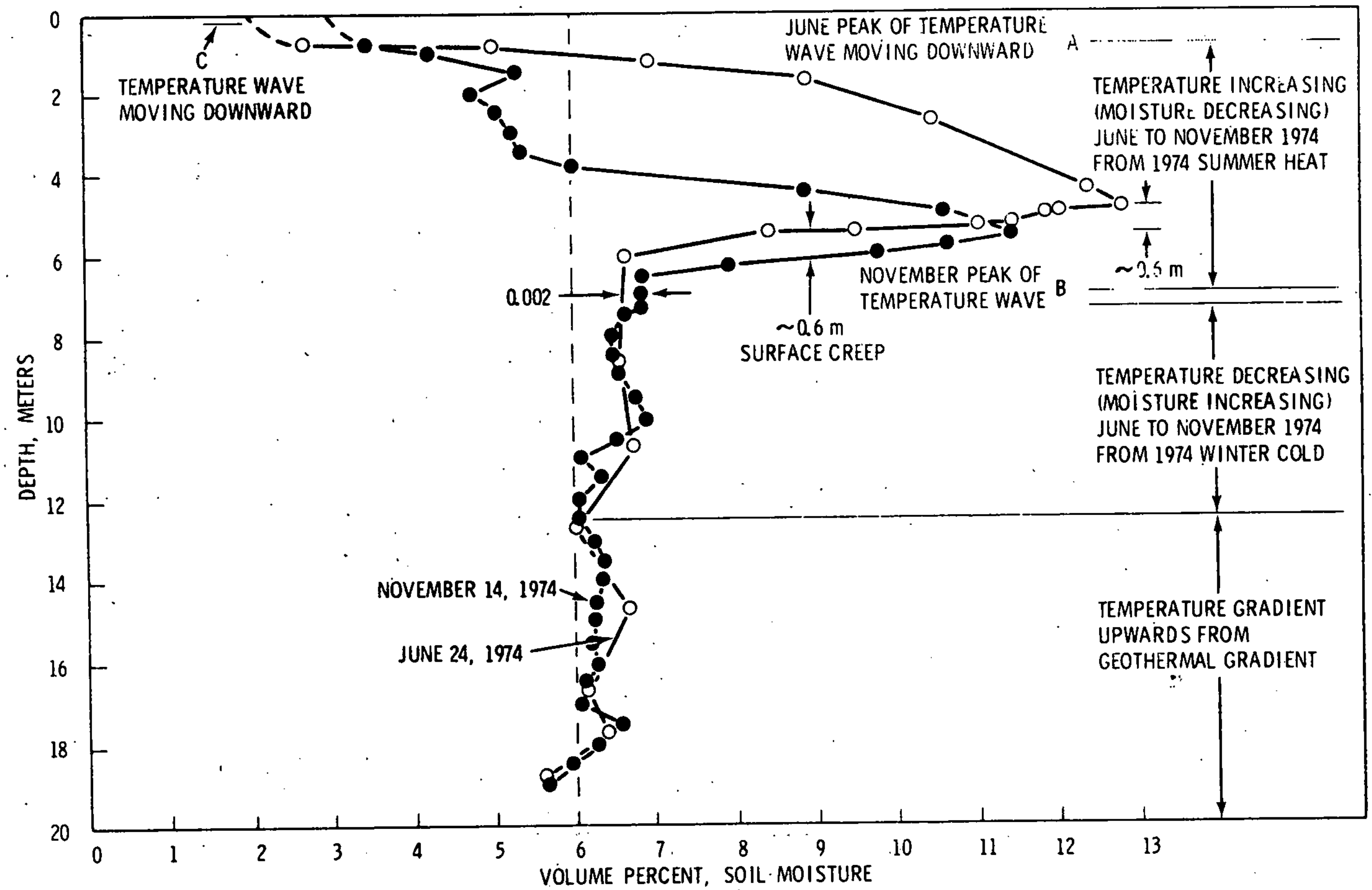


FIGURE 30

COMPARISON OF SOIL-MOISTURE PROFILES IN OPEN-BOTTOM LYSIMETER FOR JUNE AND NOVEMBER 1974 [As Average of Tubes 1 and 2 (June) and 1, 2, and 3 (November)]

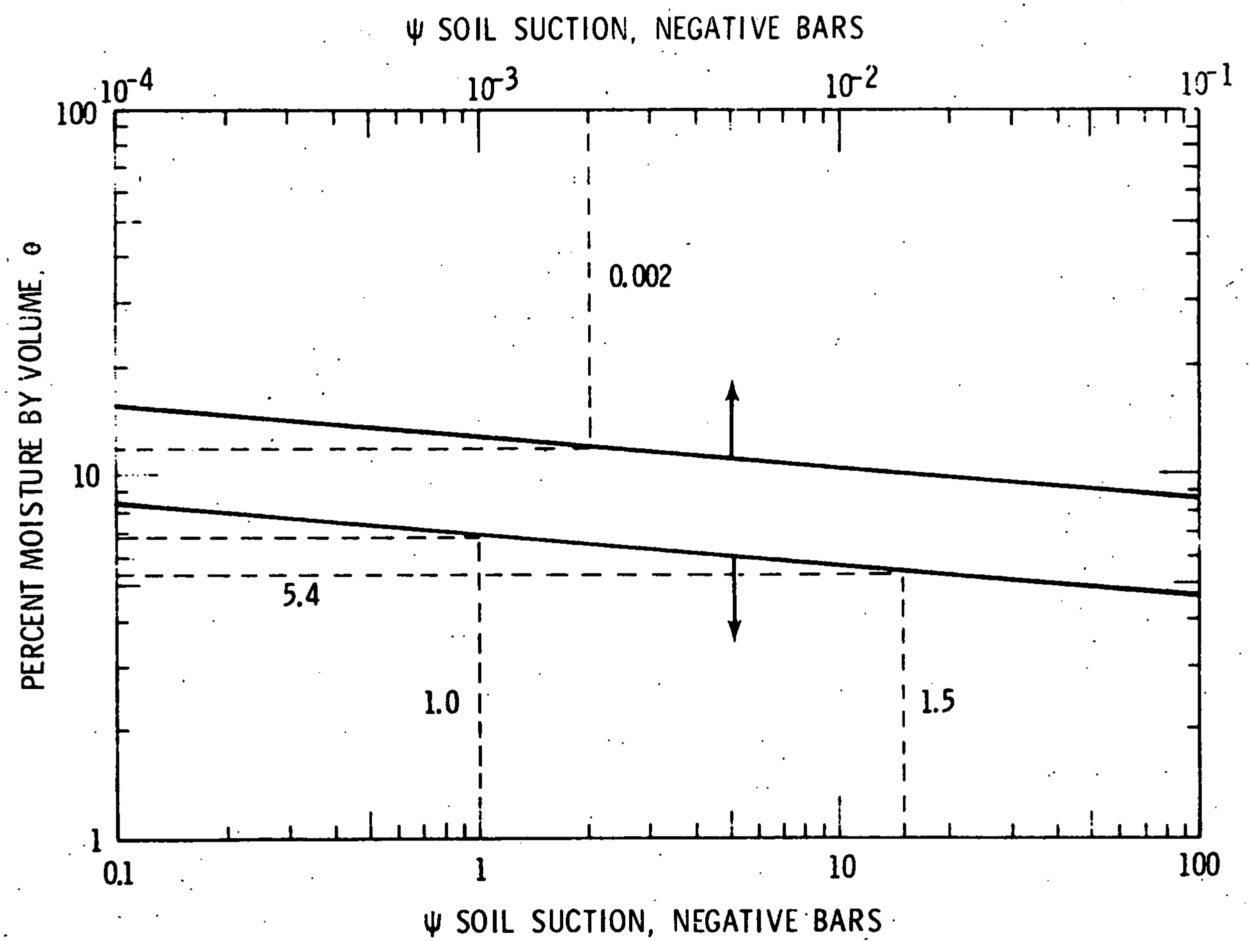


FIGURE 31

FRACTION SATURATION, θ, VERSUS WATER POTENTIAL, ψ, FOR LYSIMETER SOIL

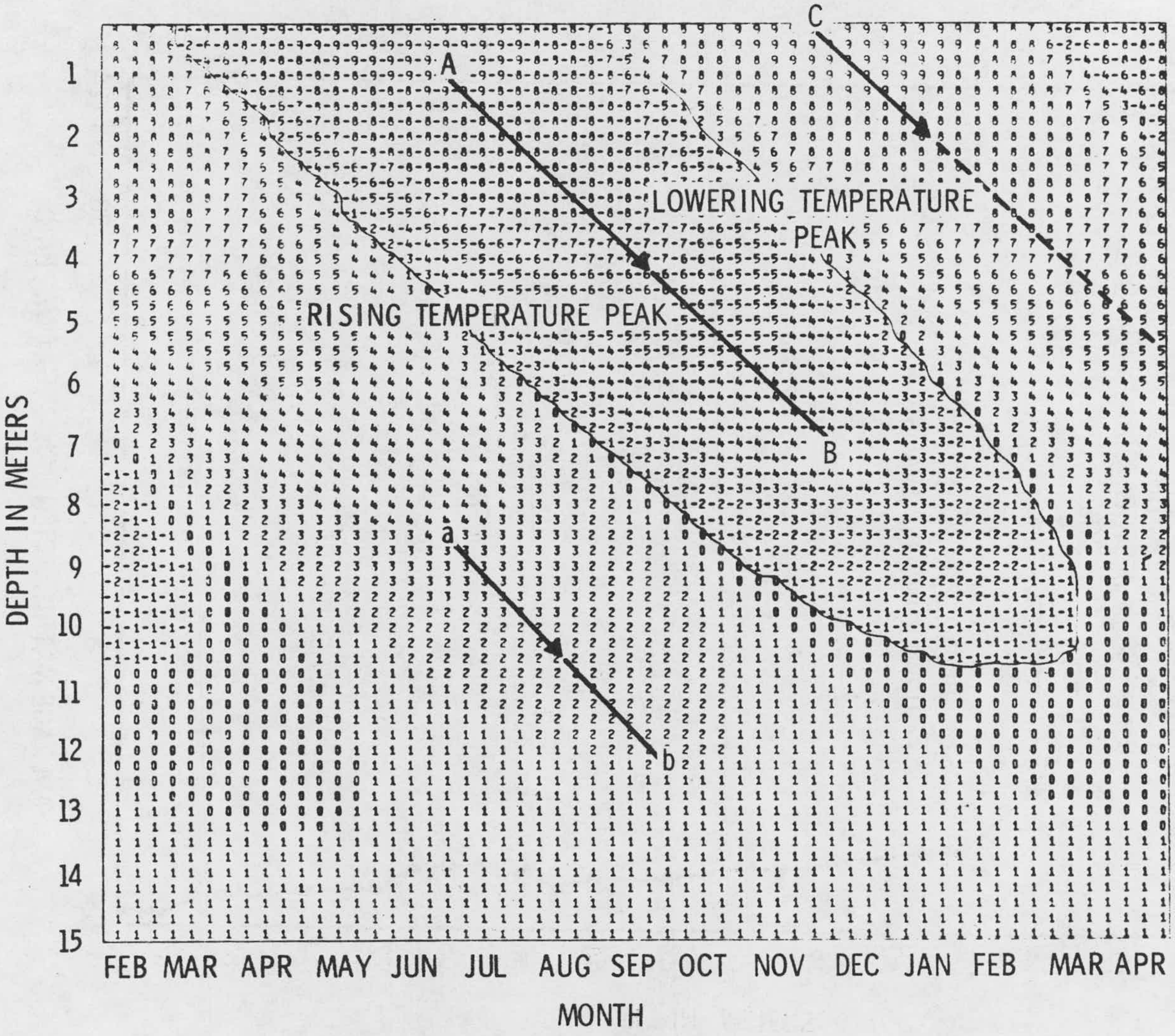


FIGURE 32

MAGNITUDES OF THERMAL DRIVING FORCES AS A FUNCTION OF DEPTH AND TIME

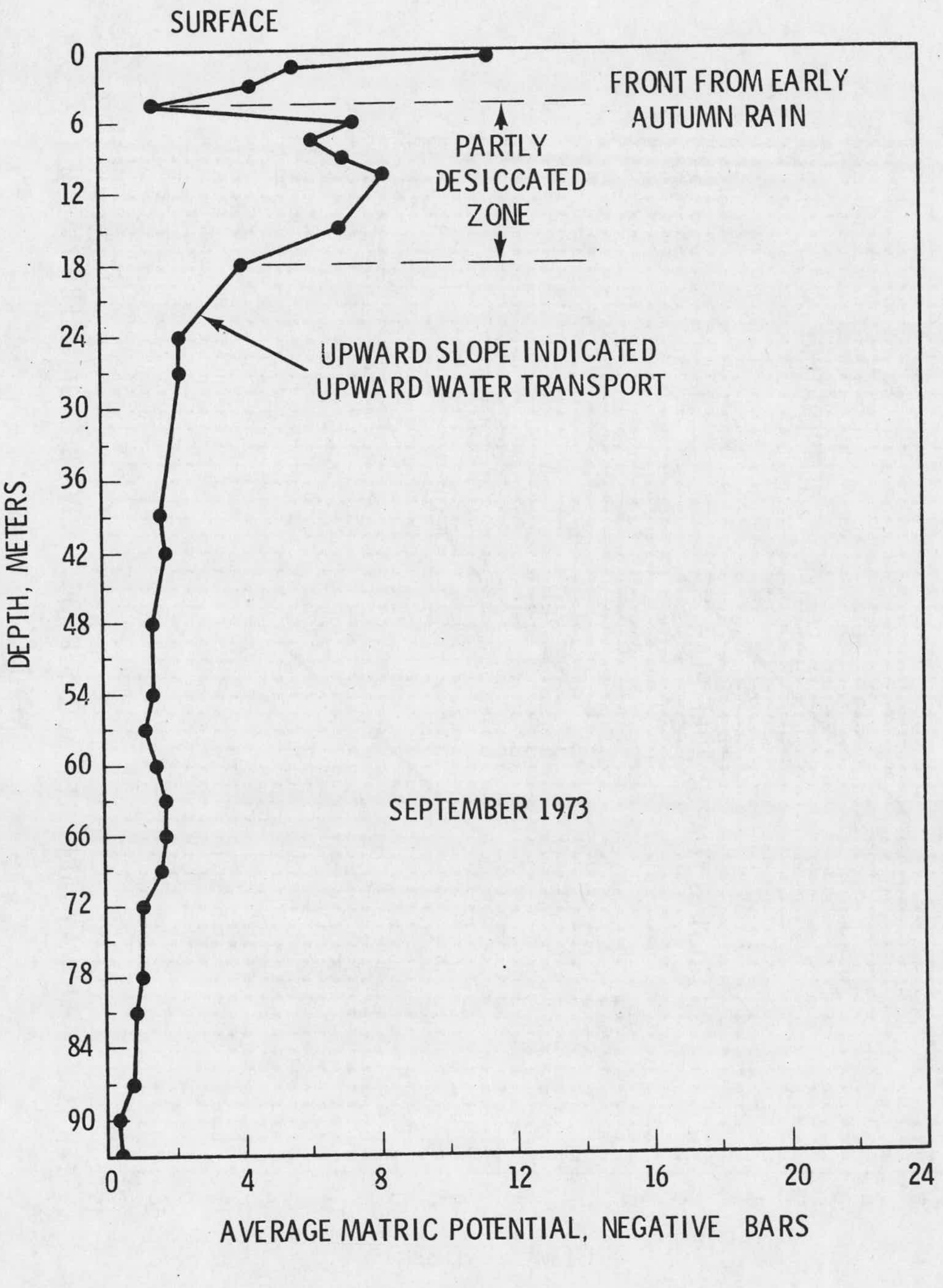


FIGURE 33

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES
AS OF SEPTEMBER 1973

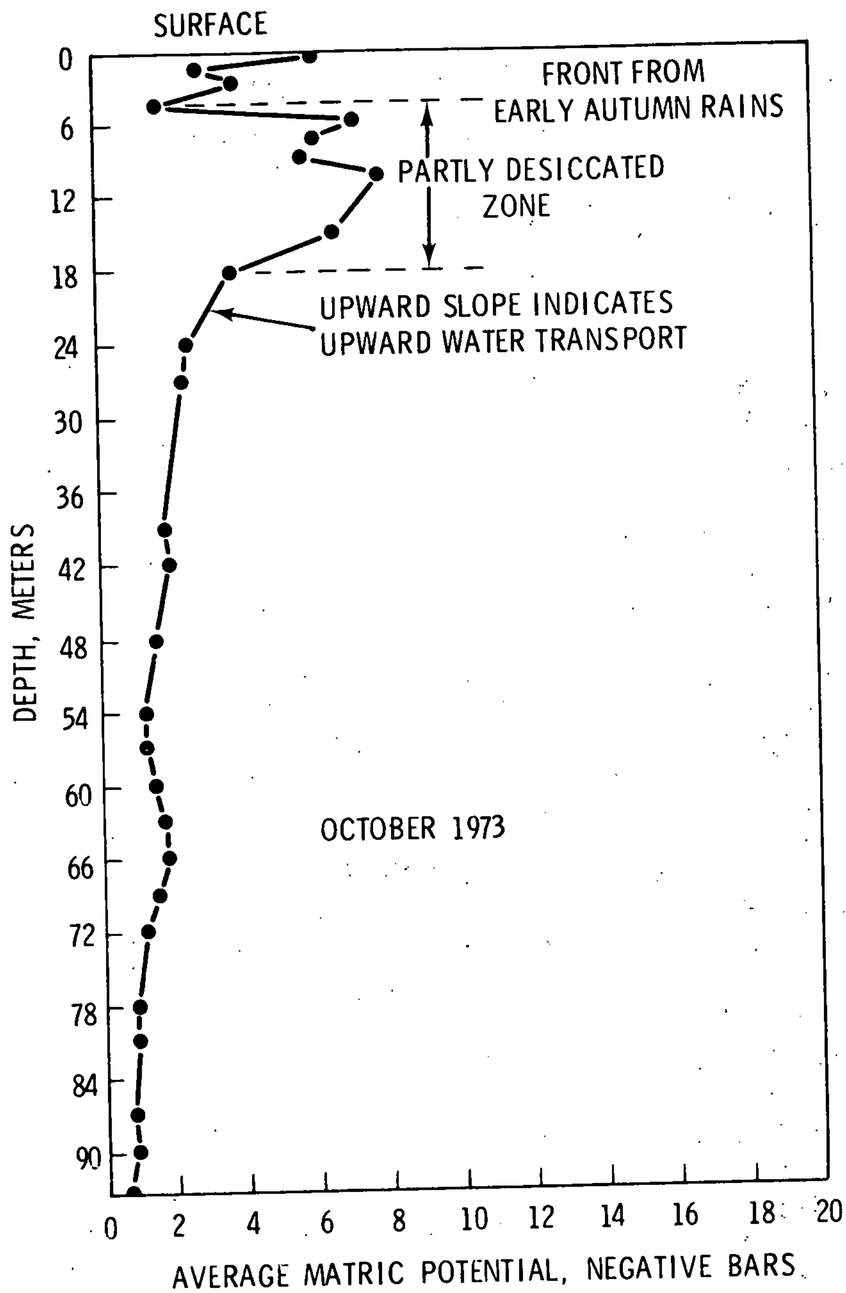


FIGURE 34

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF OCTOBER 1973

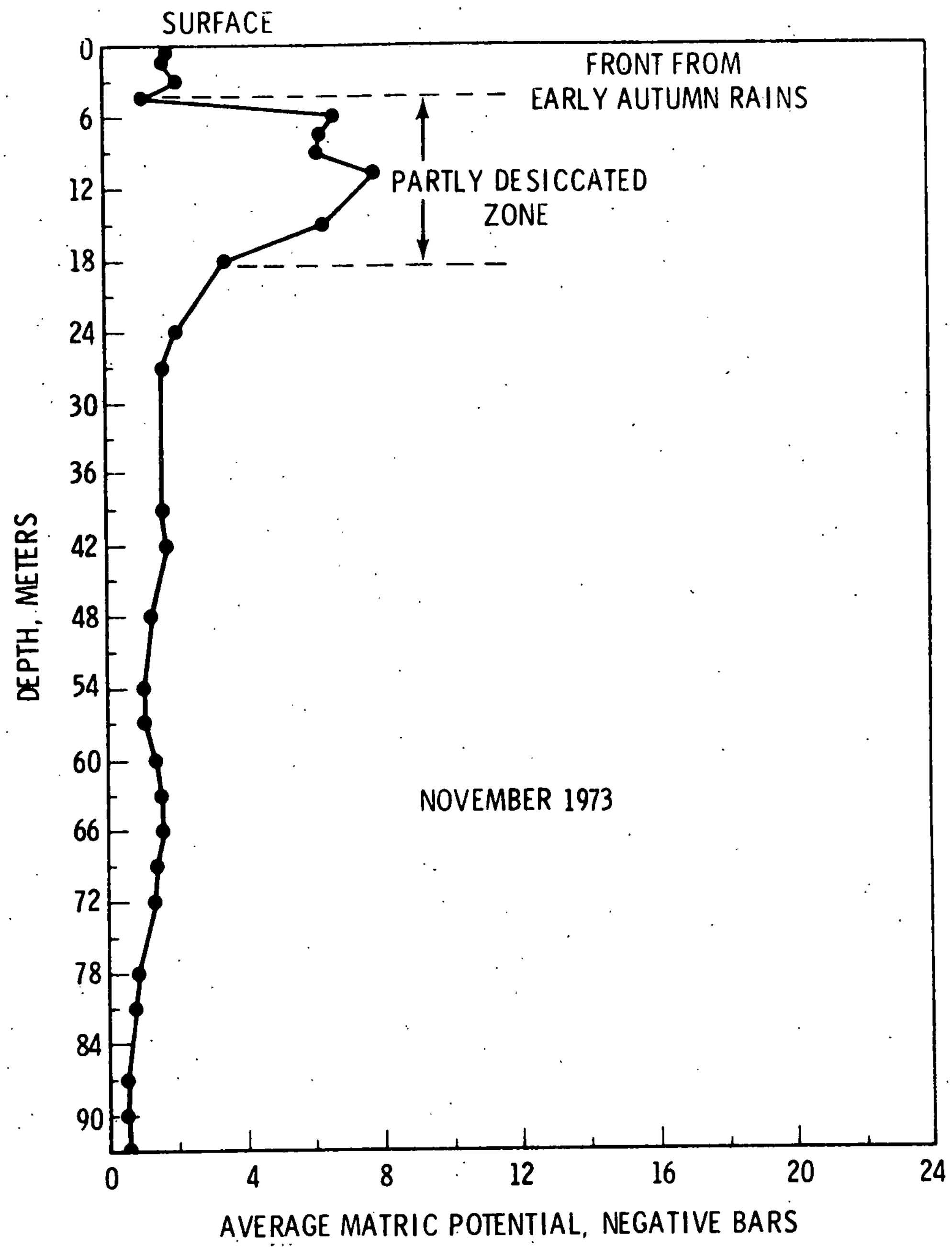


FIGURE 35

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES
AS OF NOVEMBER 1973

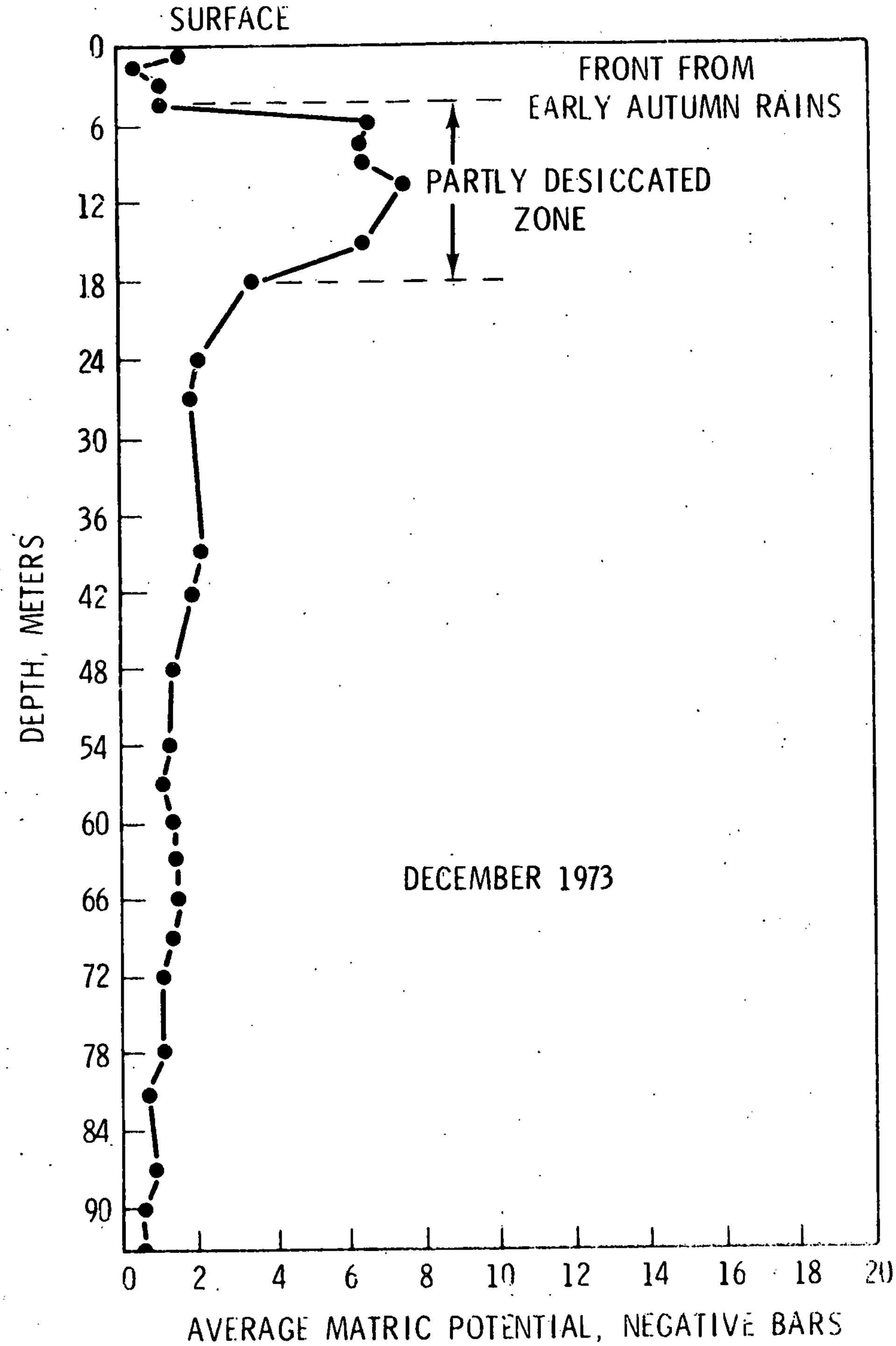


FIGURE 36

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES
AS OF DECEMBER 1973

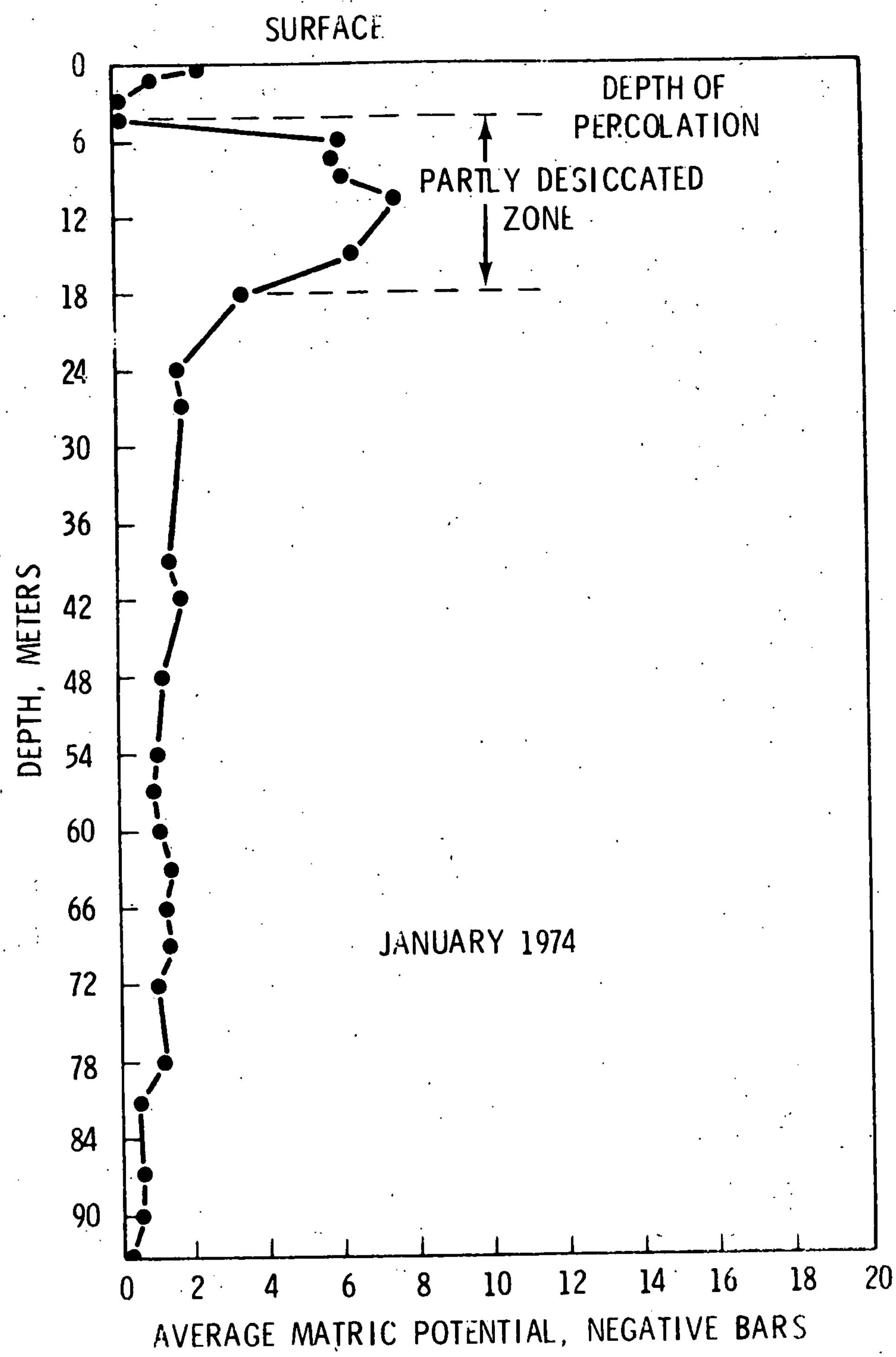


FIGURE 37

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES
AS OF JANUARY 1974

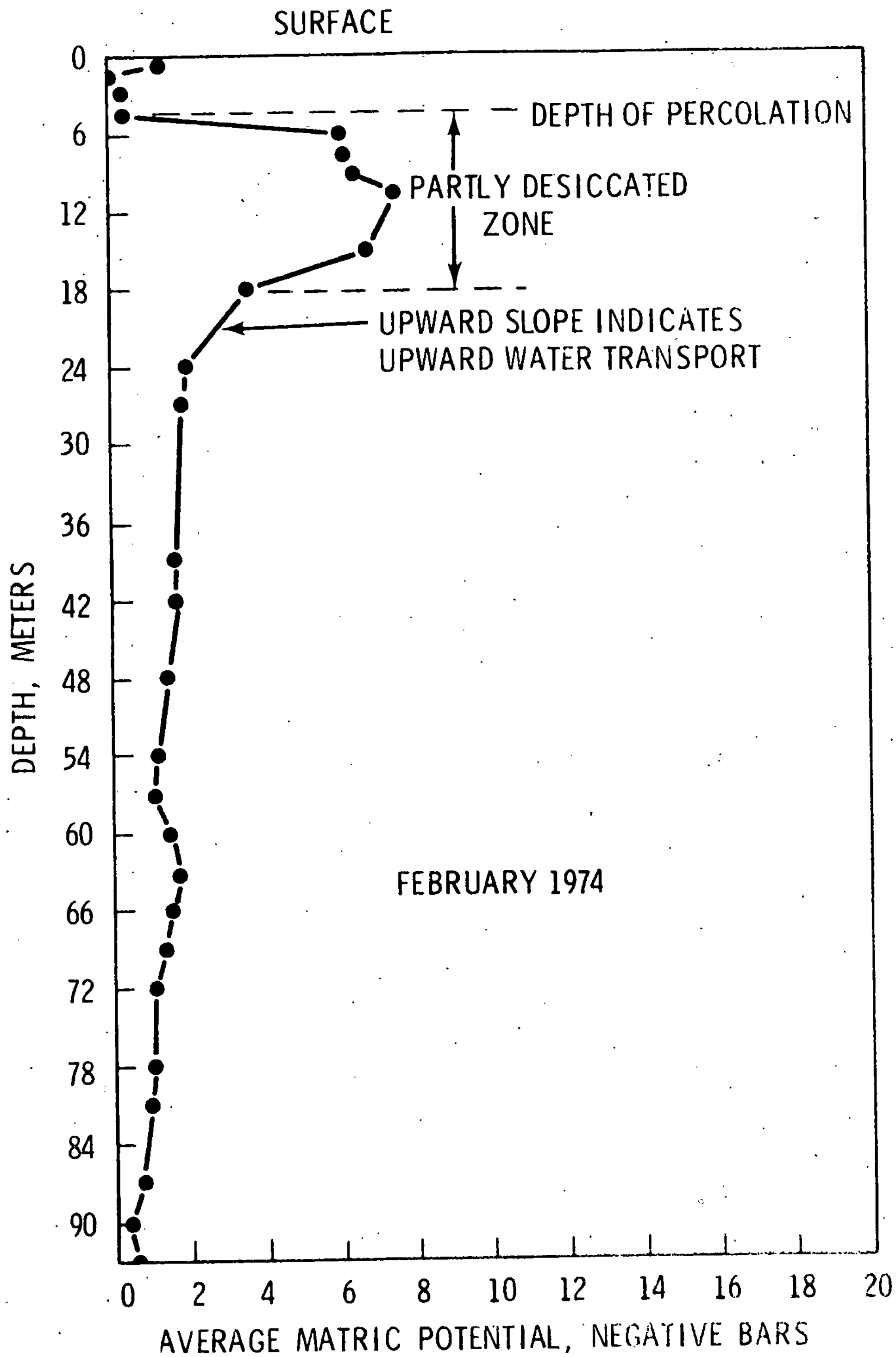


FIGURE 38

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES
AS OF FEBRUARY 1974

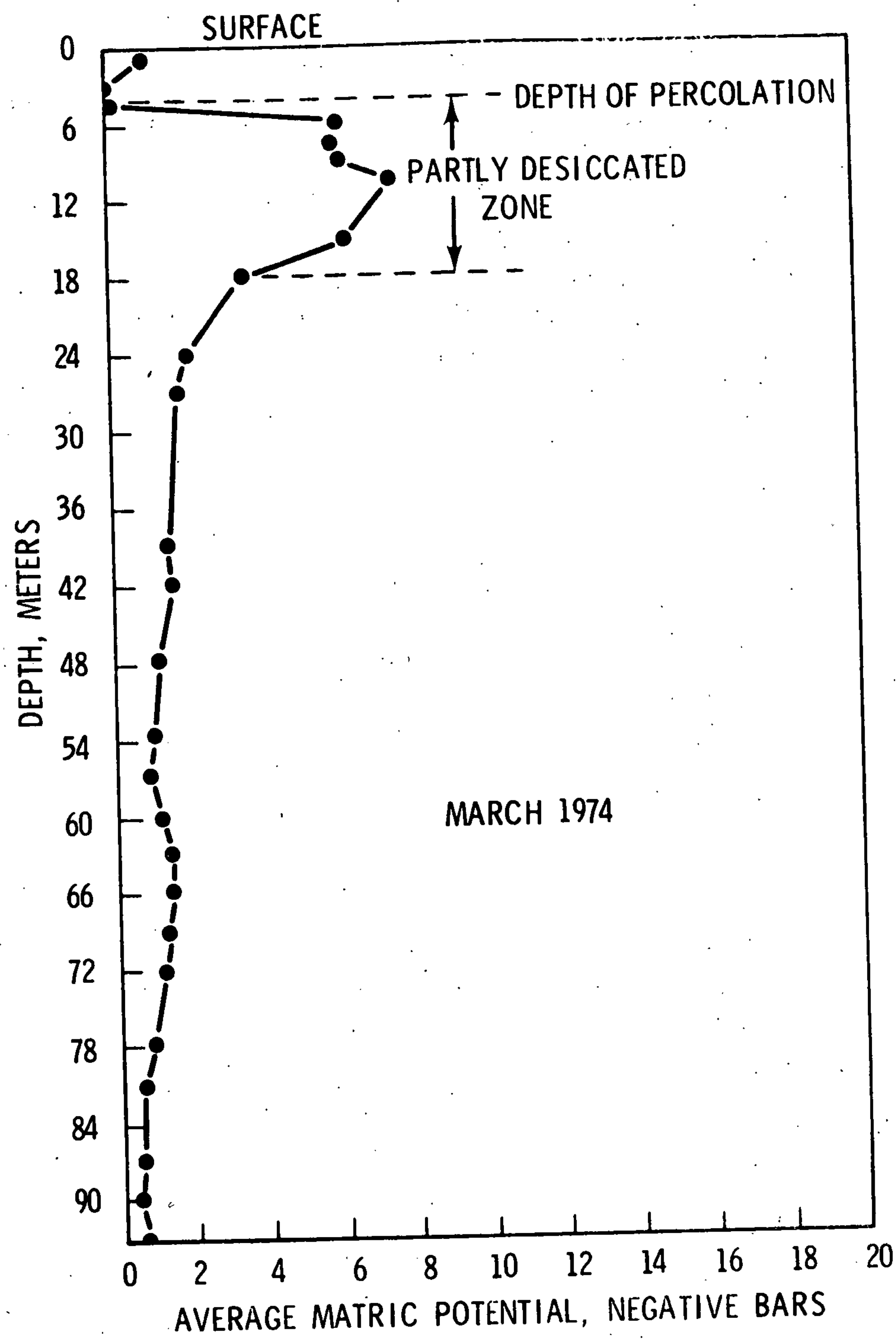


FIGURE 39

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF MARCH 1974

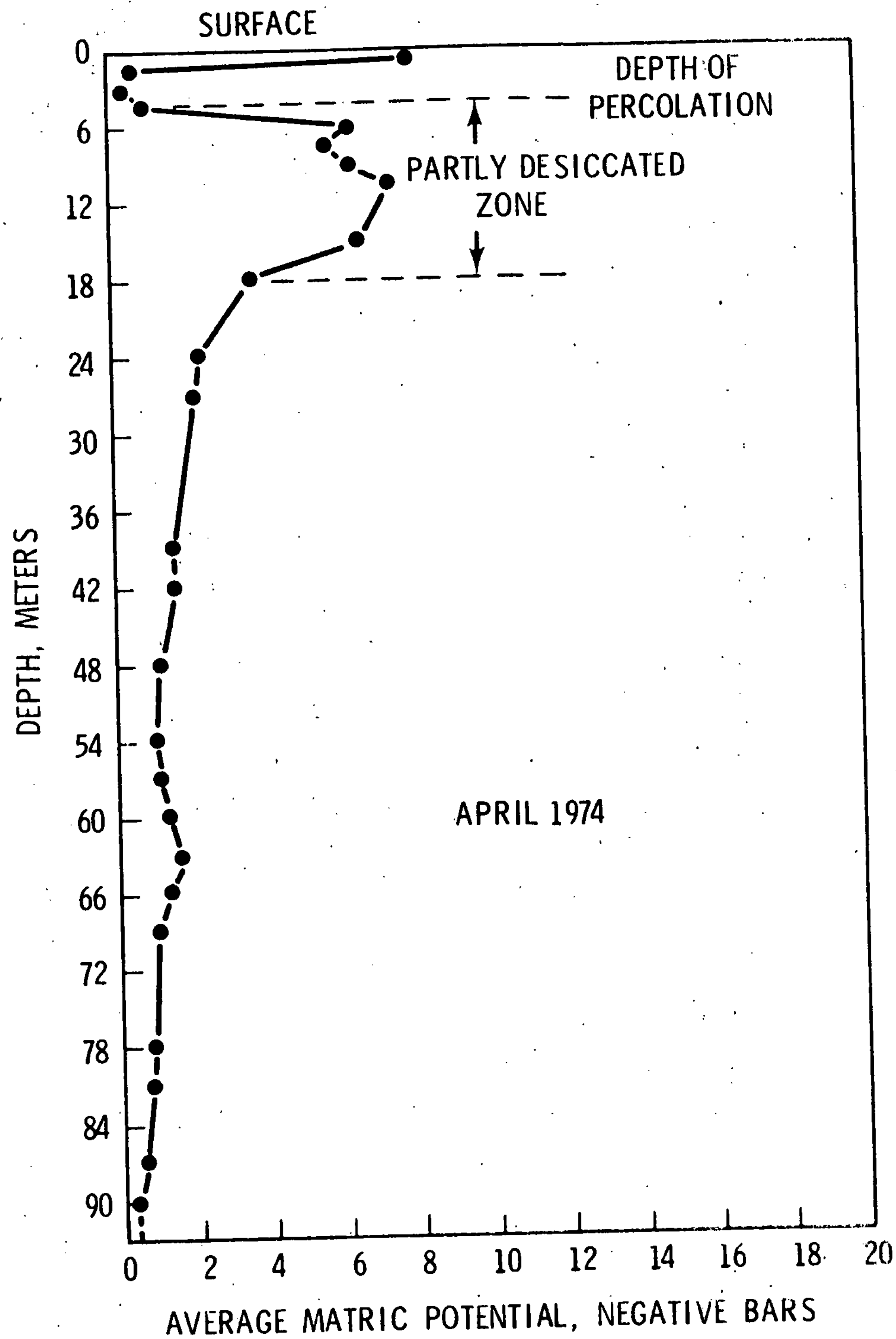


FIGURE 40

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF APRIL 1974

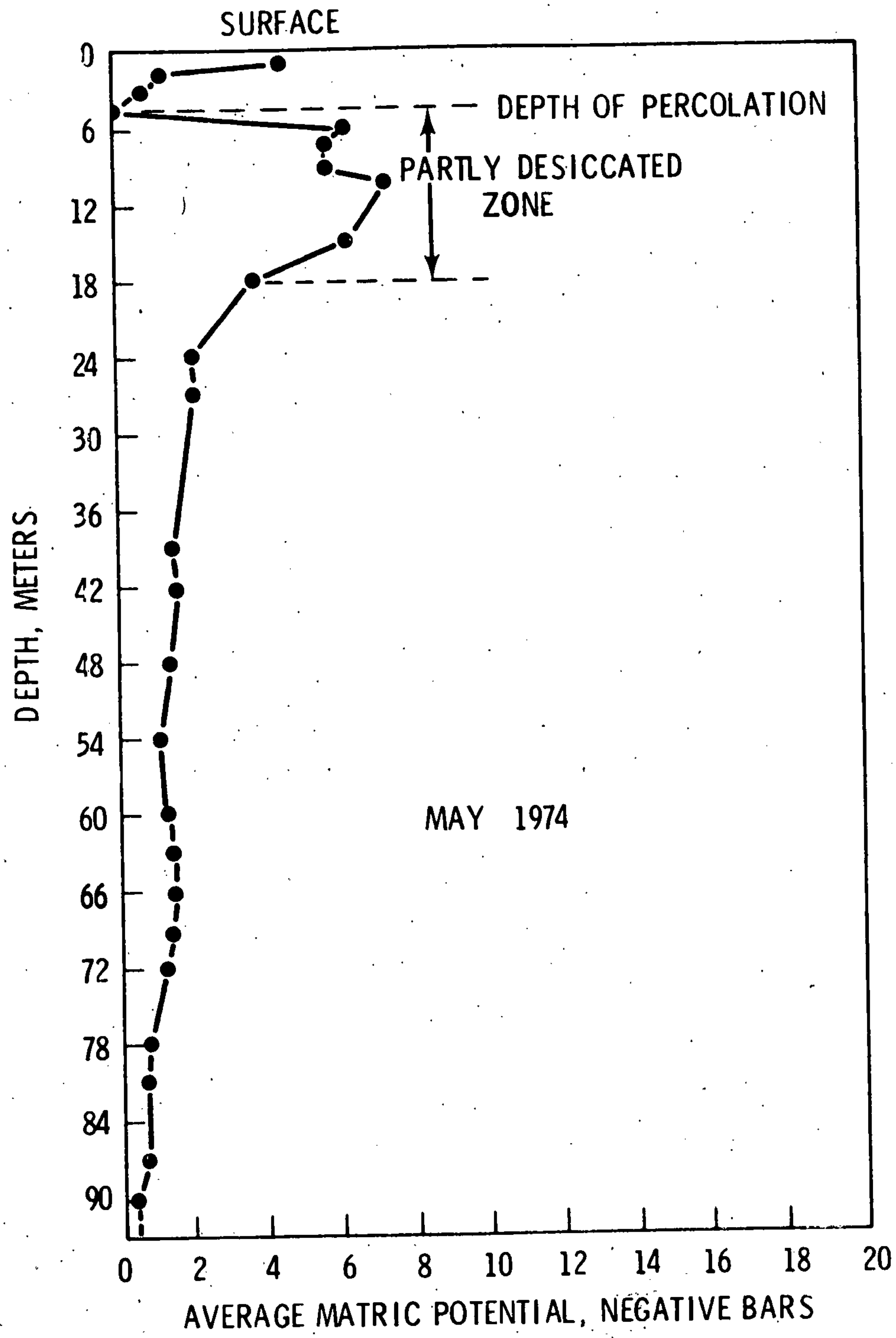


FIGURE 41

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF MAY 1974

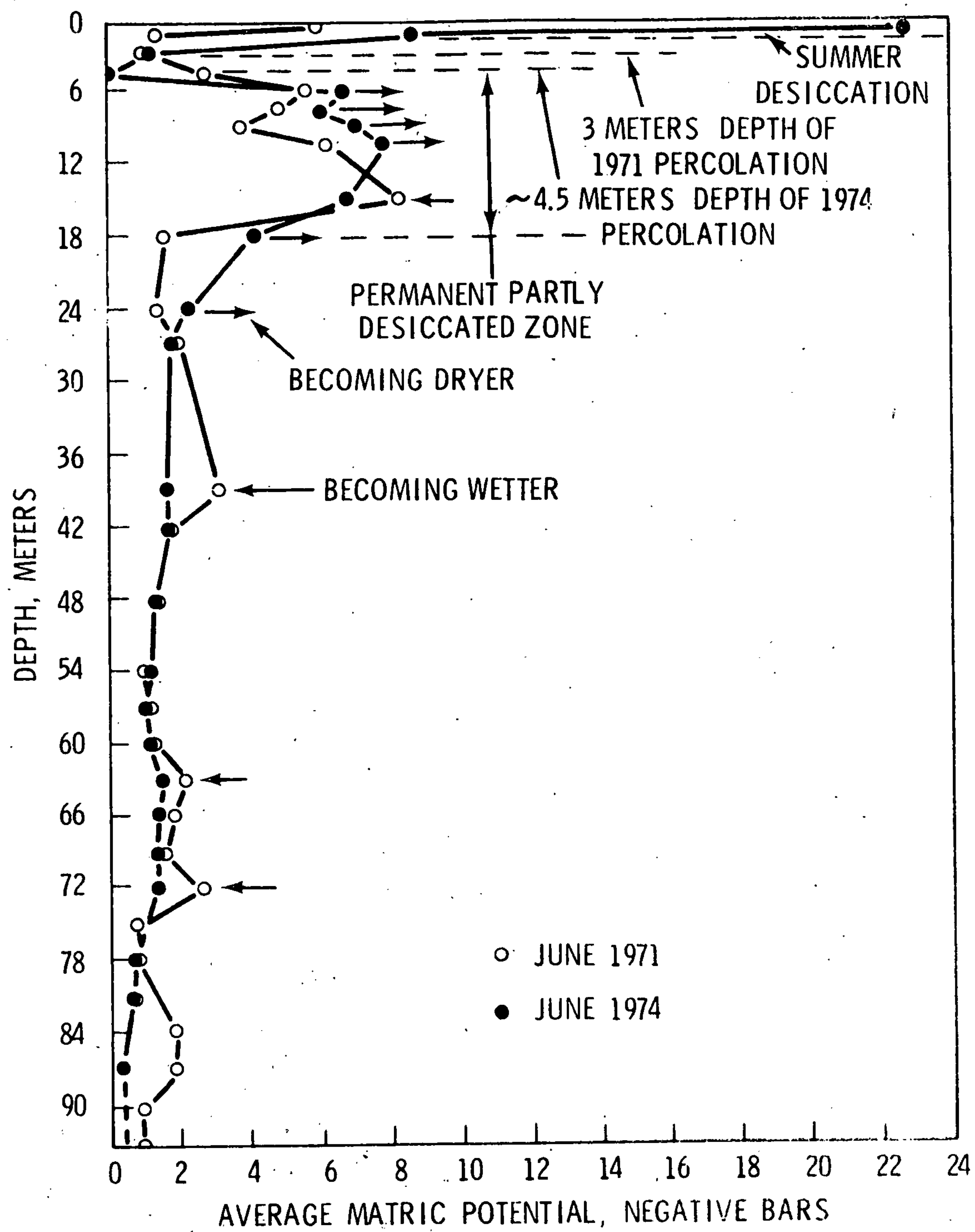


FIGURE 42

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF JUNE 1974

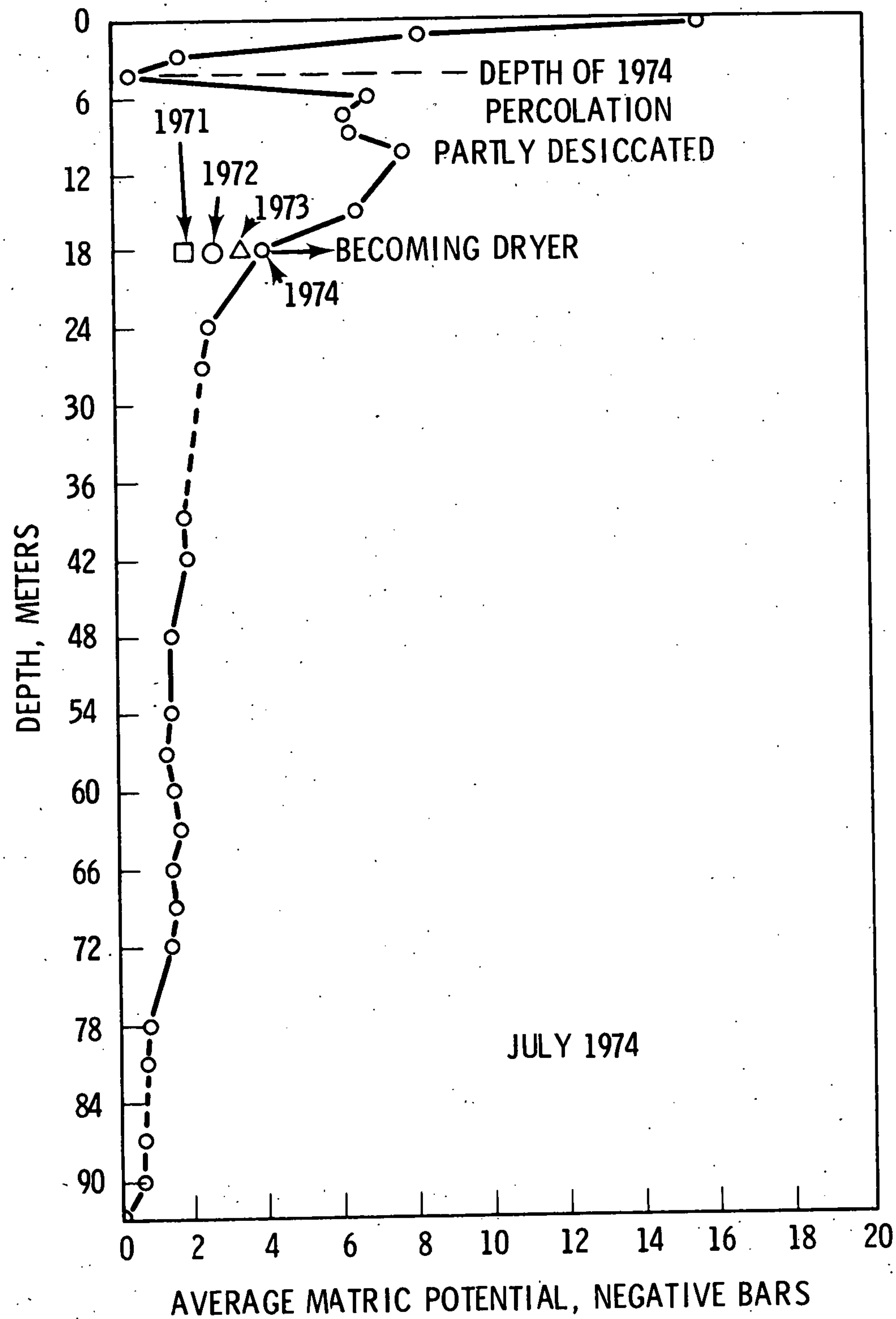


FIGURE 43

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF JULY 1974

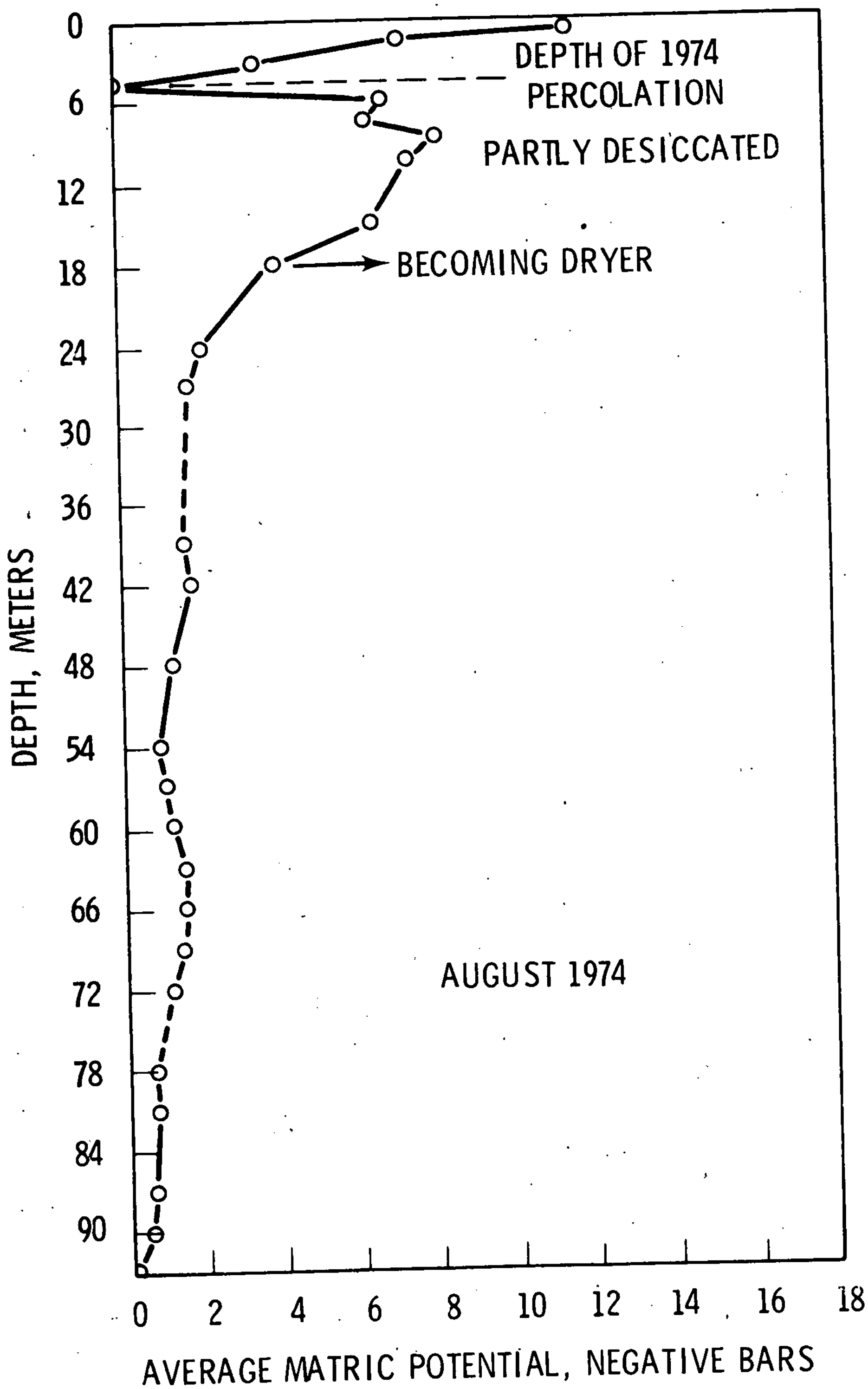


FIGURE 44

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AT OF AUGUST 1974

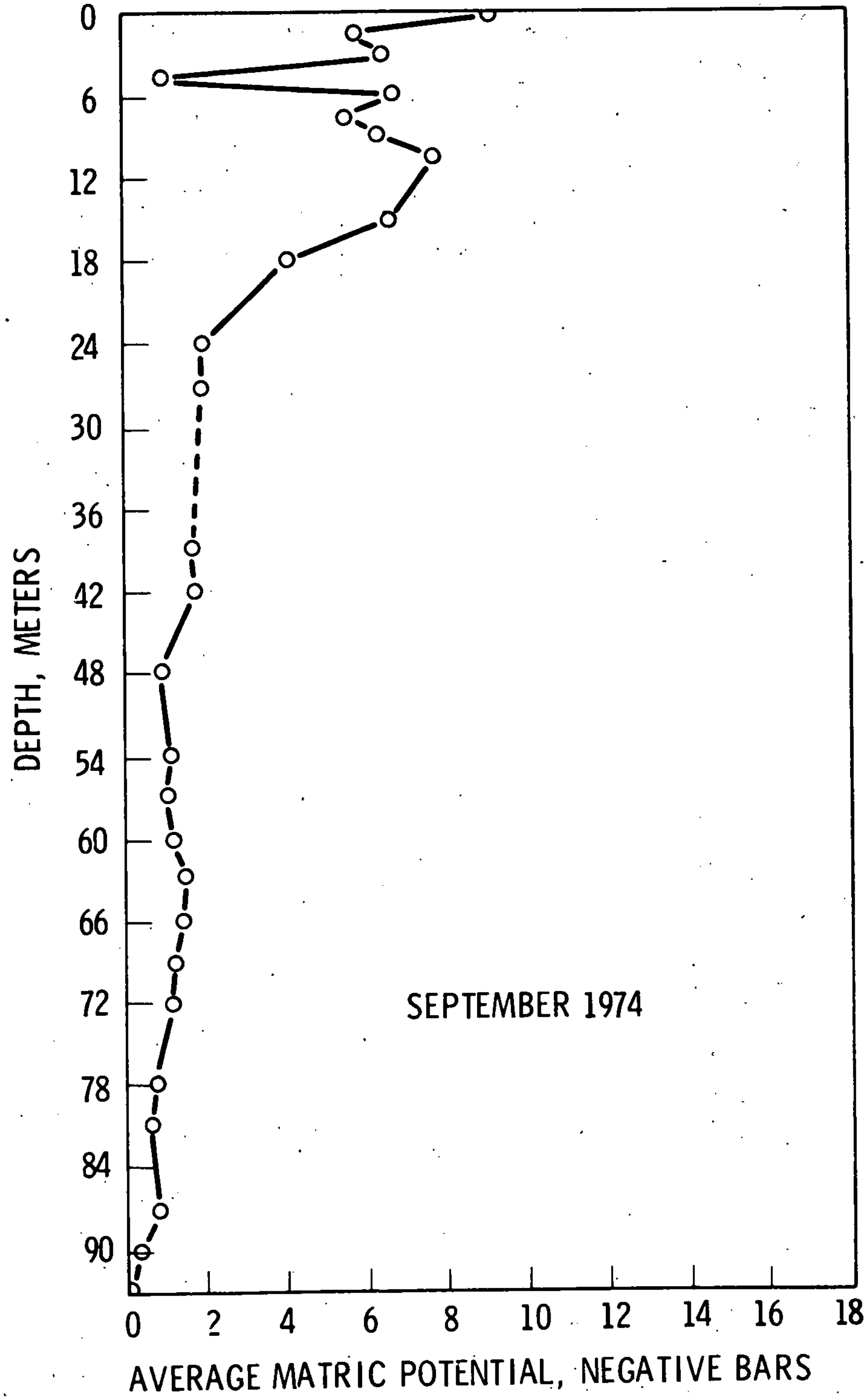


FIGURE 45

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF SEPTEMBER 1974

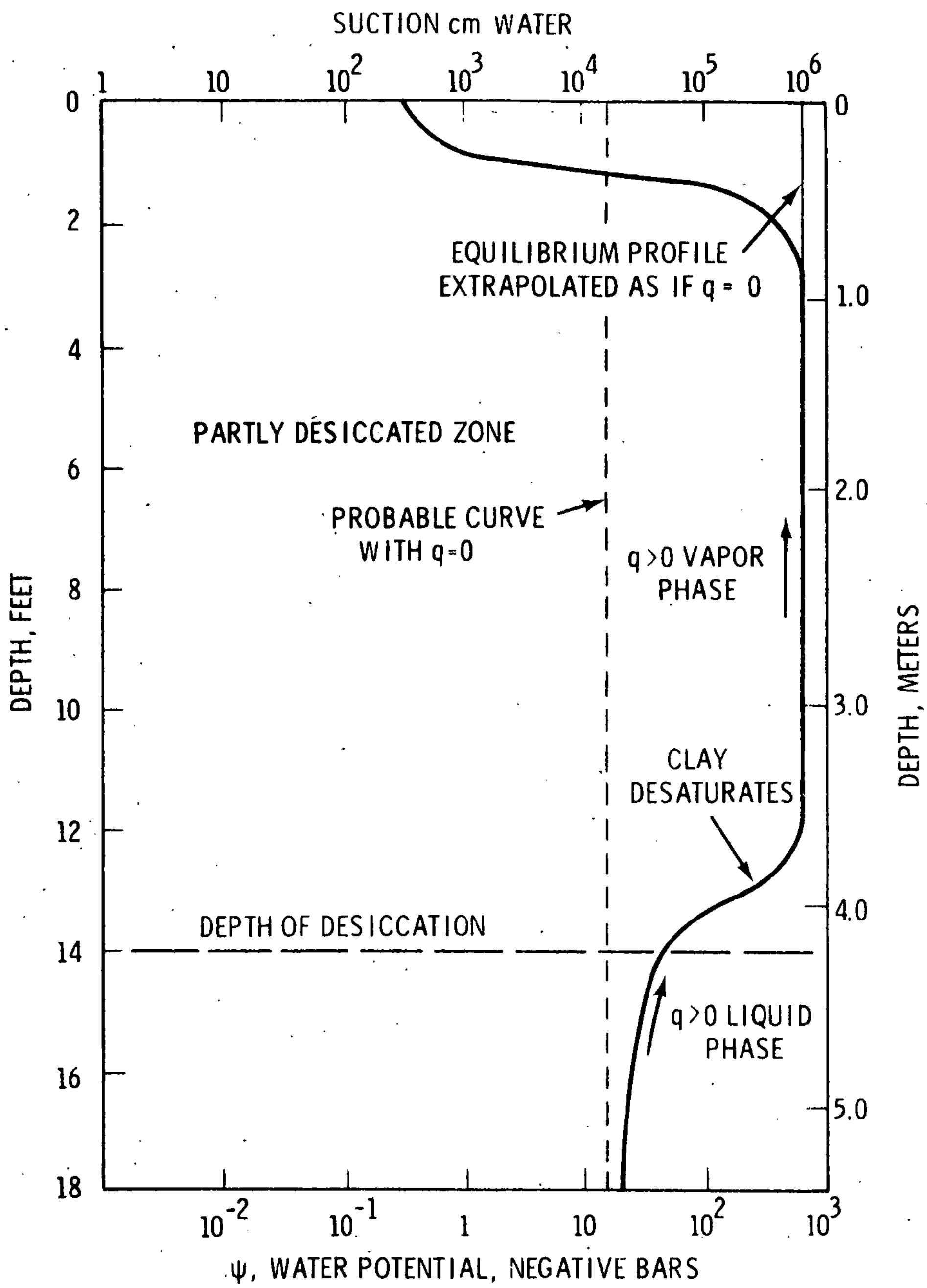


FIGURE 46

EQUILIBRIUM WATER POTENTIAL IN ARID AREAS
(B. G. Richards)[7]

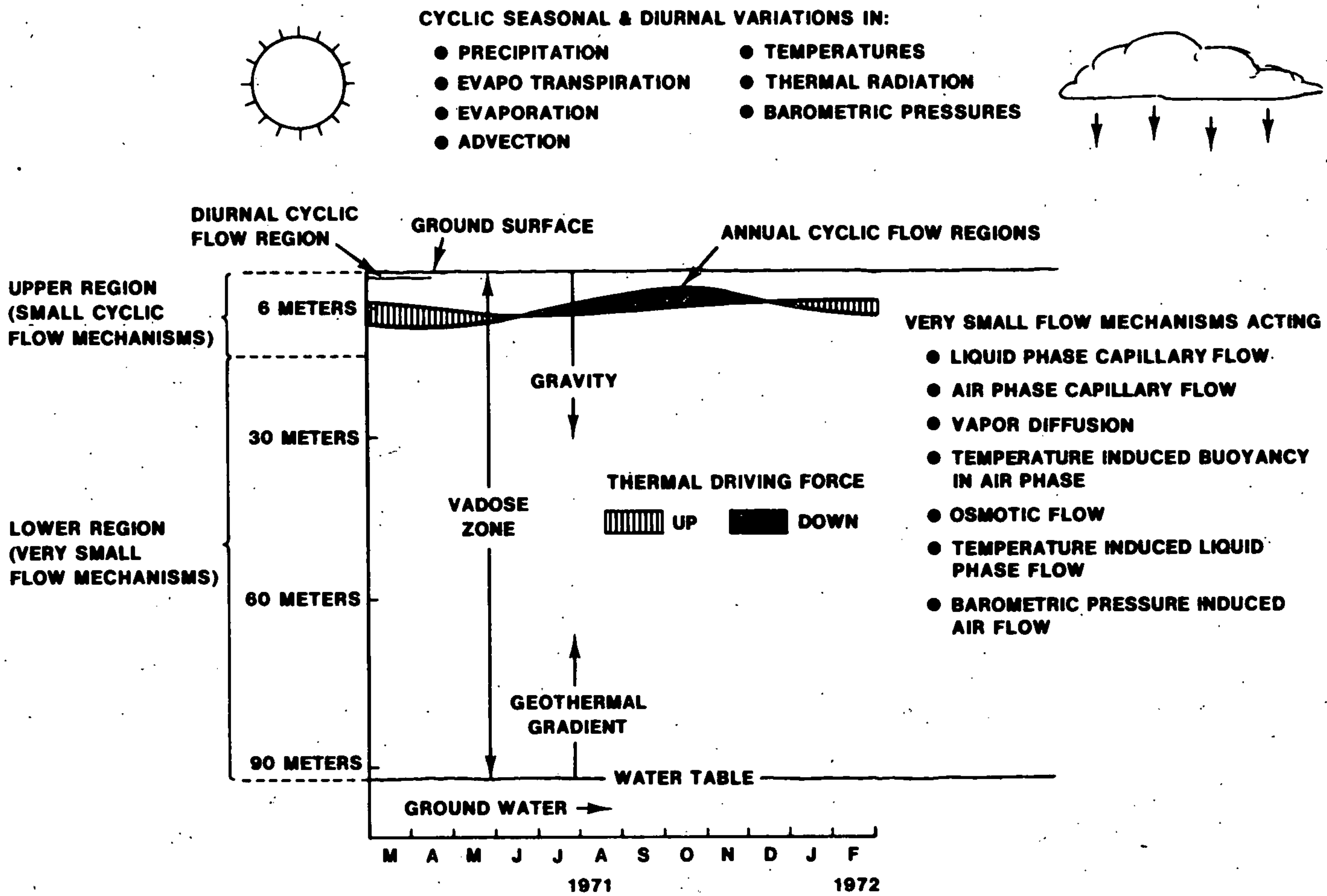


FIGURE 47

TRANSPORT MECHANISMS BASIC TO MOISTURE REDISTRIBUTION IN SEMI-ARID VADOSE ZONES

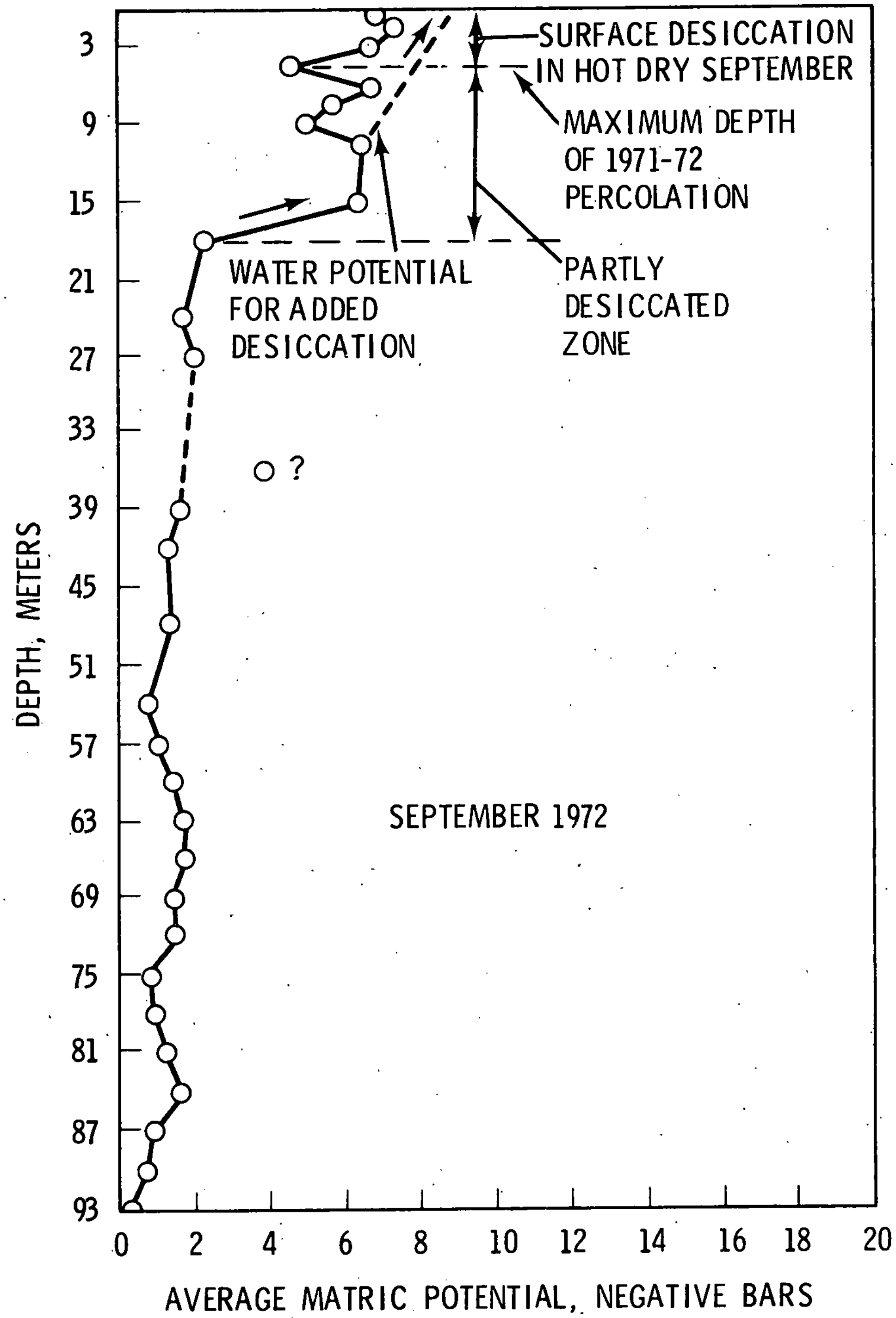


FIGURE 48

AVERAGE MATRIC POTENTIAL AT 32-49 COORDINATES AS OF SEPTEMBER 1972

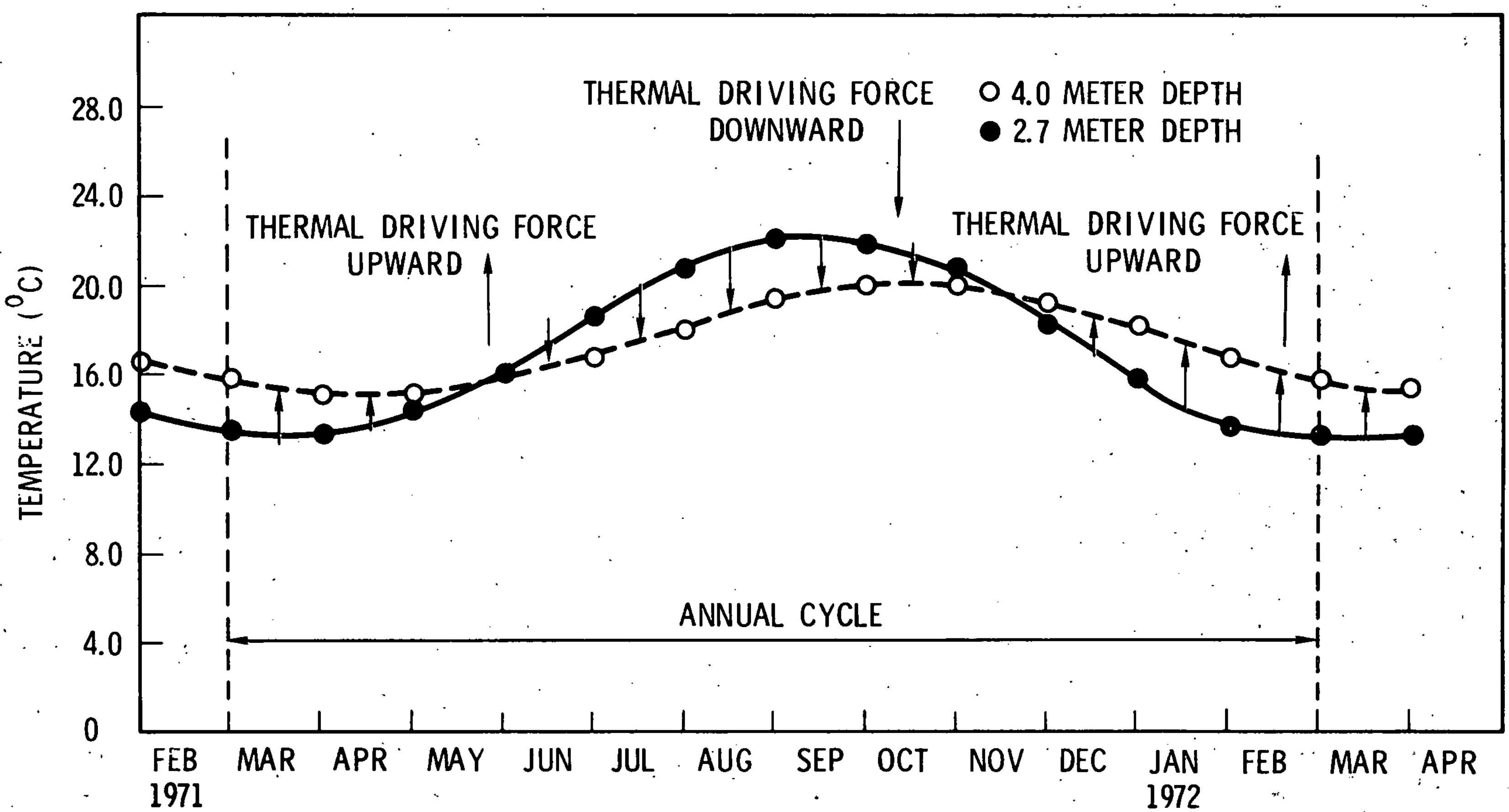


FIGURE 49

ANNUAL CYCLIC THERMAL DRIVING FORCE AT 32-49 COORDINATES
BETWEEN 4.0- TO 2.7-METER DEPTH

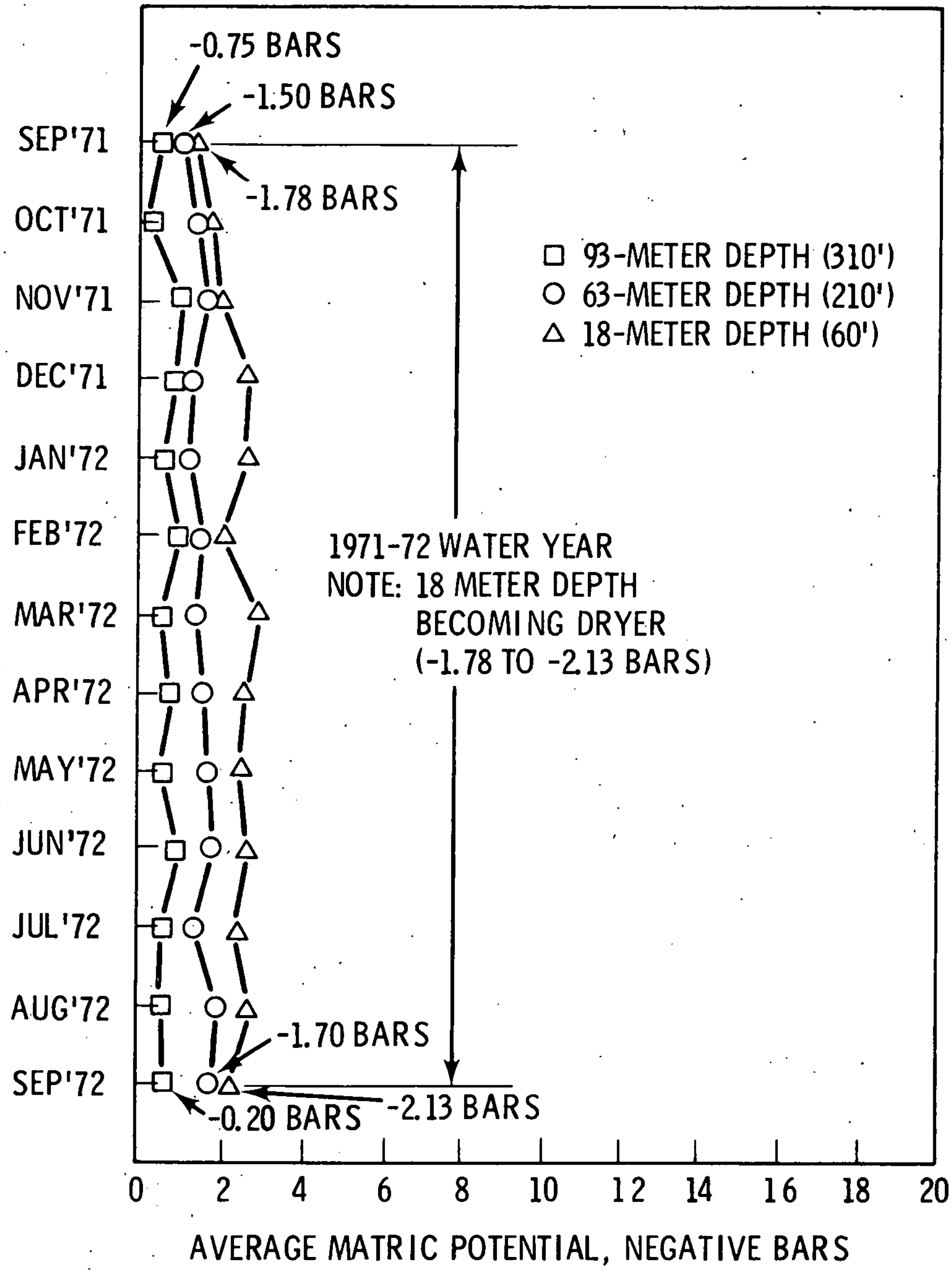


FIGURE 50

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 18-, 63-, AND 93-METER DEPTHS AT 32-49D SITE

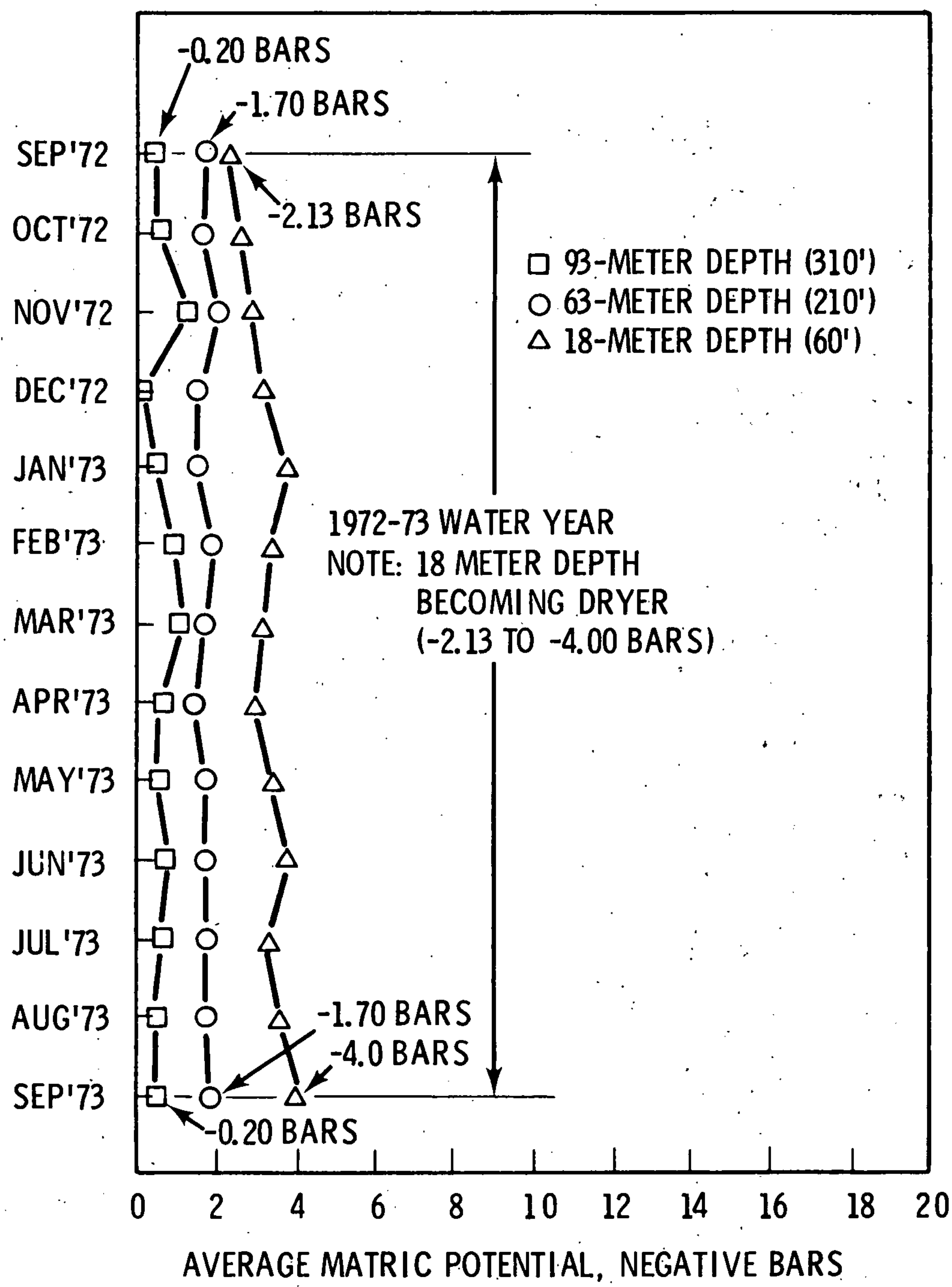


FIGURE 51

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 18-, 63-, AND 93-METER DEPTHS AT 32-49D SITE

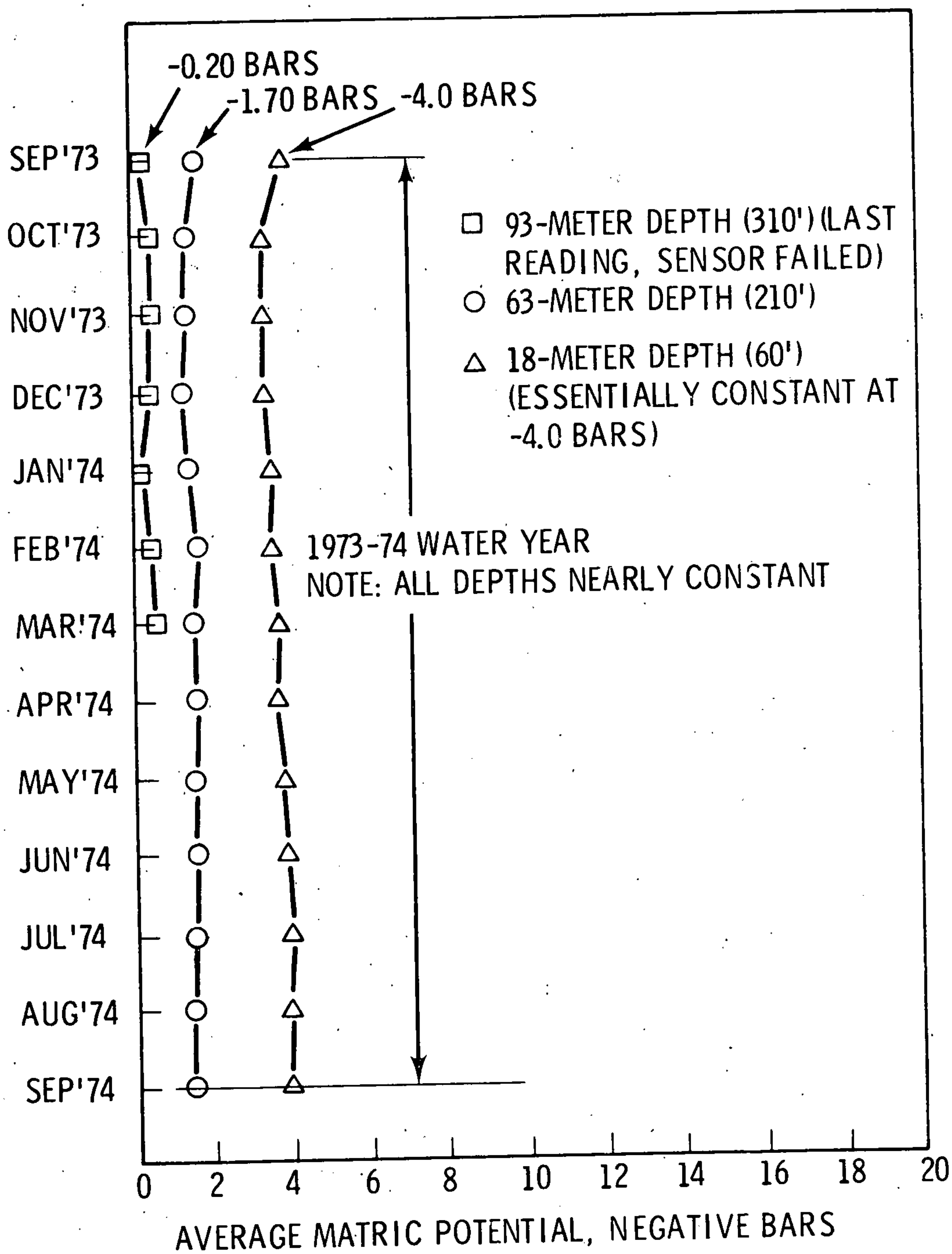


FIGURE 52

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 18-, 63-, AND 93-METER DEPTHS AT 32-49D SITE

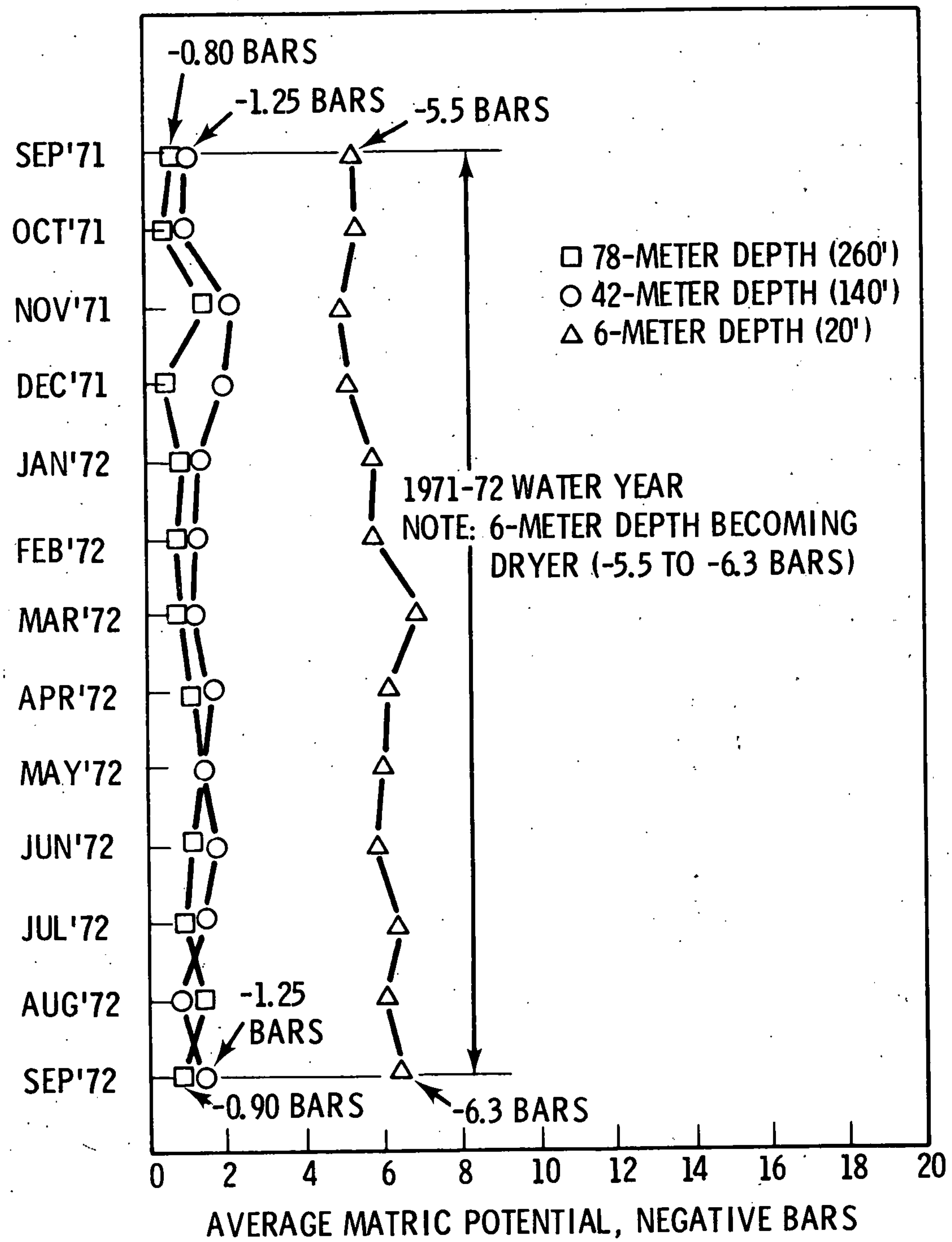


FIGURE 53

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 6-, 42-, AND 78-METER DEPTHS AT 32-49D SITE

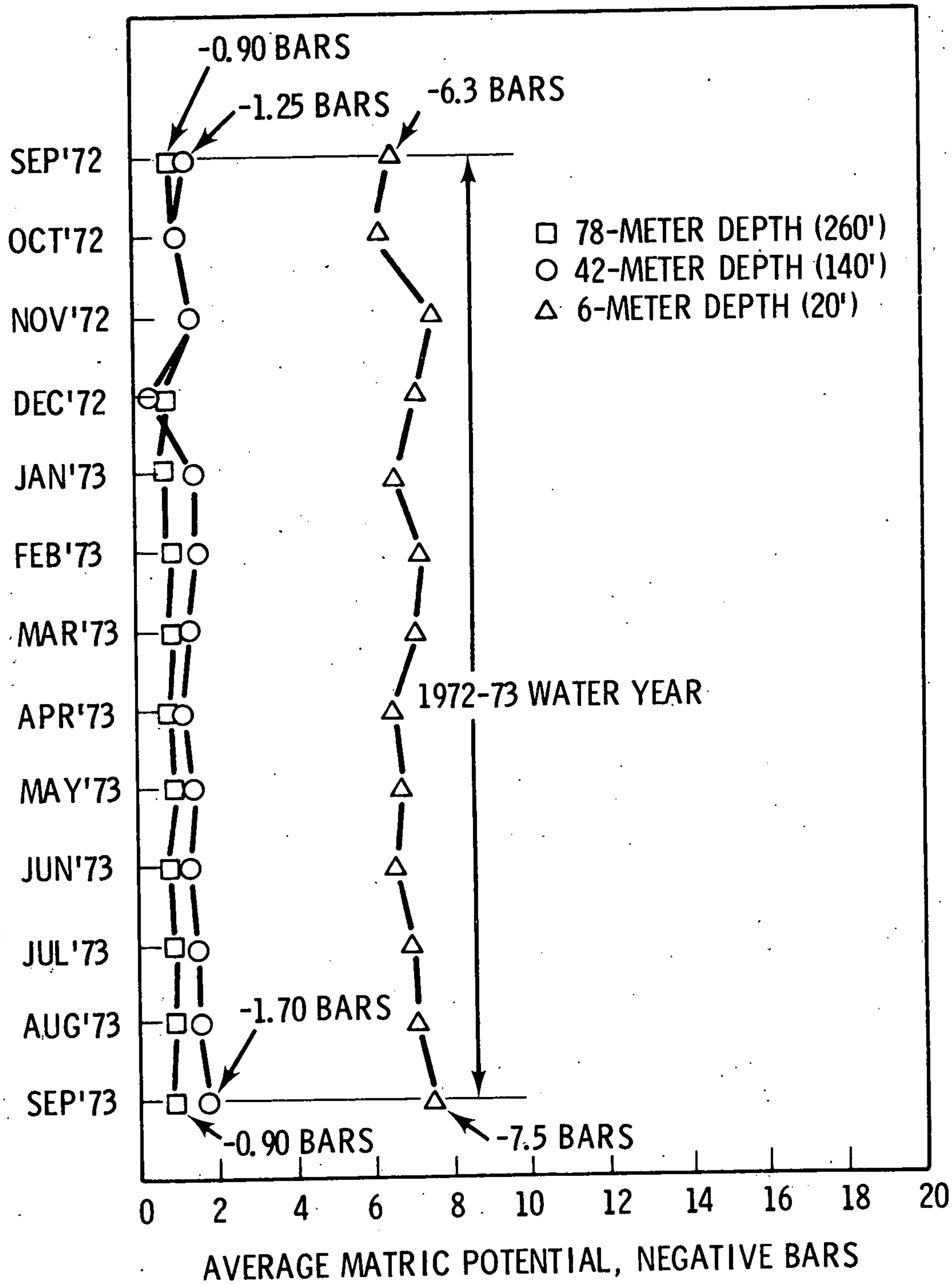


FIGURE 54

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 6-, 42-, AND 78-METER DEPTHS AT 32-49D SITE

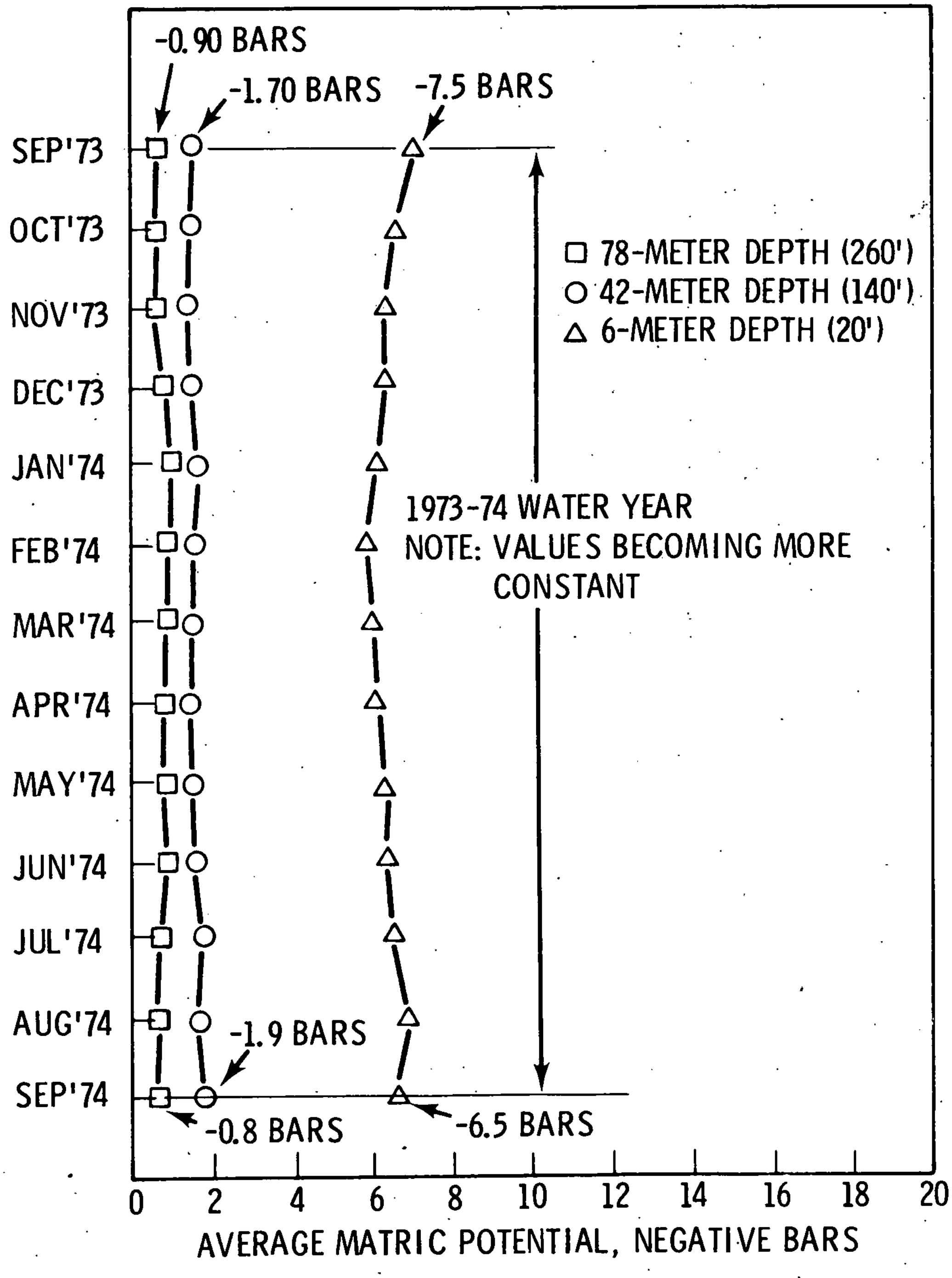


FIGURE 55

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 6-, 42-, AND 78-METER DEPTHS AT 32-49D SITE

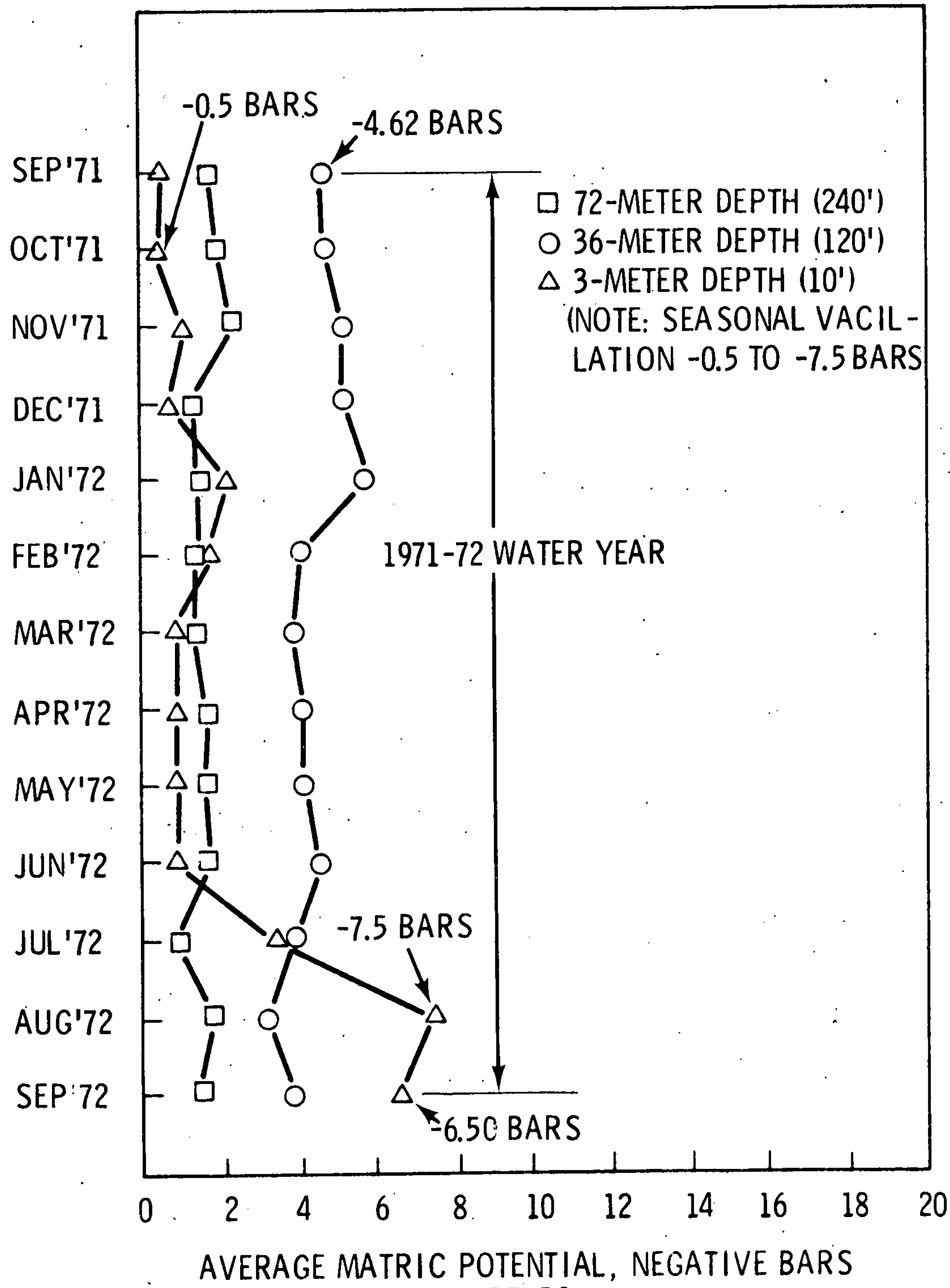


FIGURE 56

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 3-, 36-, AND 72-METER DEPTHS AT 32-49D SITE

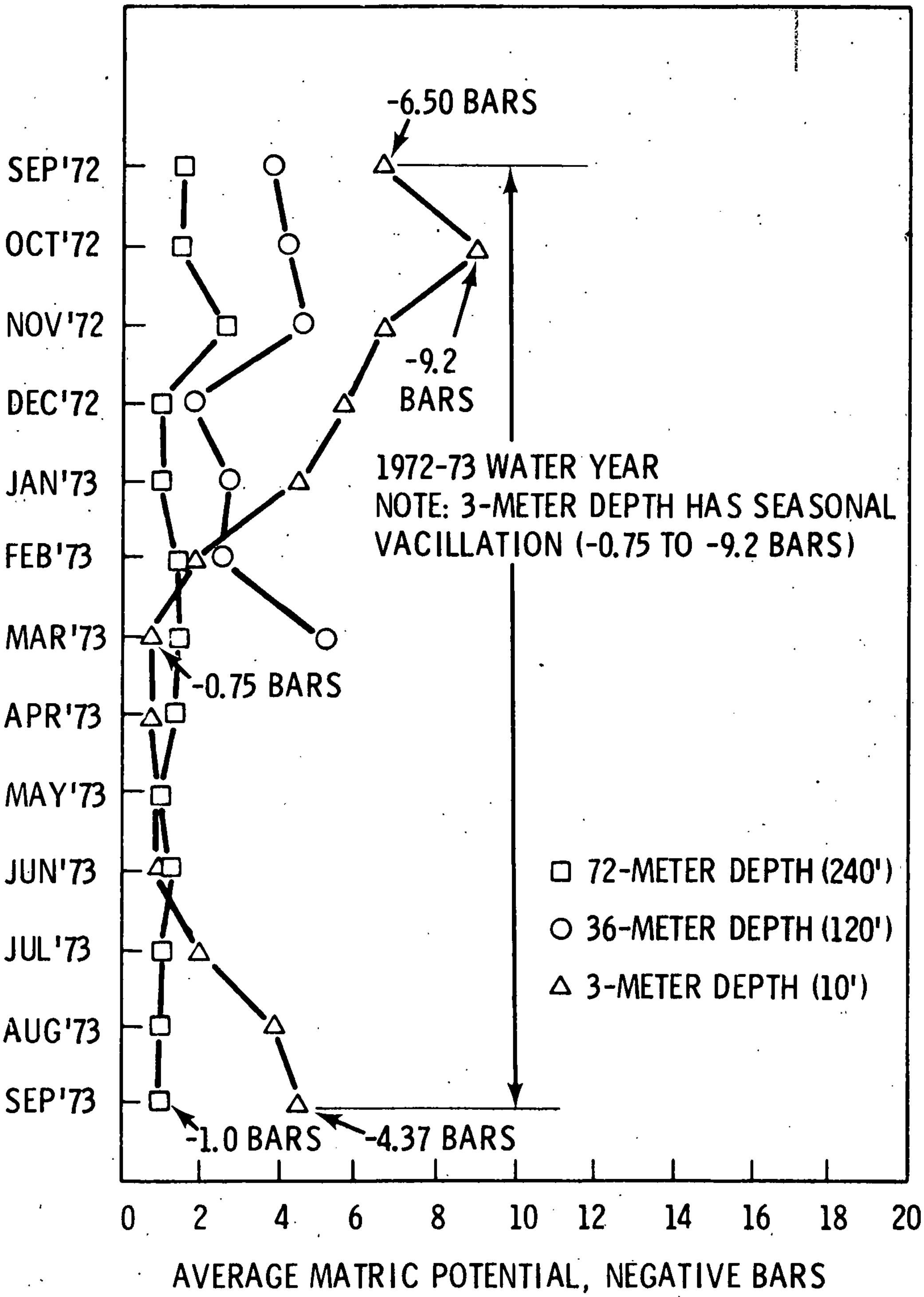


FIGURE 57

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 3-, 36-, AND 72-METER DEPTHS AT 32-49 SITE

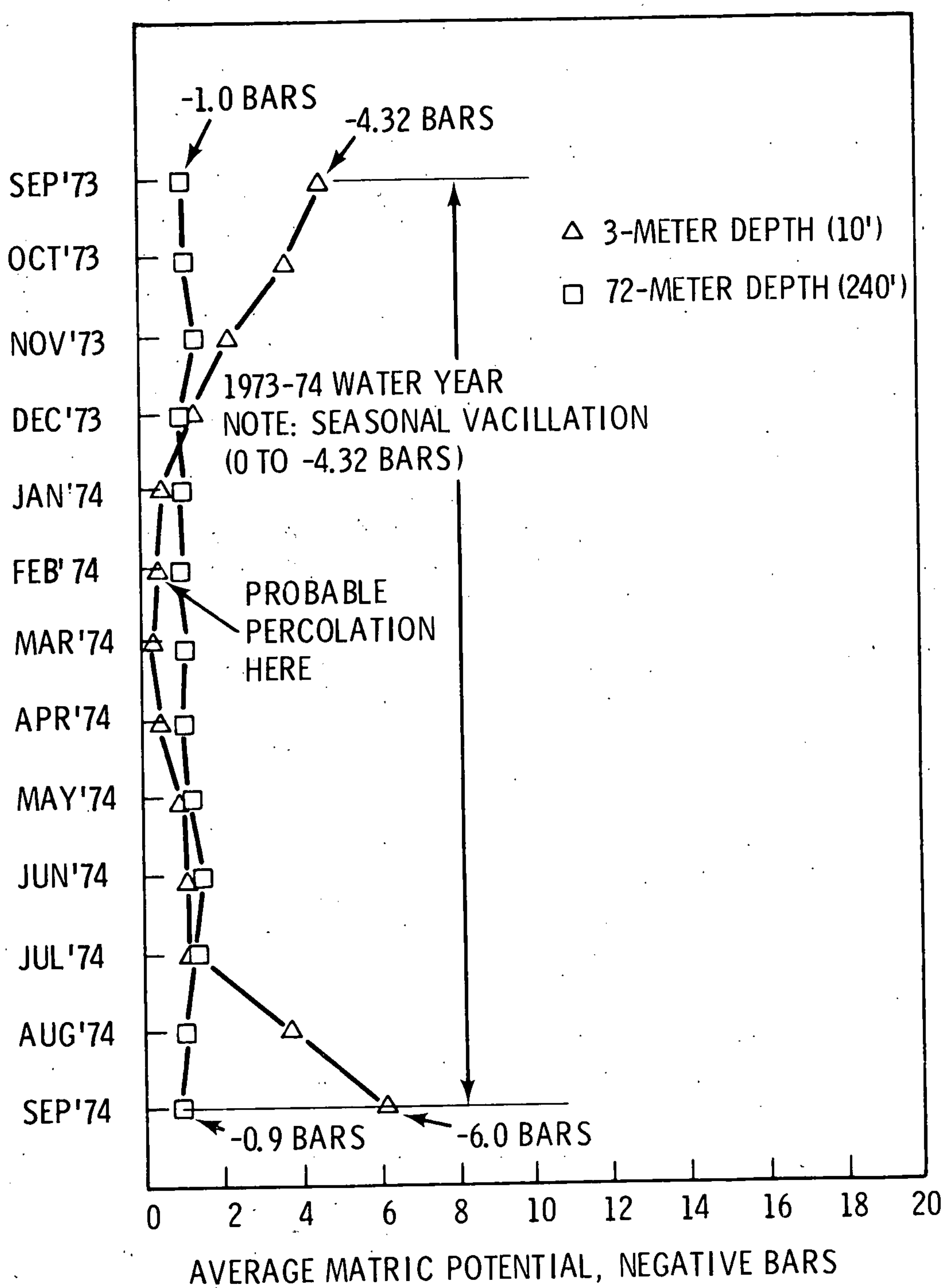


FIGURE 58

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 3- AND 72-METER DEPTHS AT 32-49D SITE

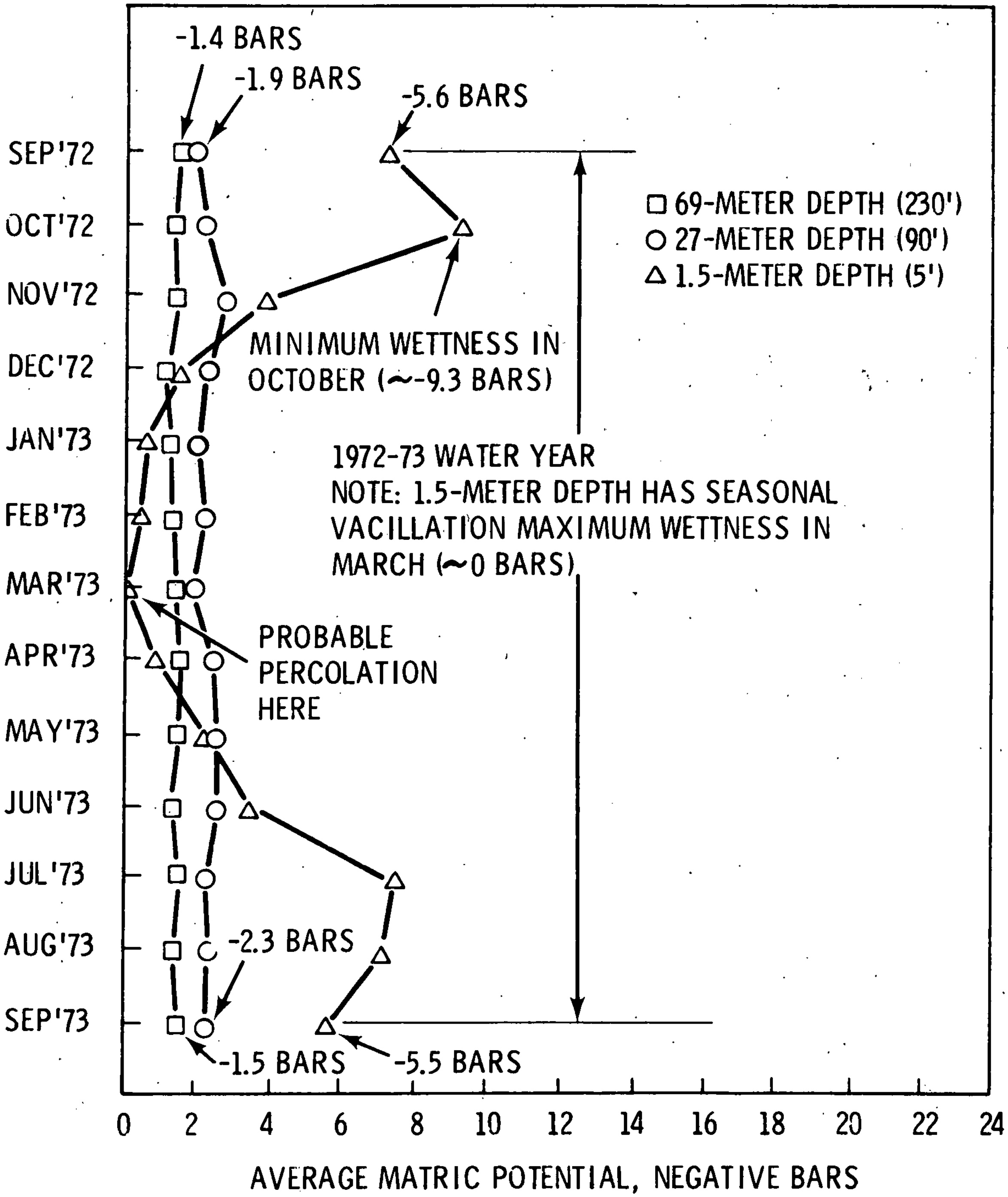


FIGURE 59

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 1.5-, 27-, AND 69-METER DEPTHS AT 32-49D SITE

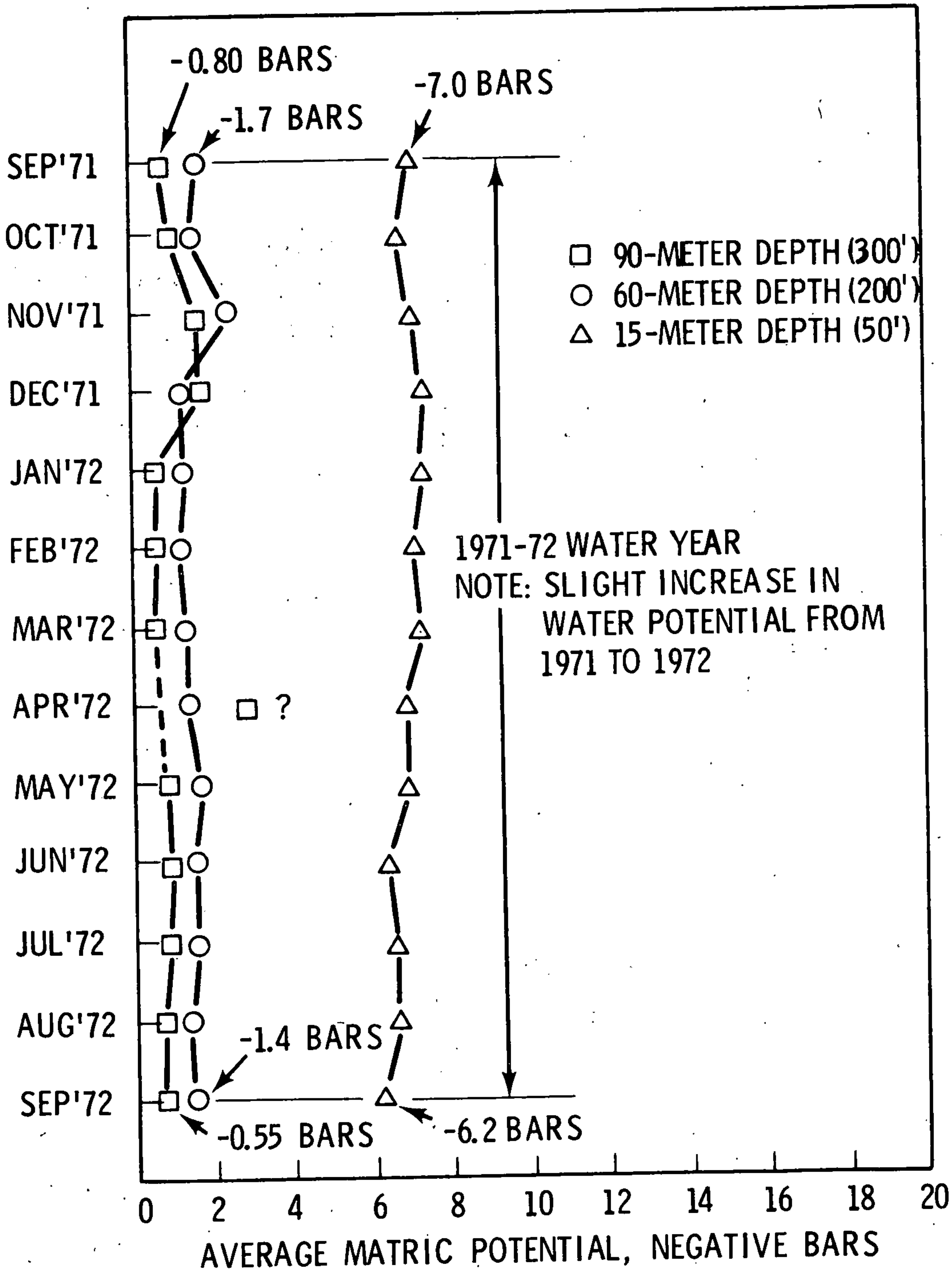


FIGURE 60

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 15-, 60-, AND 90-METER DEPTHS AT 32-49D SITE

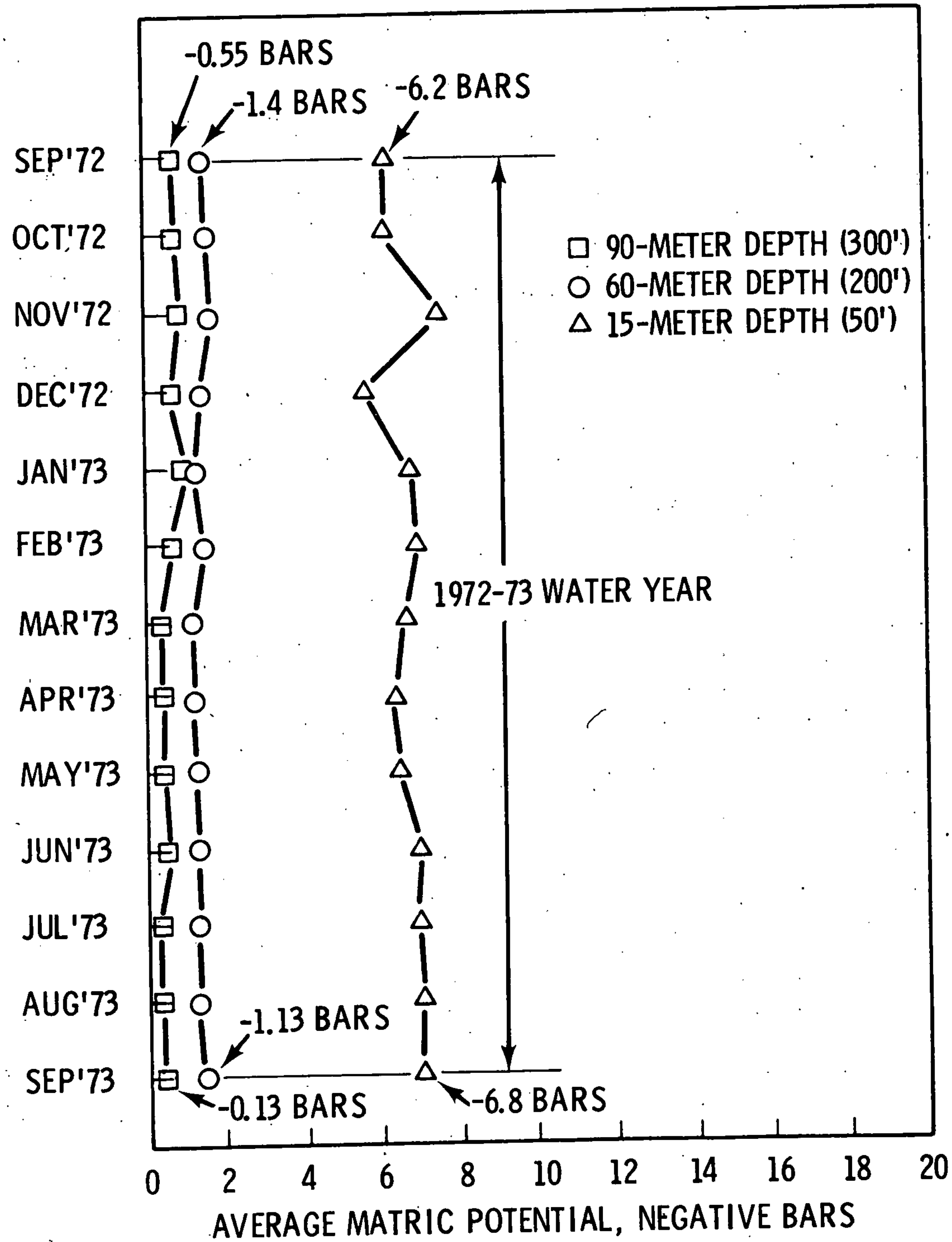


FIGURE 61

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 15-, 60-, AND 90-METER DEPTHS AT 32-49D SITE

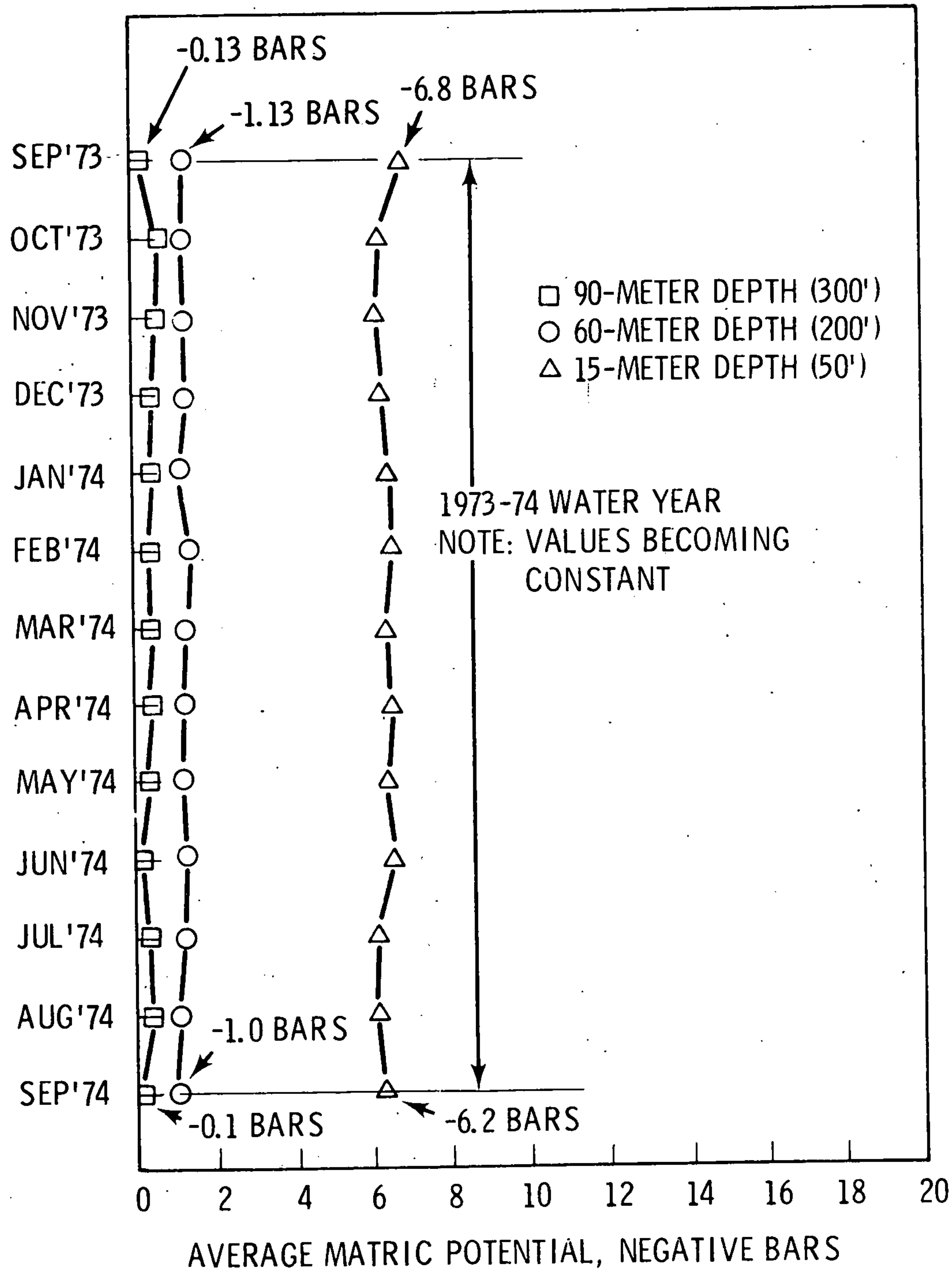


FIGURE 62

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 15-, 60-, AND 90-METER DEPTHS AT 32-49D SITE

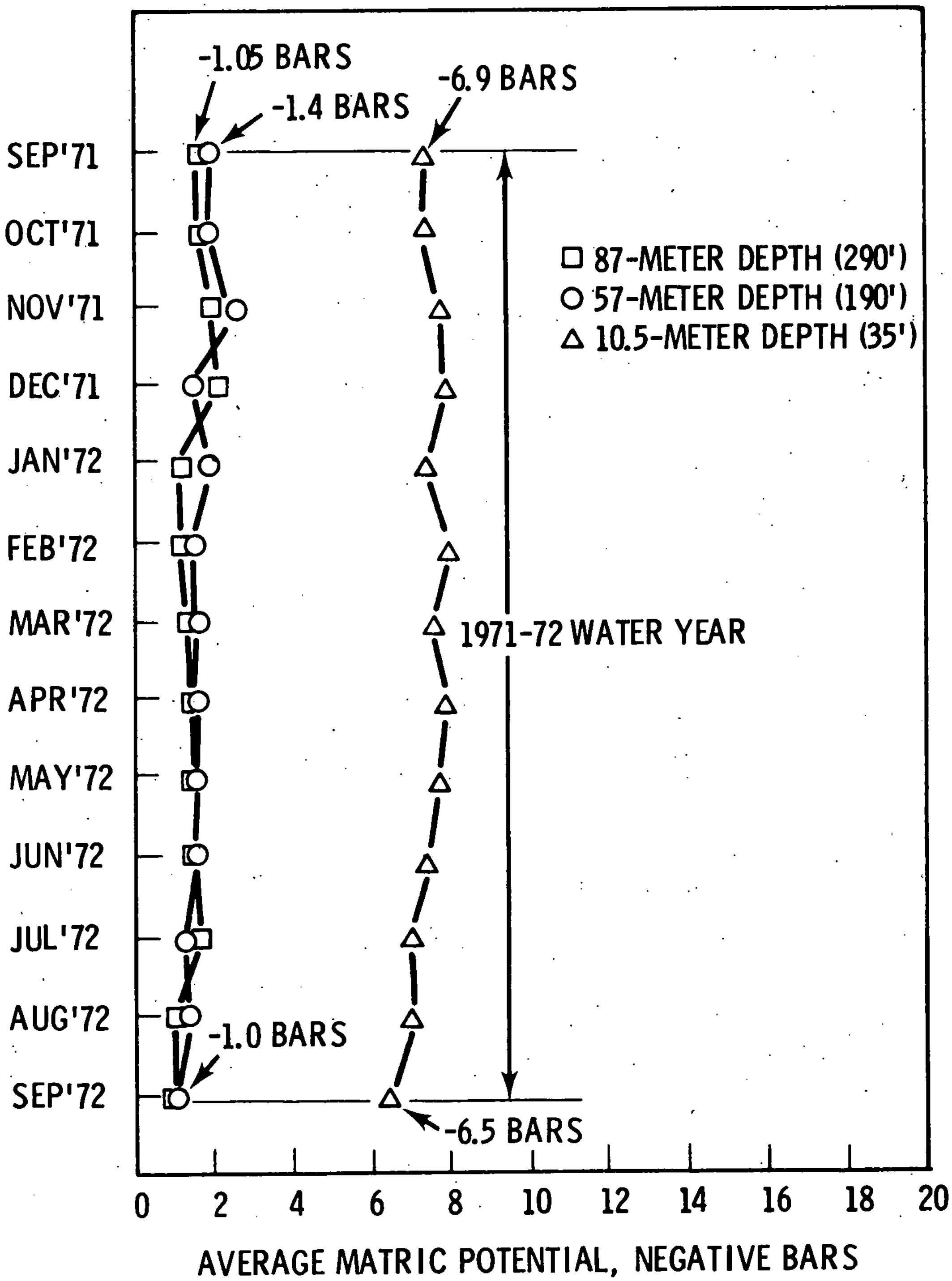


FIGURE 63

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 10.5-, 57-, AND 87-METER DEPTHS AT 32-49D SITE

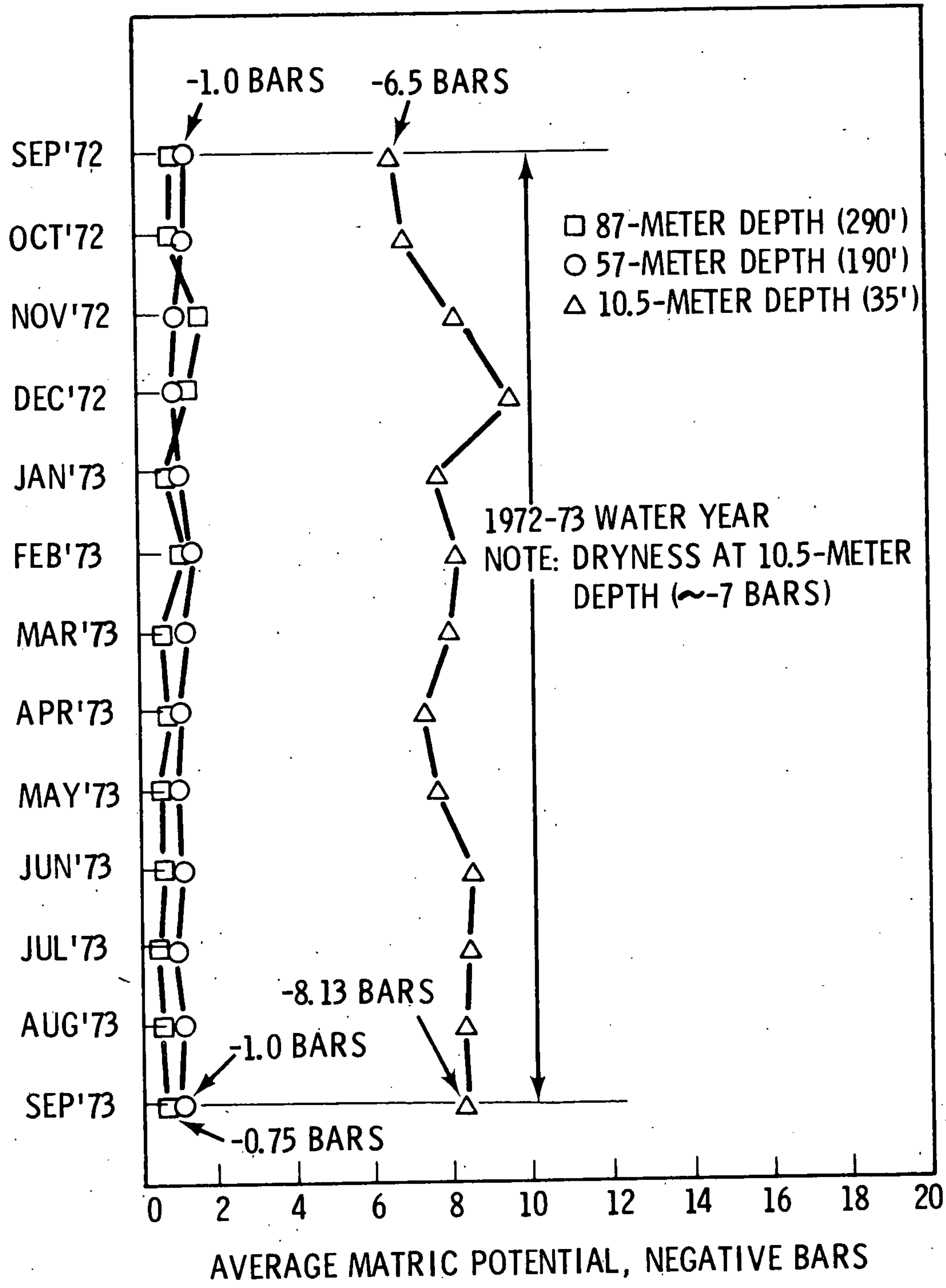


FIGURE 64

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 10.5-, 57-, AND 87-METER DEPTHS AT 32-49D SITE

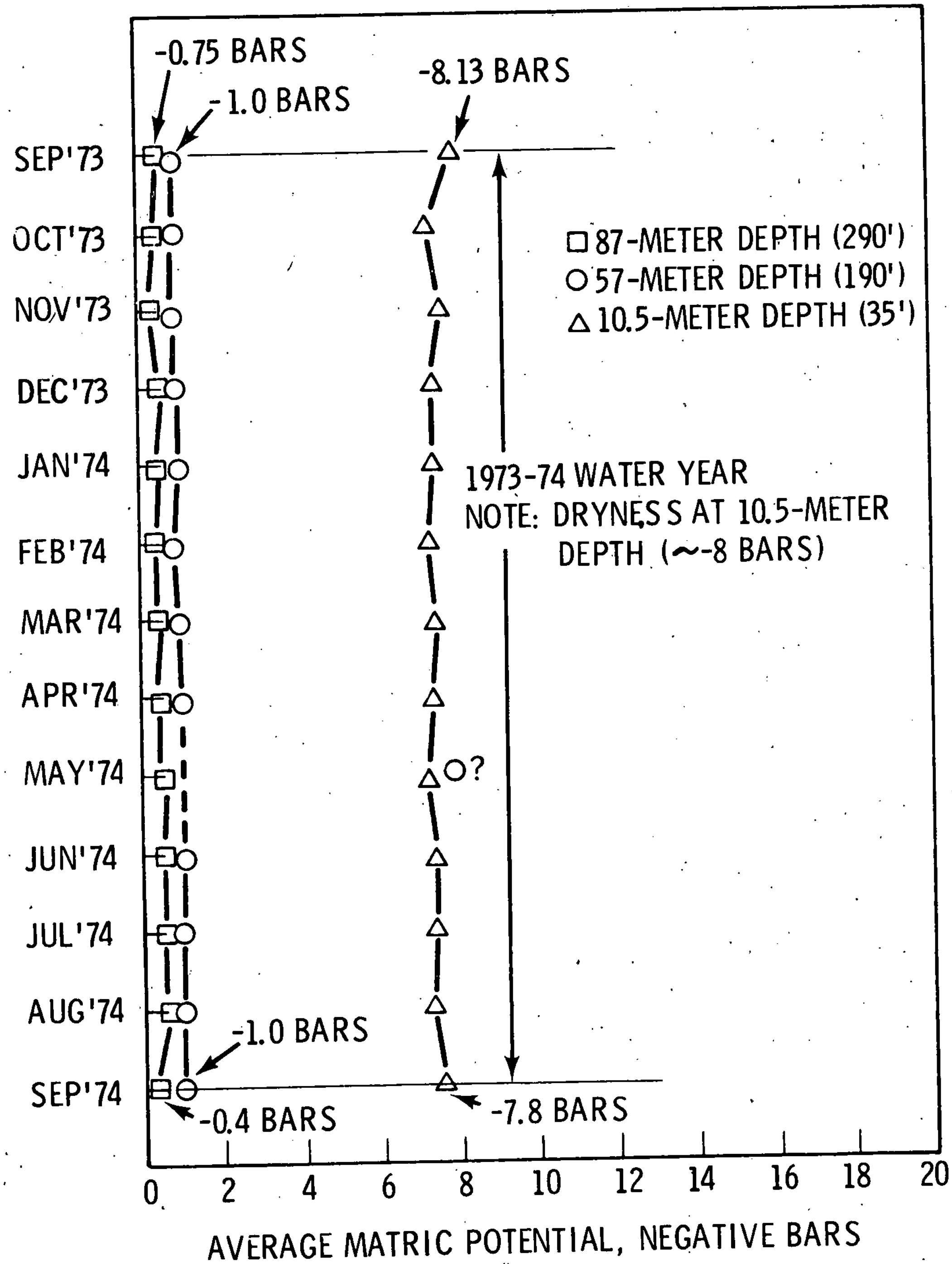


FIGURE 65

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 10.5-, 57-, AND 87-METER DEPTHS AT 32-49D SITE

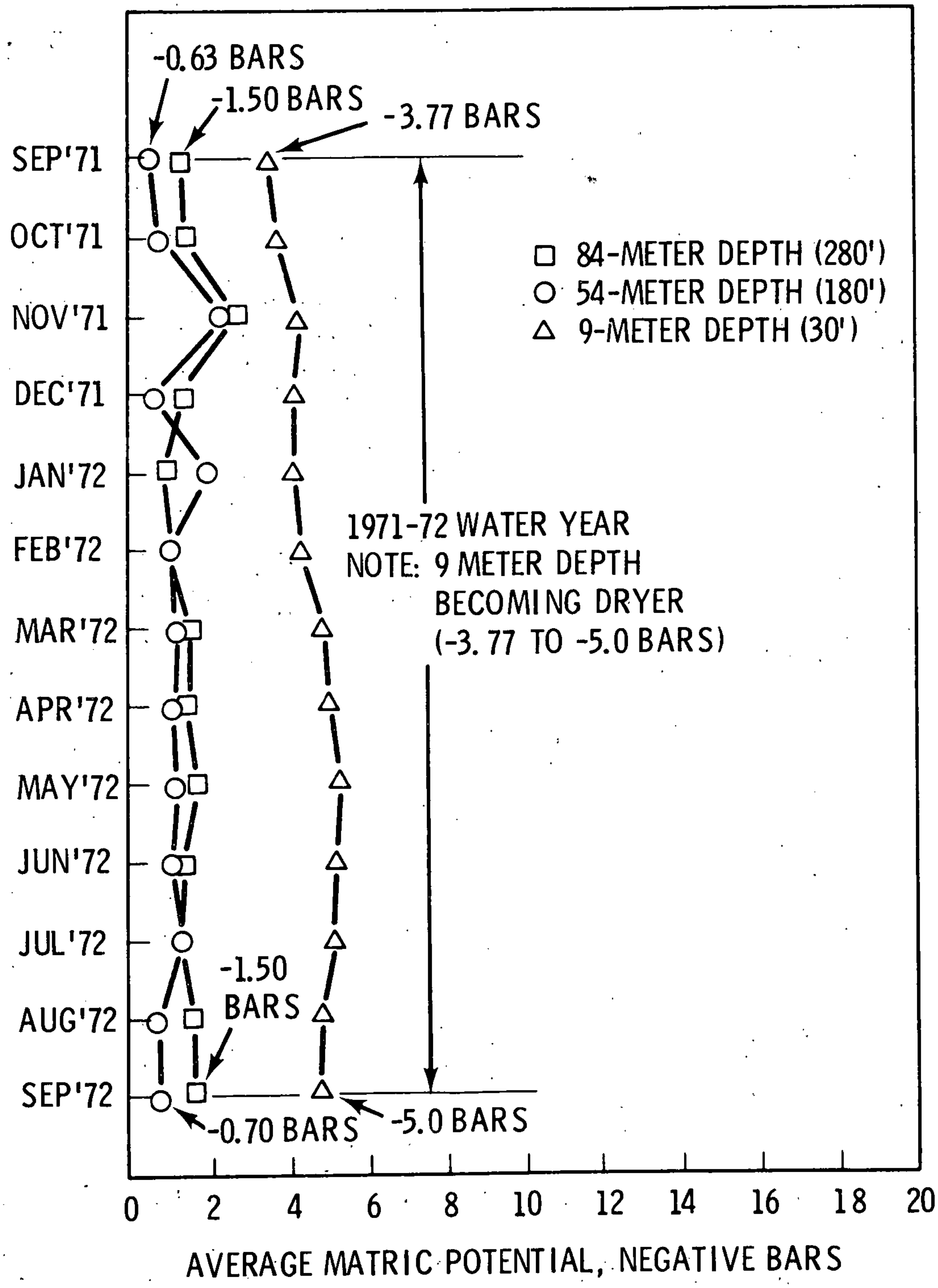


FIGURE 66

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 9-, 54-, AND 84-METER DEPTHS AT 32-49D SITE

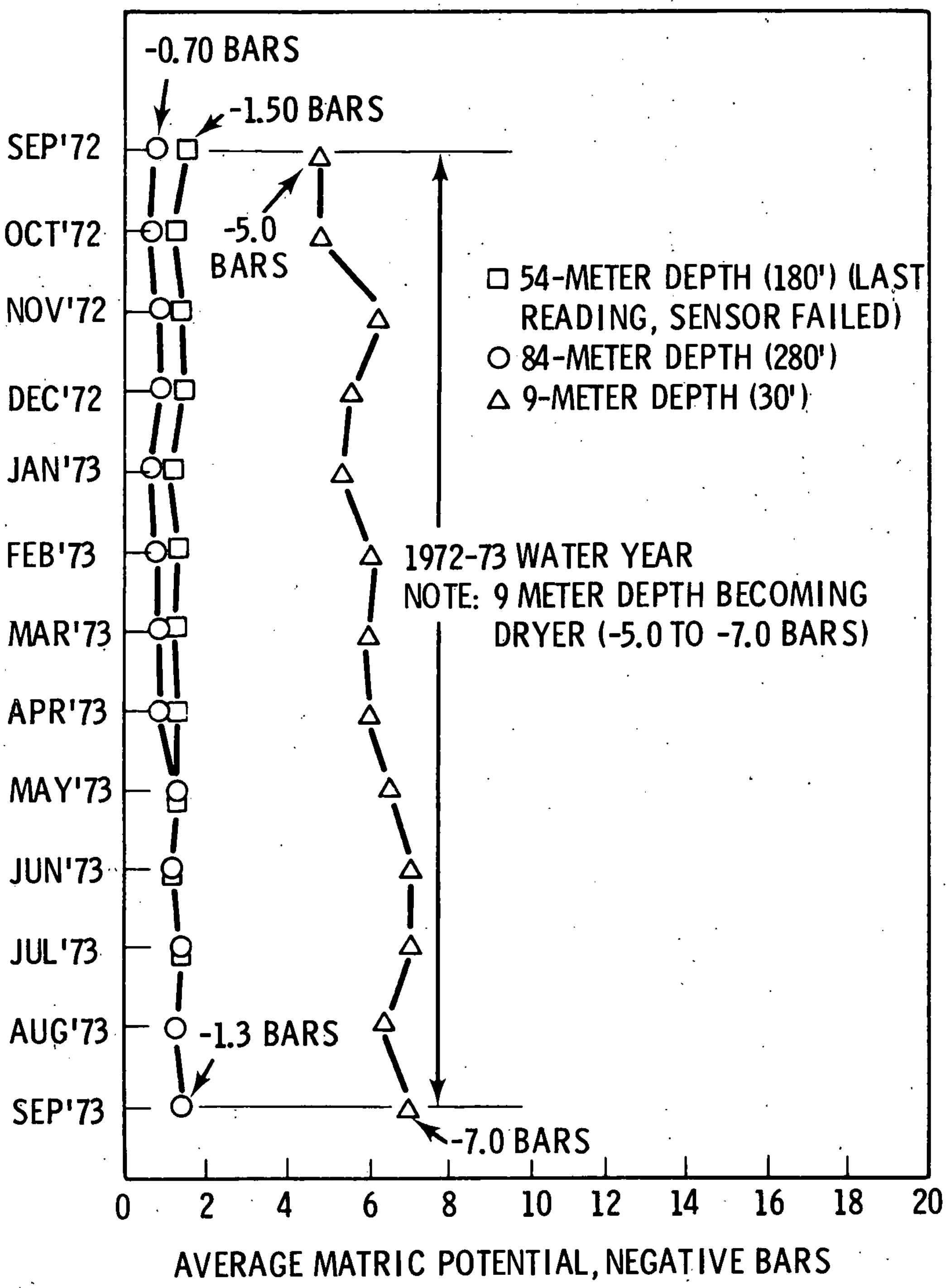


FIGURE 67

AVERAGE MATRIX POTENTIAL FOR 1972-1973 WATER YEAR AND 9-, 54-, AND 84-METER DEPTHS AT 32-49D SITE

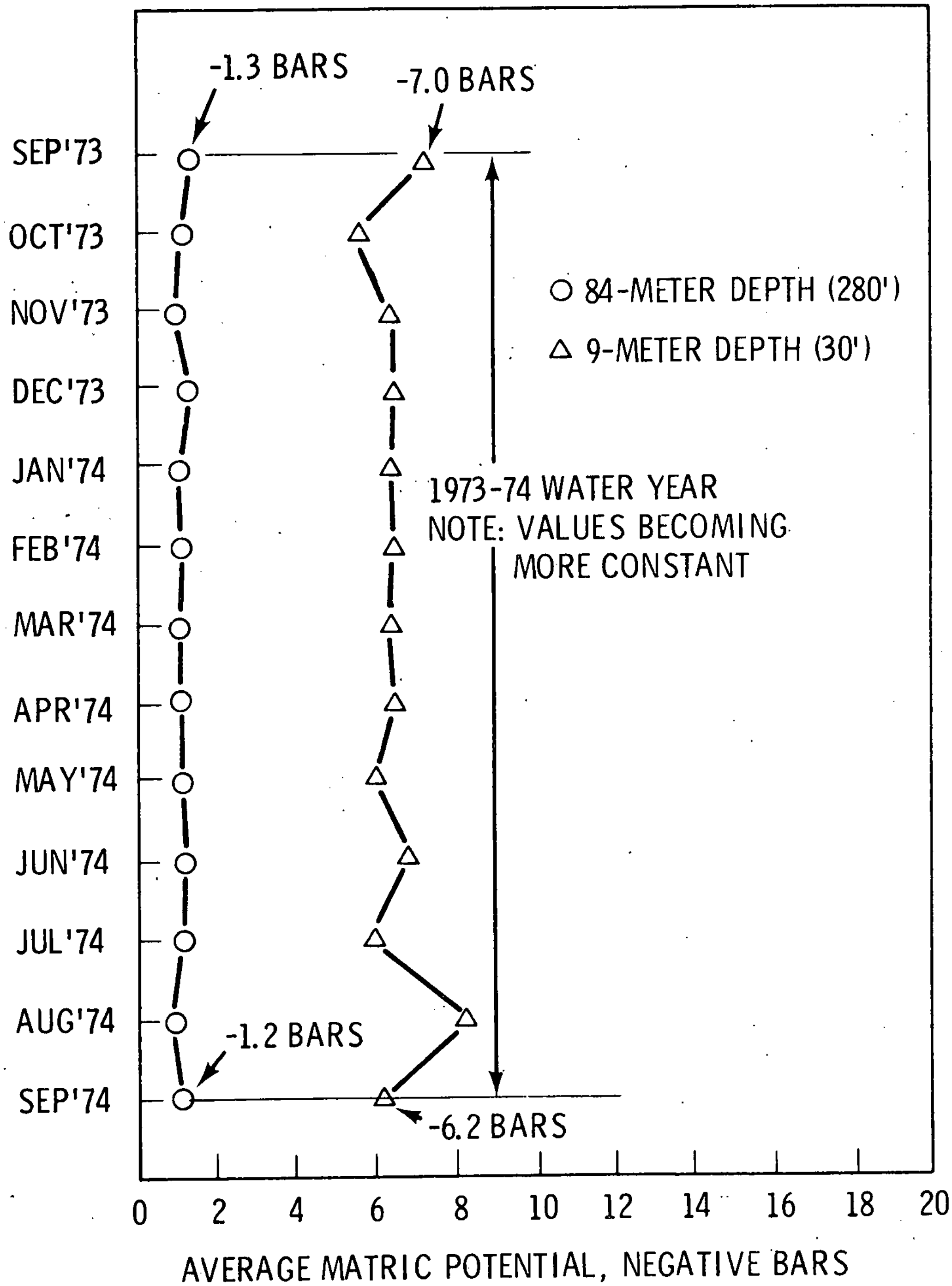


FIGURE 68

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 9- AND 84-METER DEPTHS AT 32-49D SITE

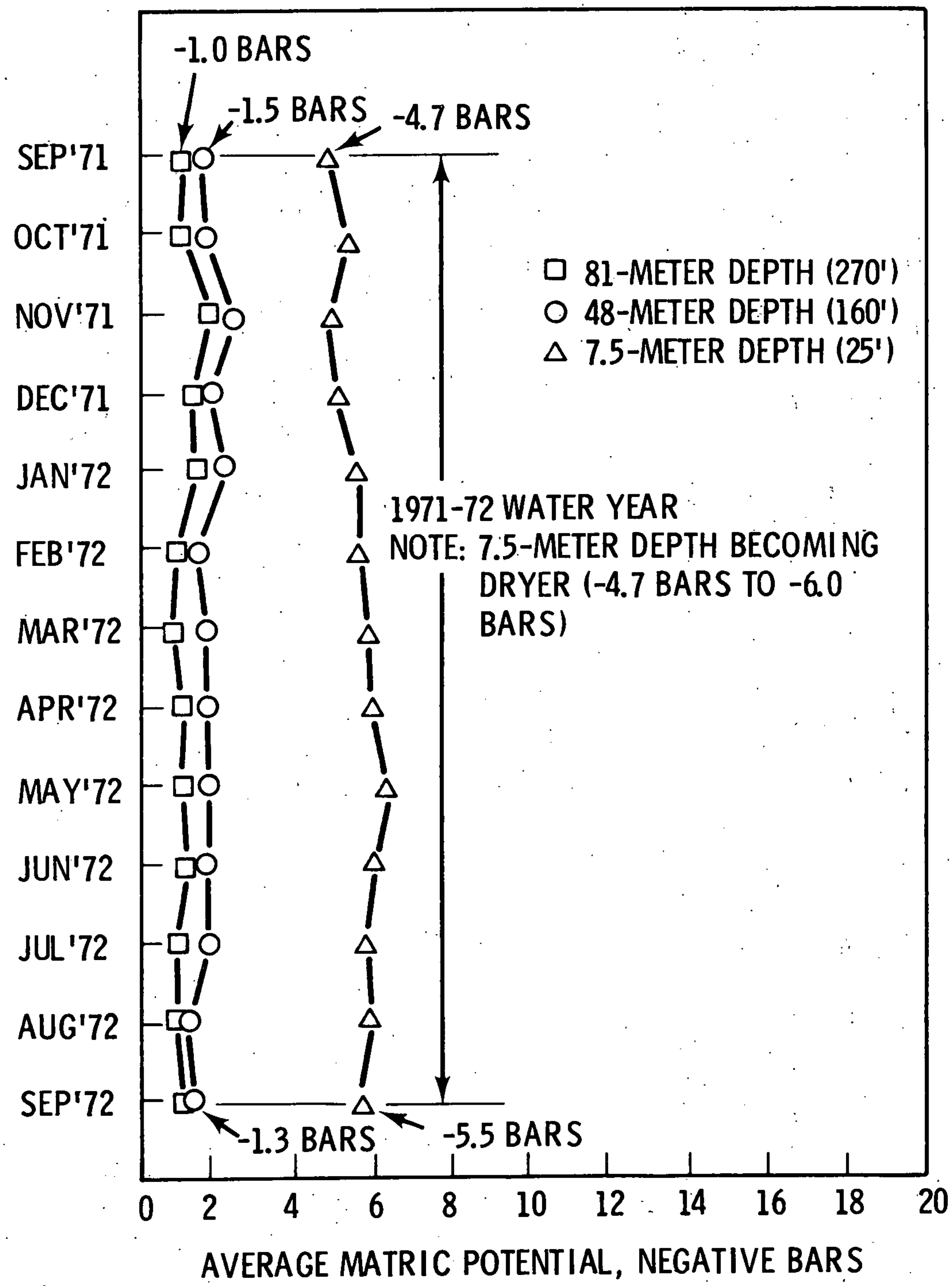


FIGURE 69

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 7.5-, 48-, AND 81-METER DEPTHS AT 32-49D SITE

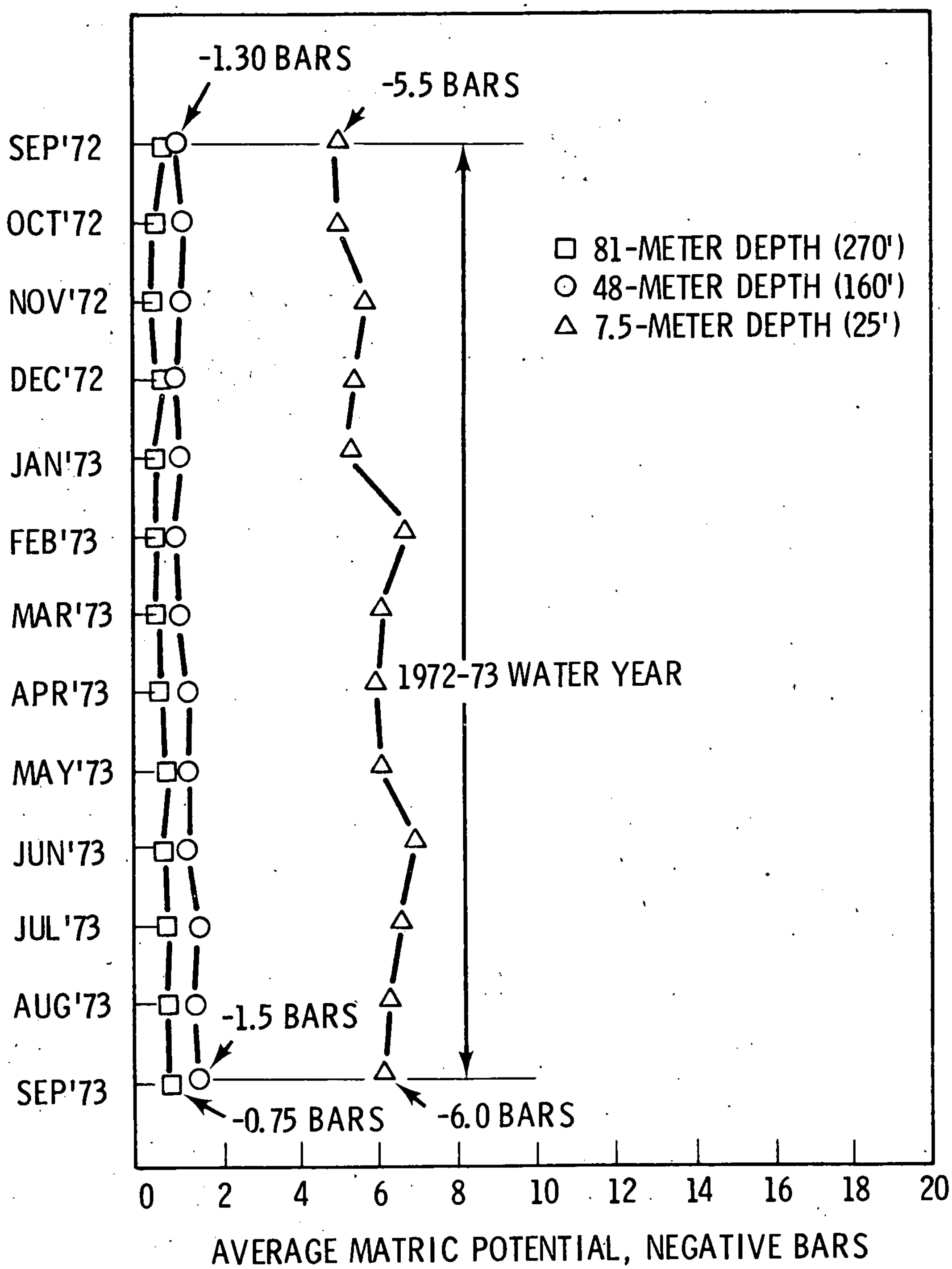


FIGURE 70

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 7.5-, 48-, AND 81-METER DEPTHS AT 32-49D SITE

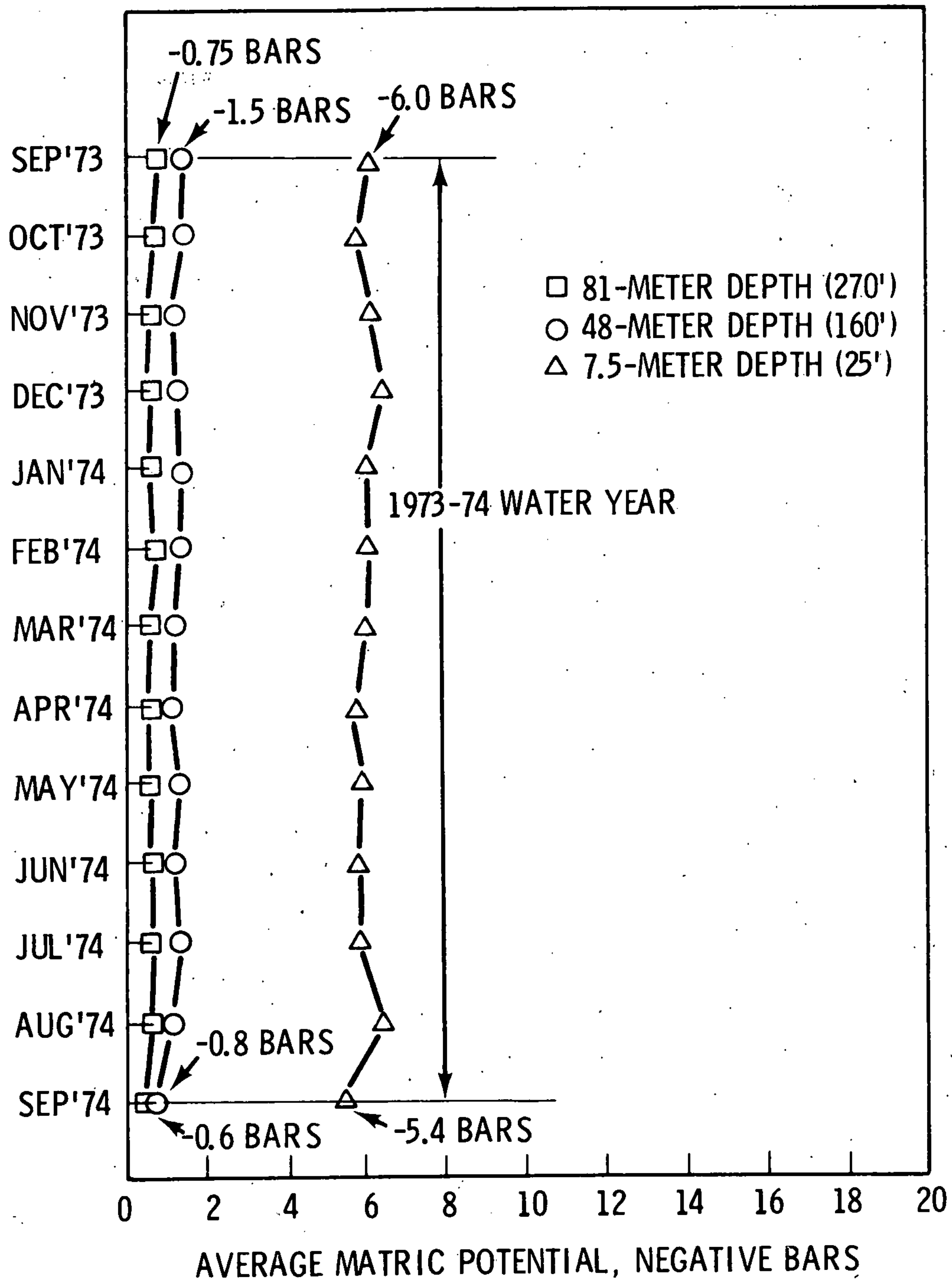


FIGURE 71

AVERAGE MATRIC POTENIAL FOR 1973-1974 WATER YEAR AND 7.5-, 48-, AND 81-METER DEPTHS AT 32-49D SITE

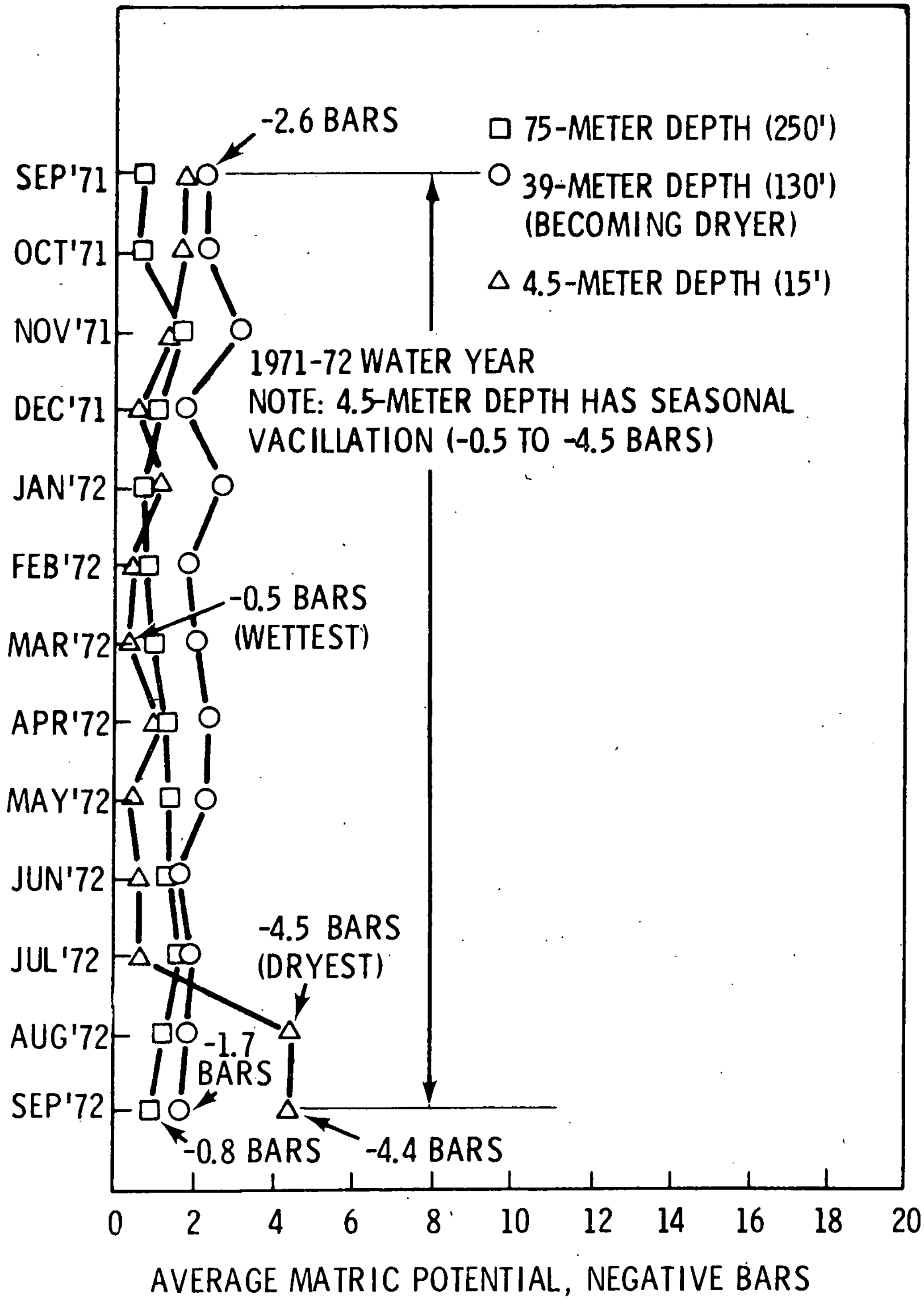


FIGURE 72

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 4.5-, 39-, AND 75-METER DEPTHS AT 32-49D SITE

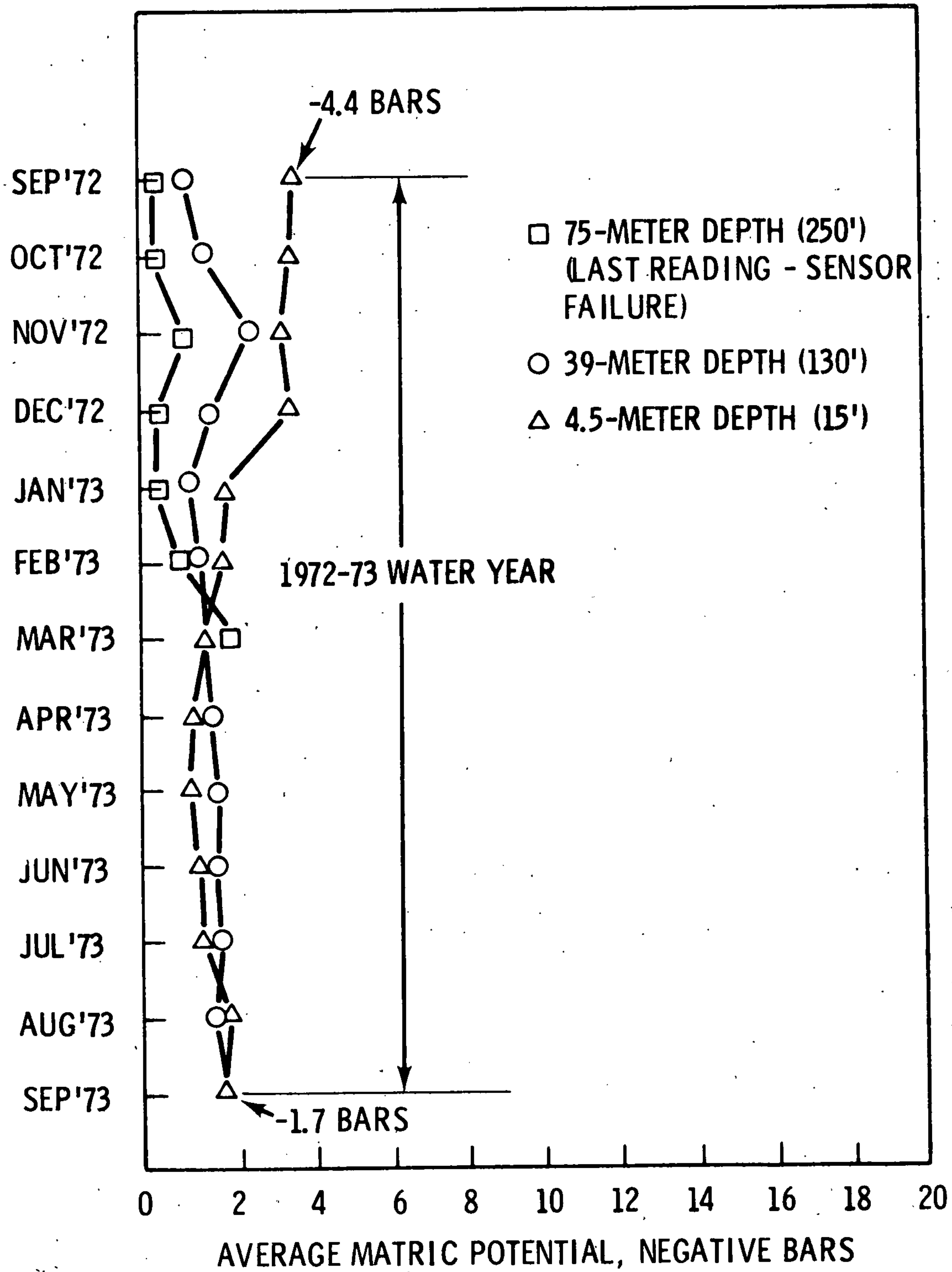


FIGURE 73

AVERAGE MATRIC POTENTIAL FOR 1972-1973 WATER YEAR AND 4.5-, 39-, AND 75-METER DEPTHS AT 32-49D SITE

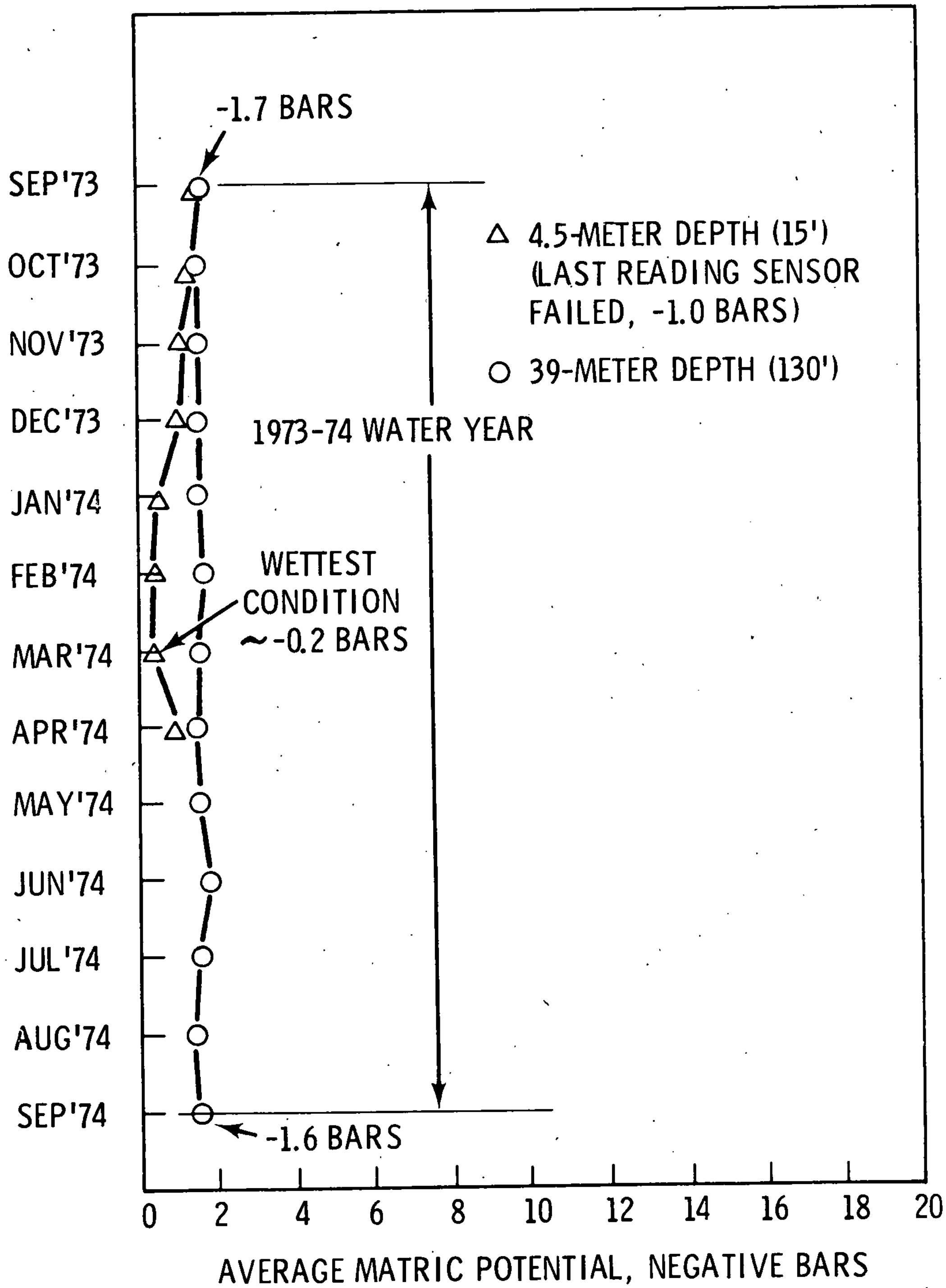


FIGURE 74

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 4.5- AND 39-METER DEPTHS AT 32-49D SITE

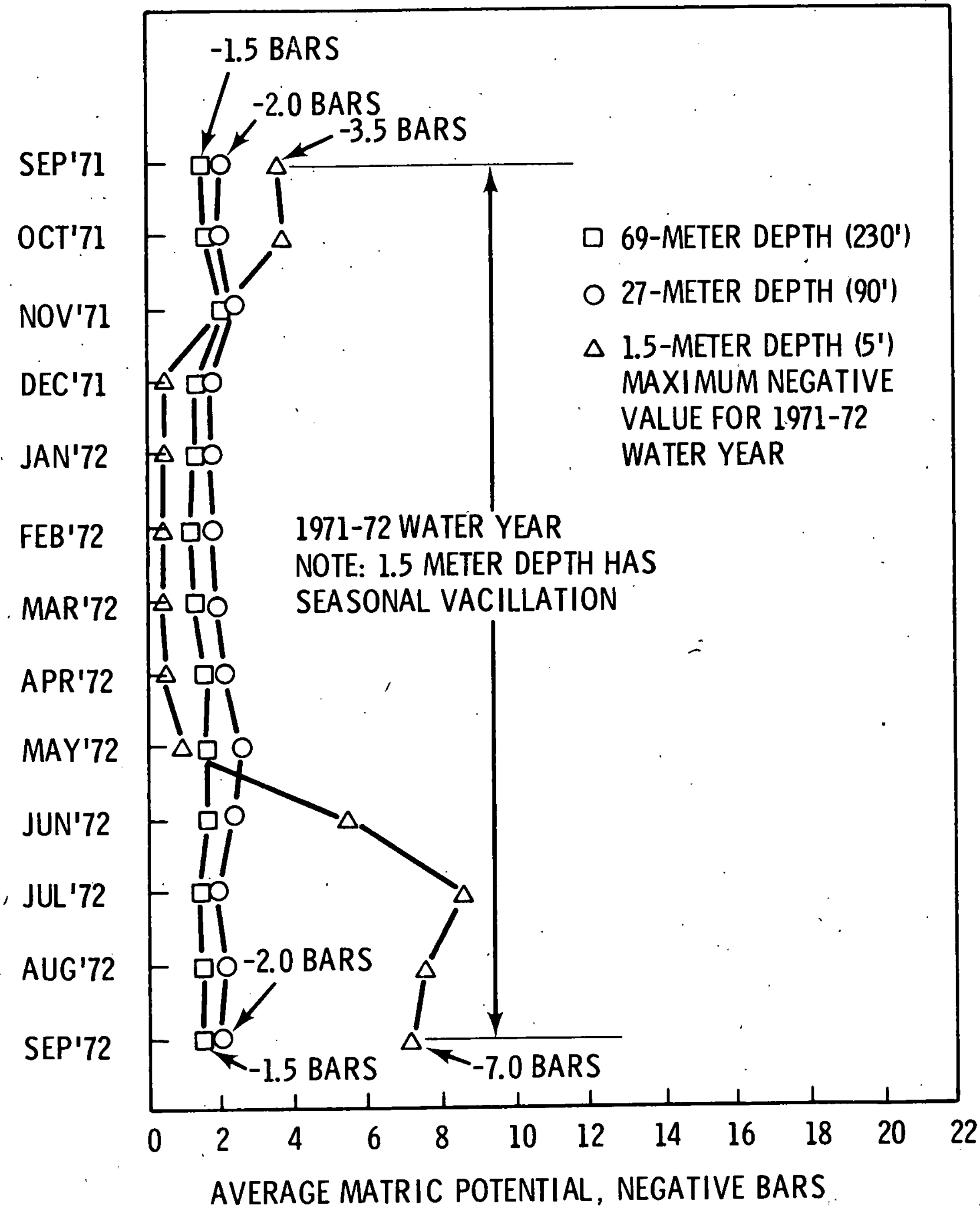


FIGURE 75

AVERAGE MATRIC POTENTIAL FOR 1971-1972 WATER YEAR AND 1.5-, 27-, AND 69-METER DEPTHS AT 32-49D SITE

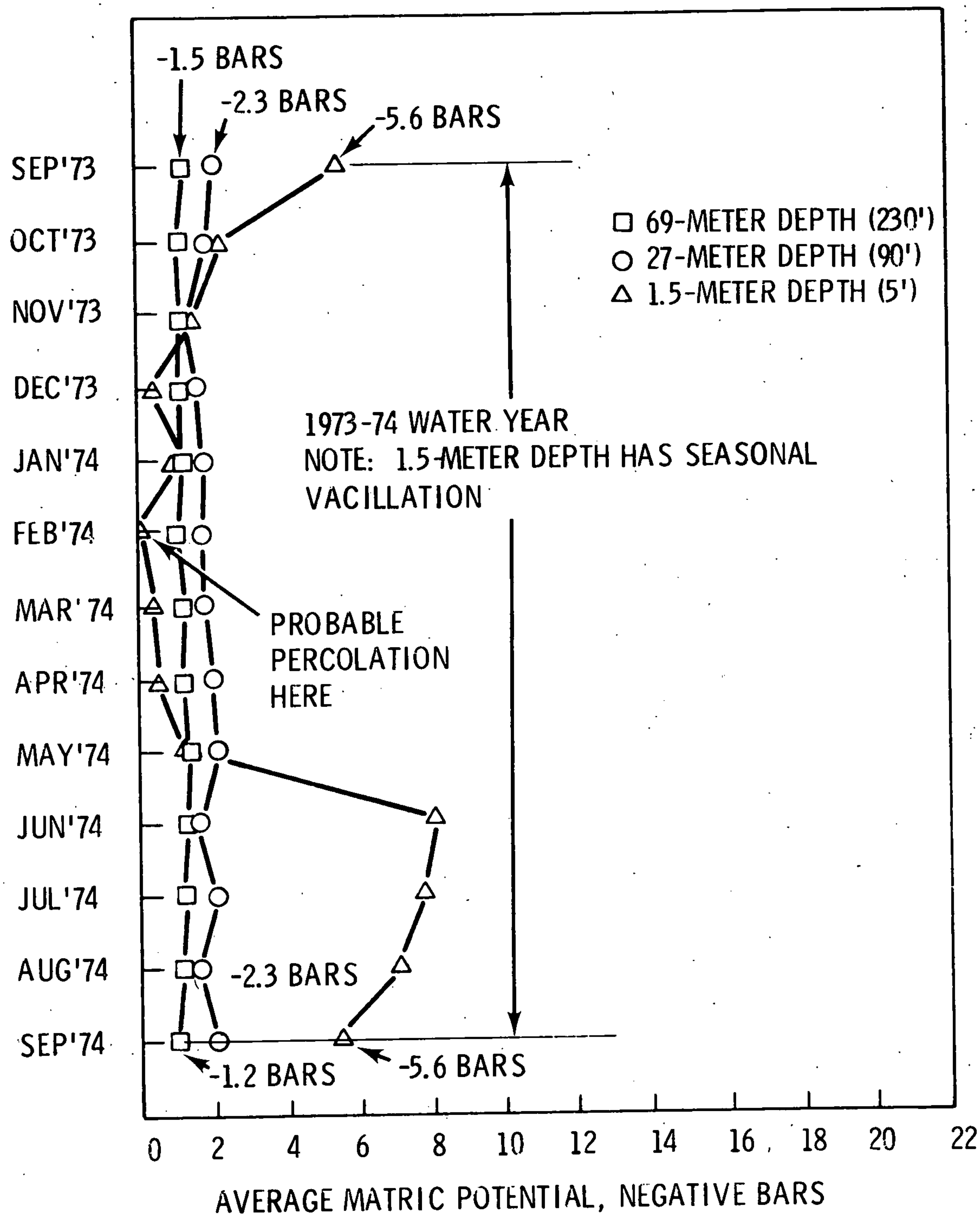


FIGURE 76

AVERAGE MATRIC POTENTIAL FOR 1973-1974 WATER YEAR AND 1.5-, 27-, AND 69-METER DEPTHS AT 32-49D SITE

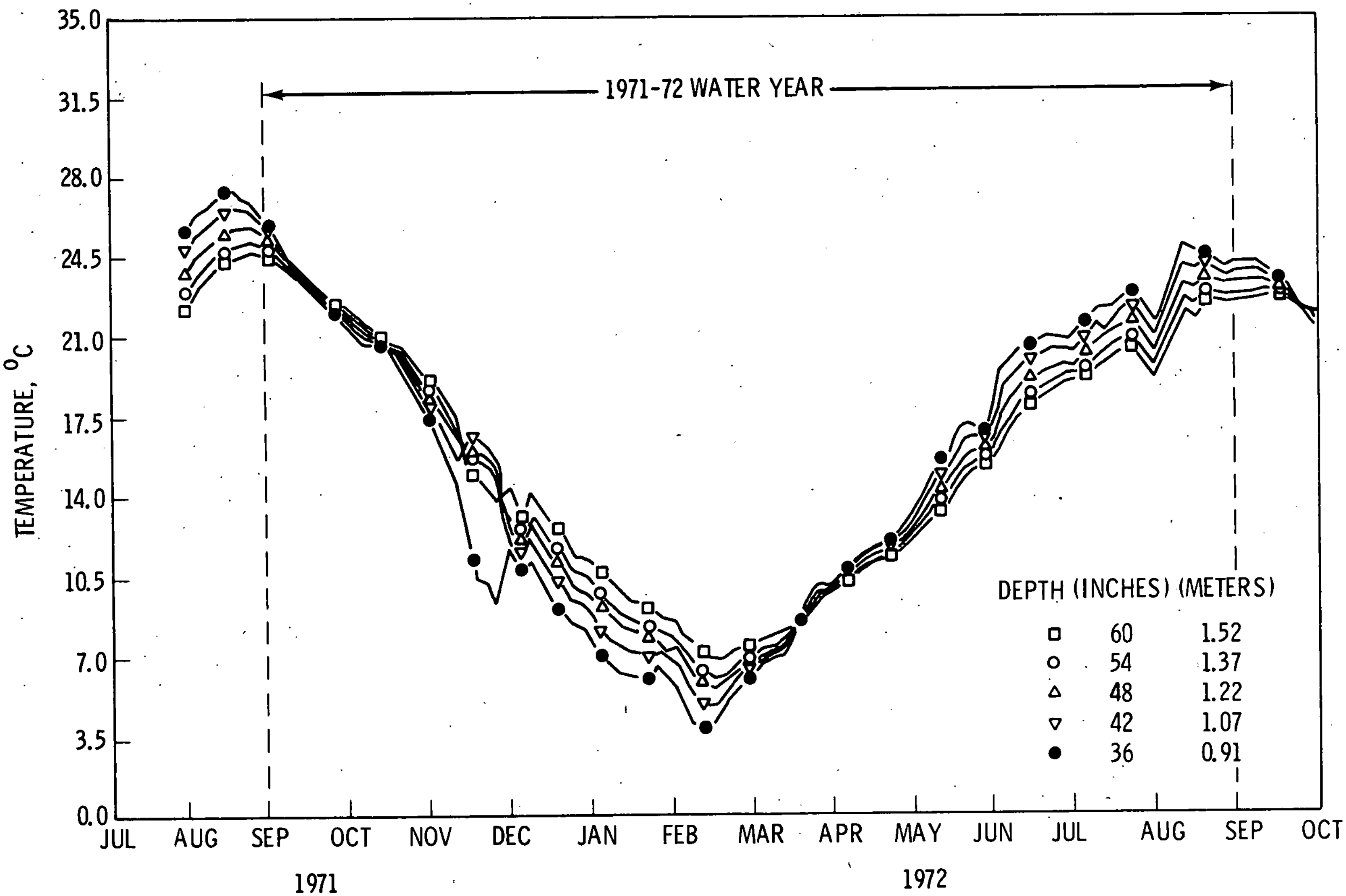


FIGURE 77

TEMPERATURE VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

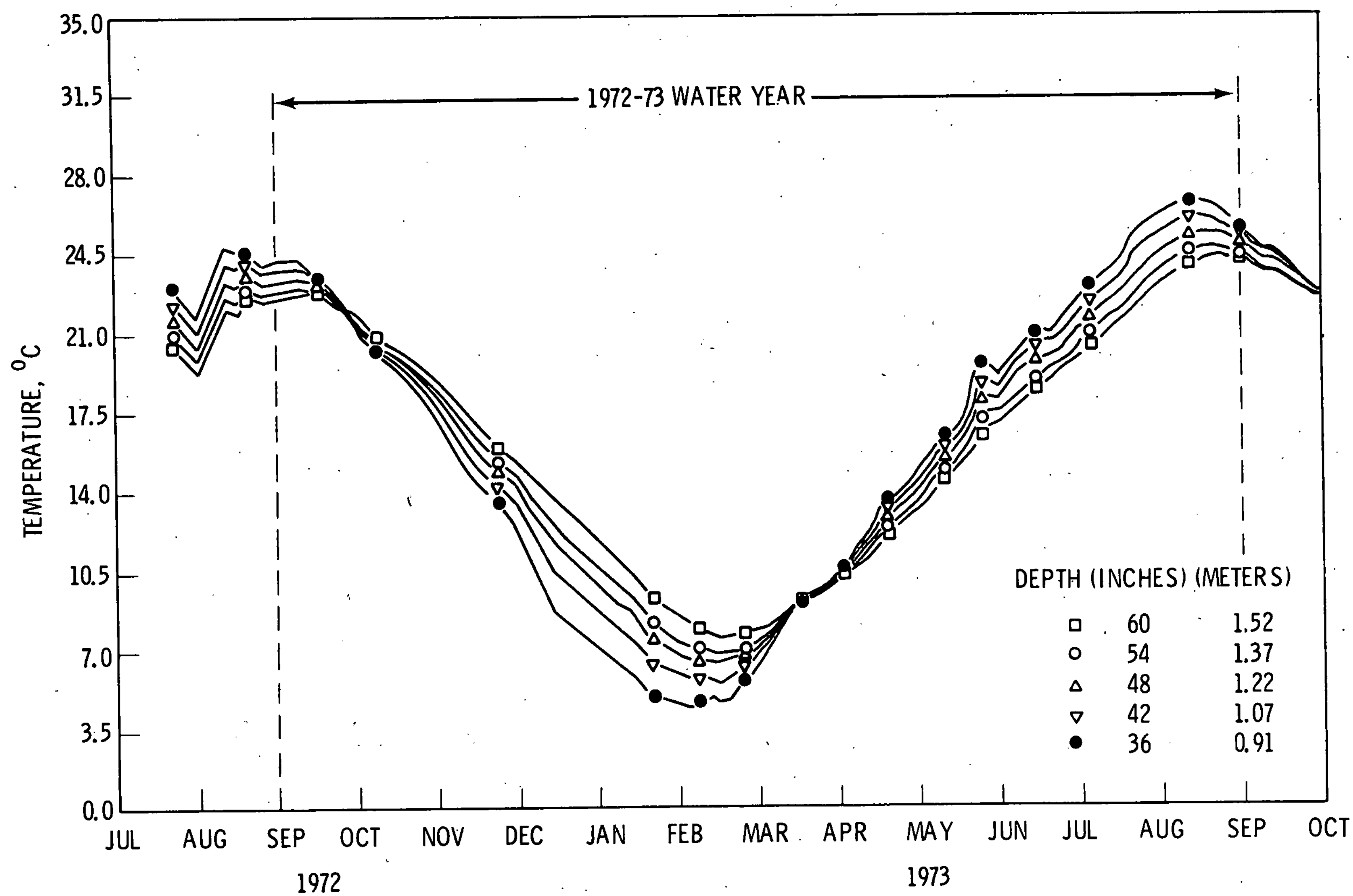


FIGURE 78

TEMPERATURE VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

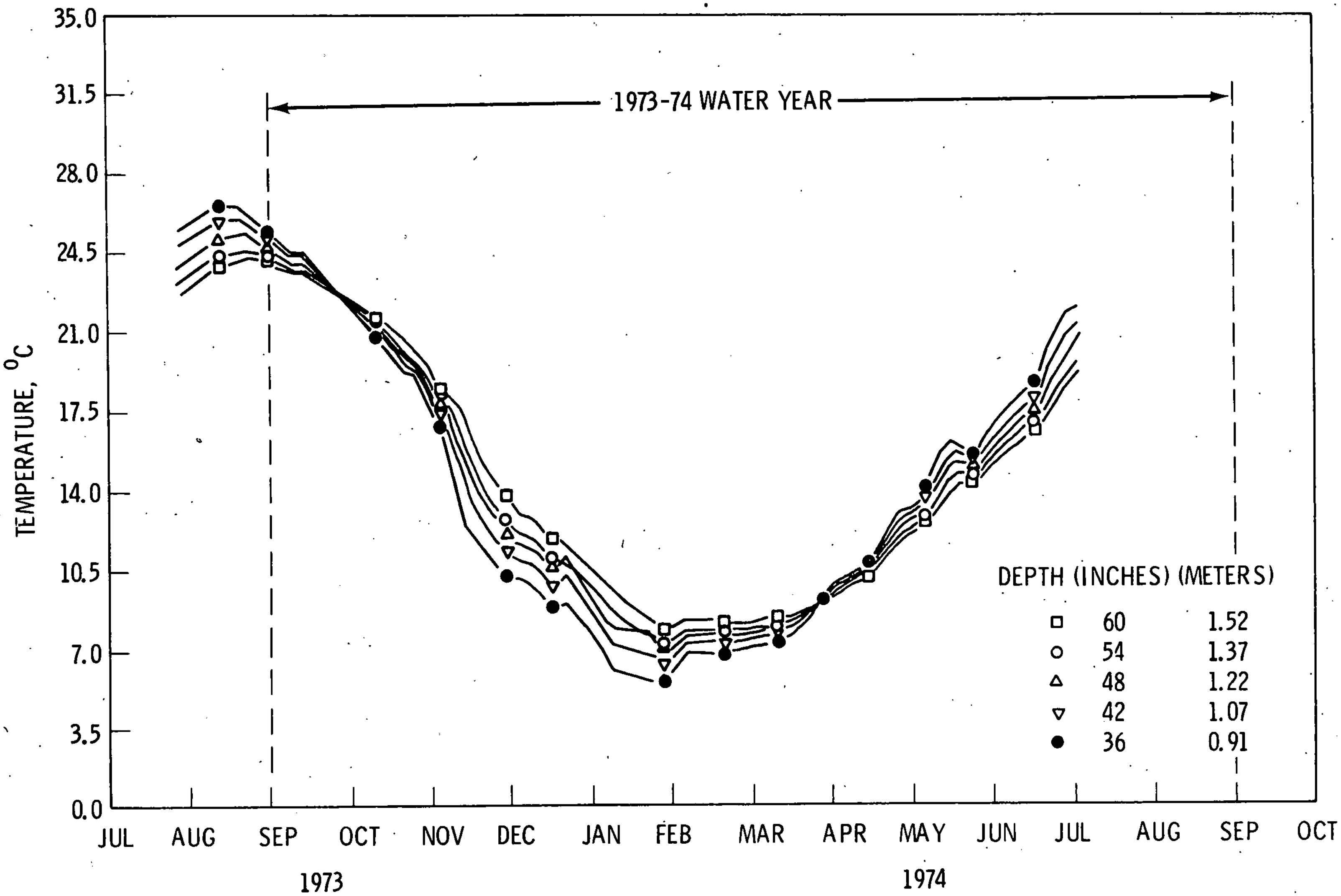


FIGURE 79

TEMPERATURE VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

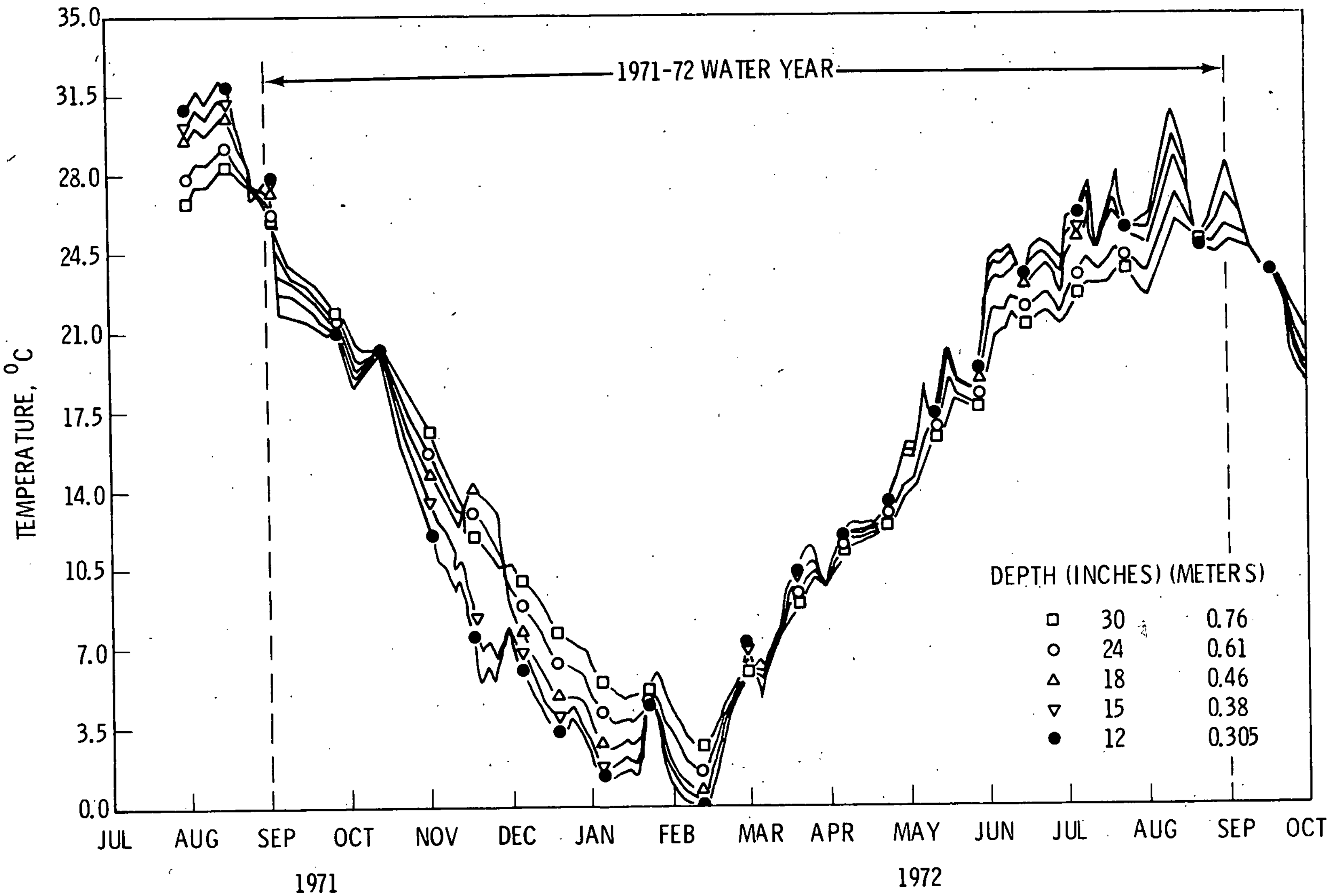


FIGURE 80

TEMPERATURE VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPTHS AT 32-49 COORDINATES

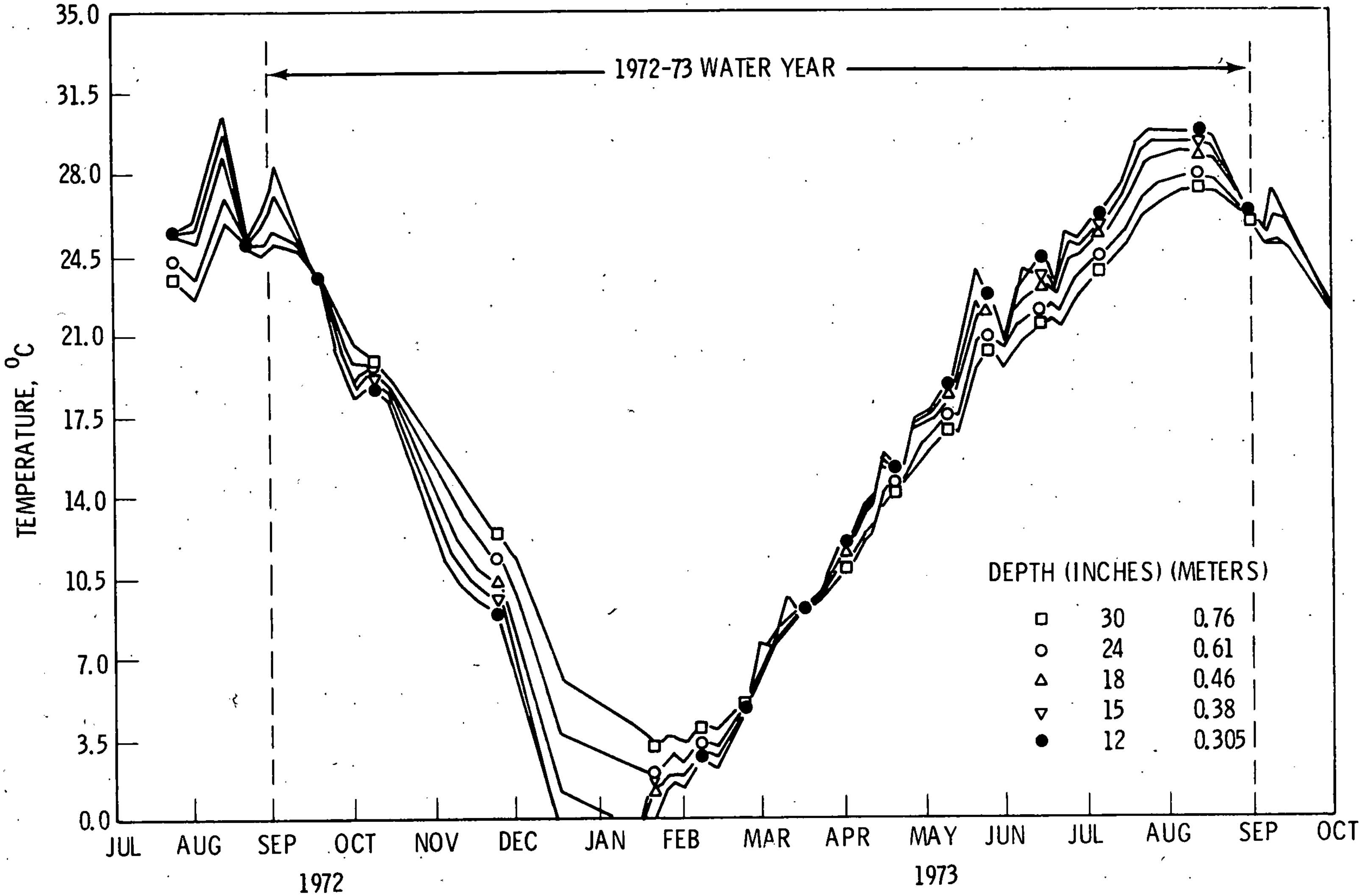


FIGURE 81

TEMPERATURE VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPTHS AT 32-49 COORDINATES

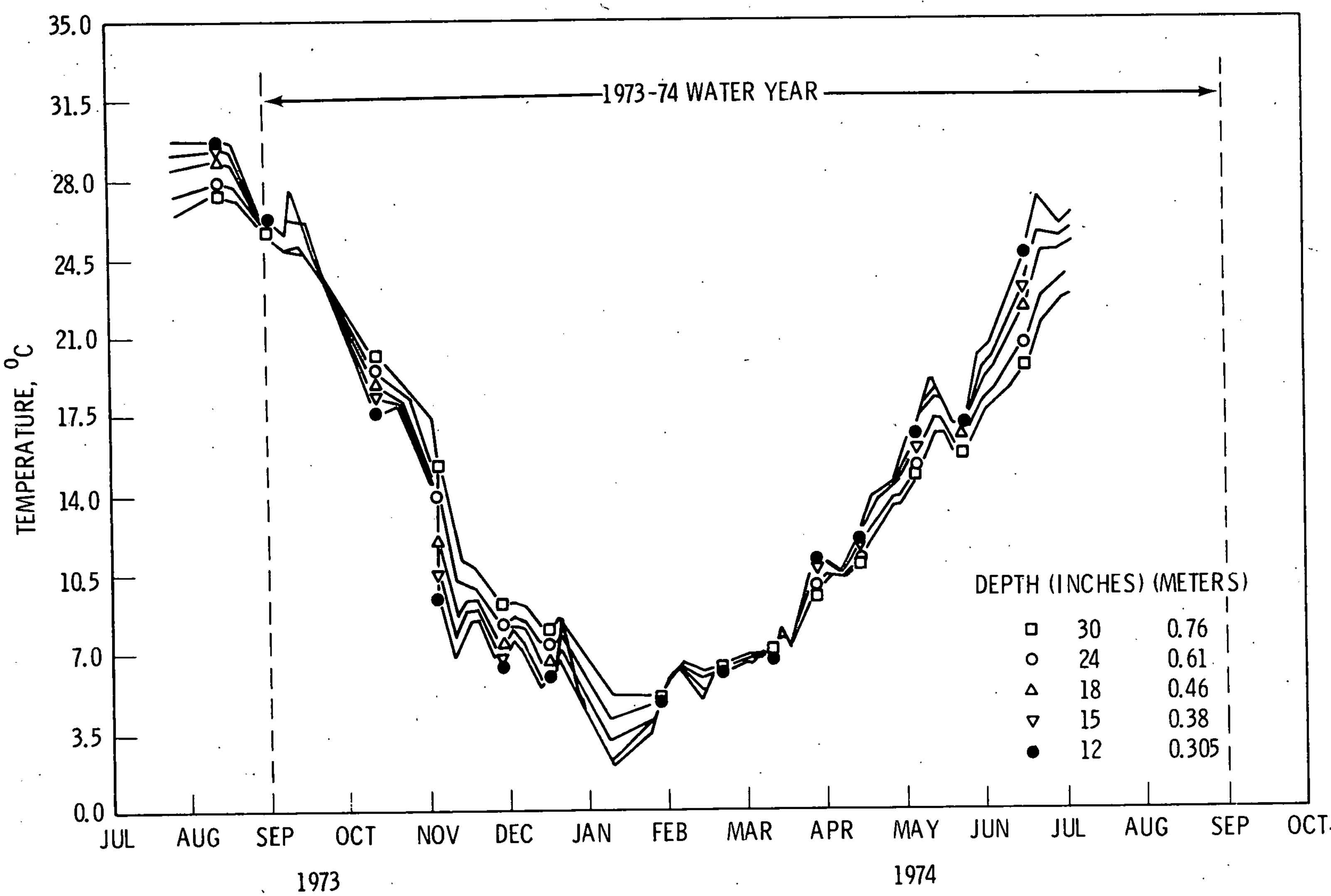


FIGURE 82

TEMPERATURE VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPTHS AT 32-49 COORDINATES

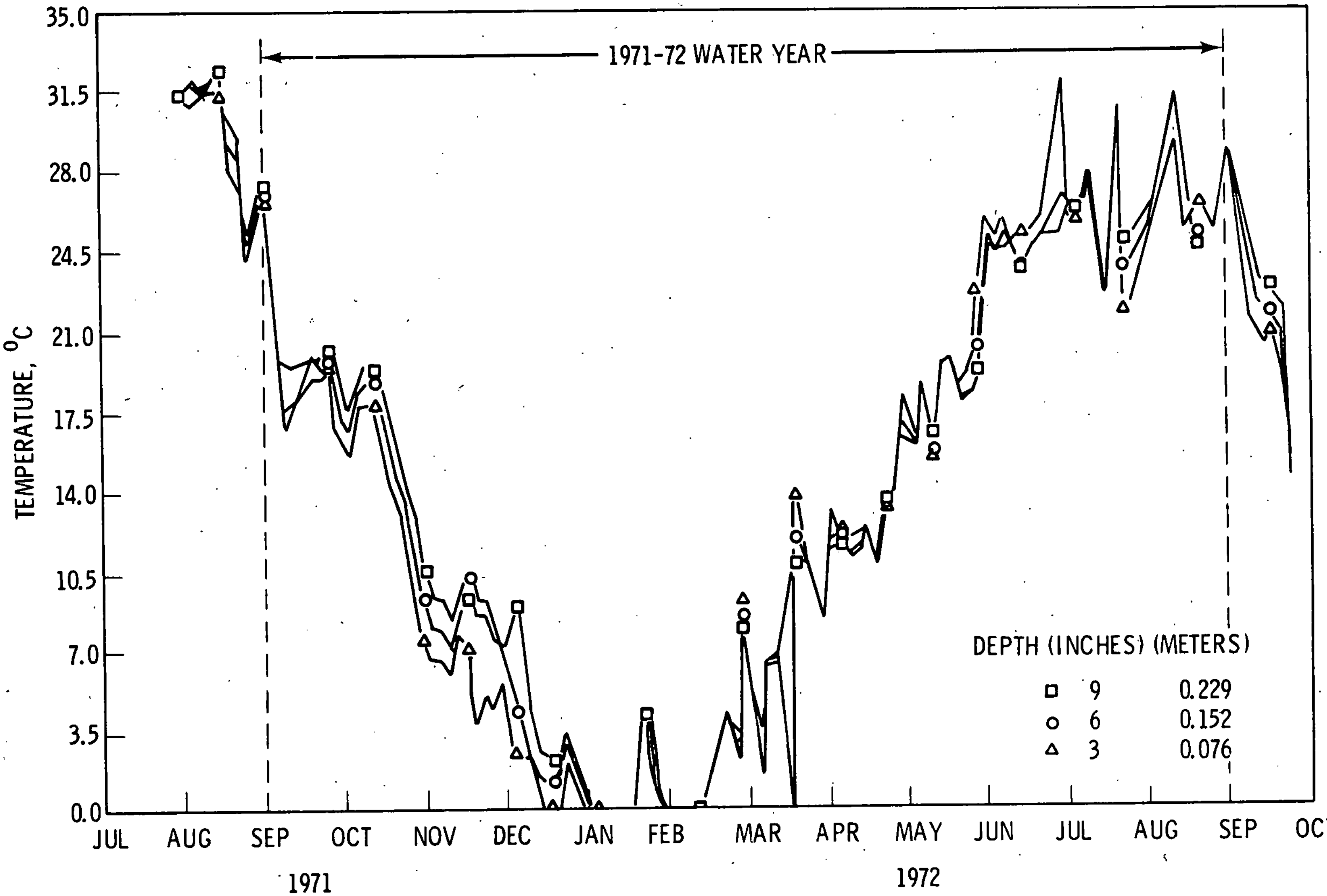


FIGURE 83

TEMPERATURE VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.076- TO 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

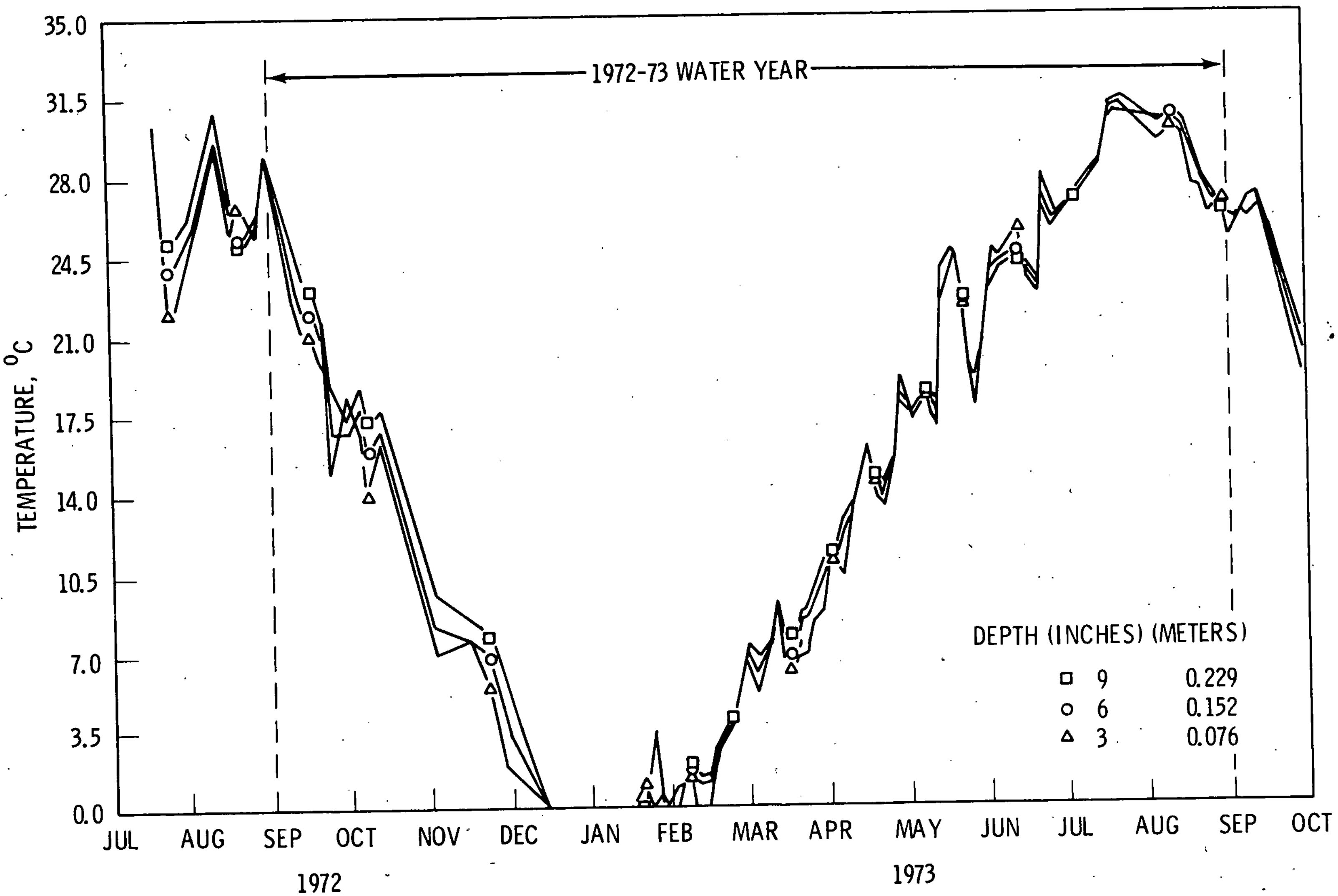


FIGURE 84

TEMPERATURE VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.076- TO 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

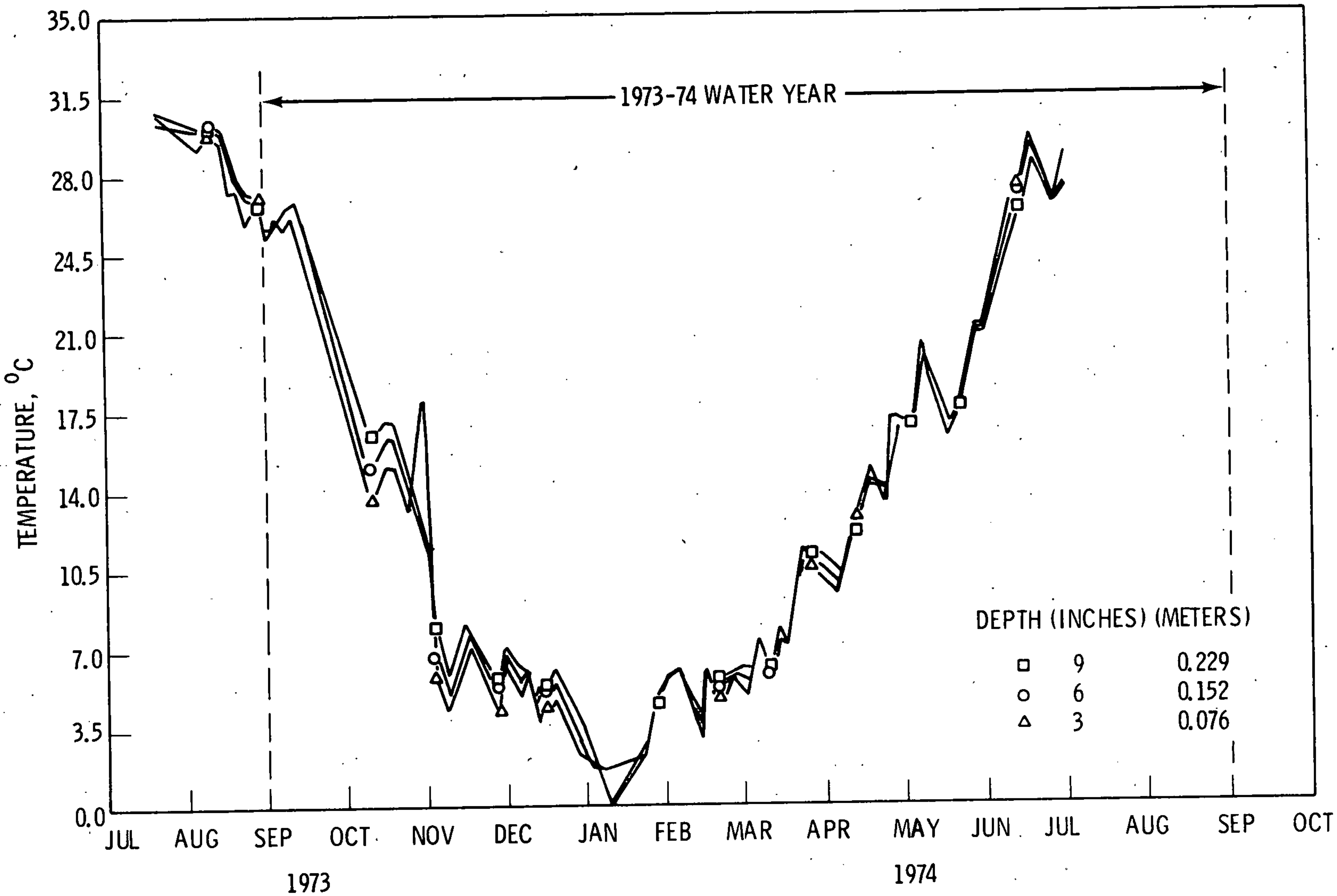


FIGURE 85

TEMPERATURE VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.076- TO 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

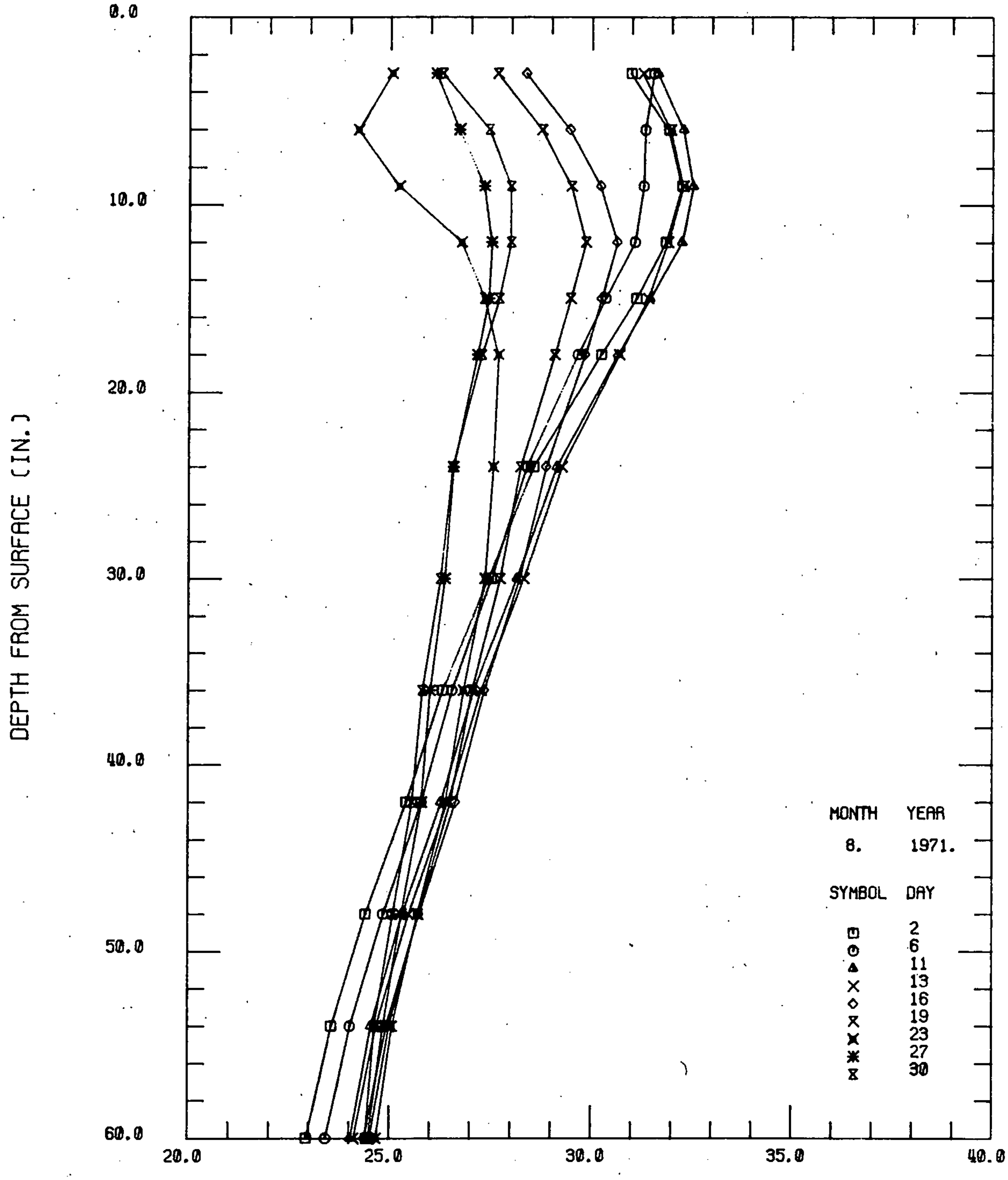


FIGURE 86

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR AUGUST 1971

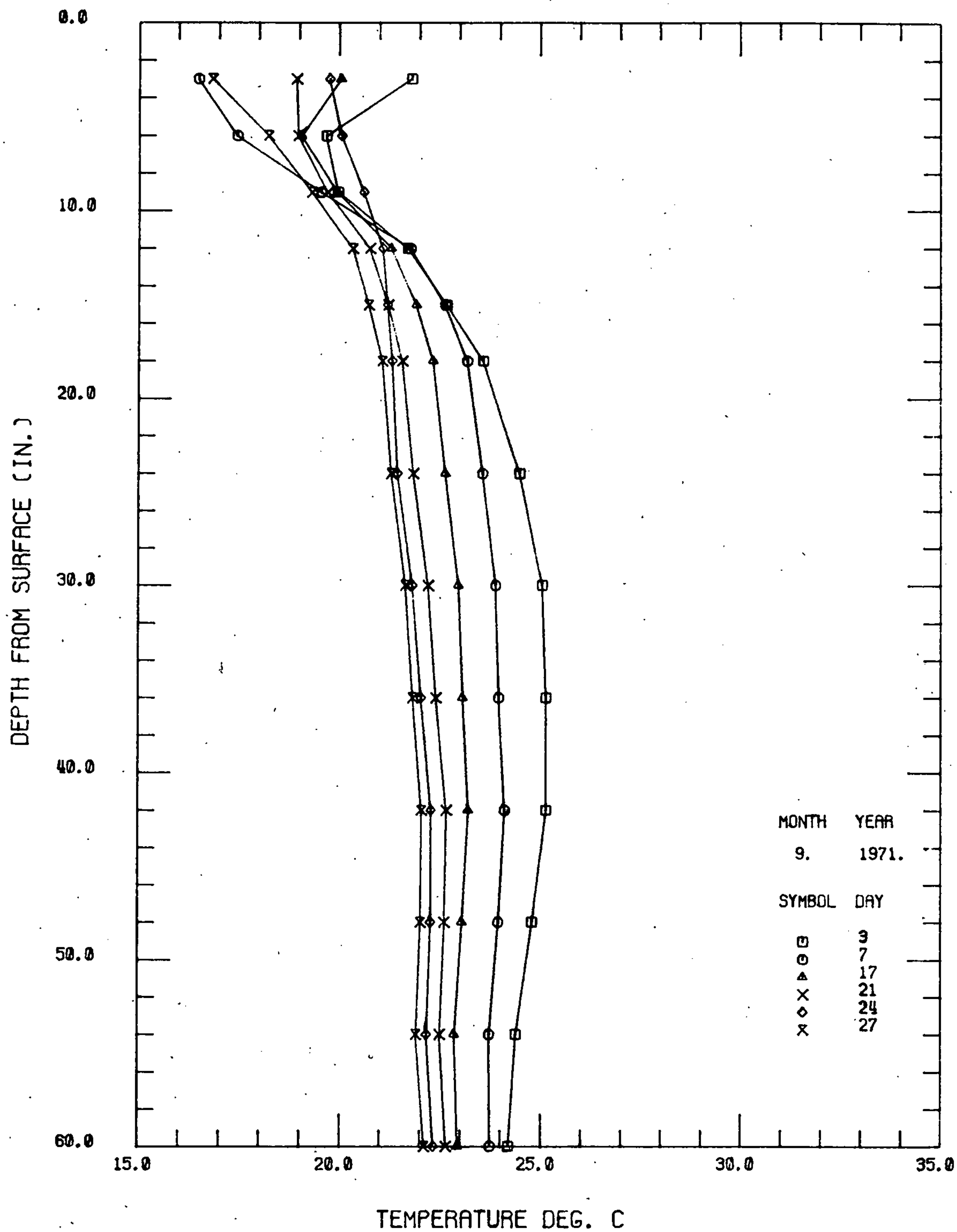


FIGURE 87

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR SEPTEMBER 1971

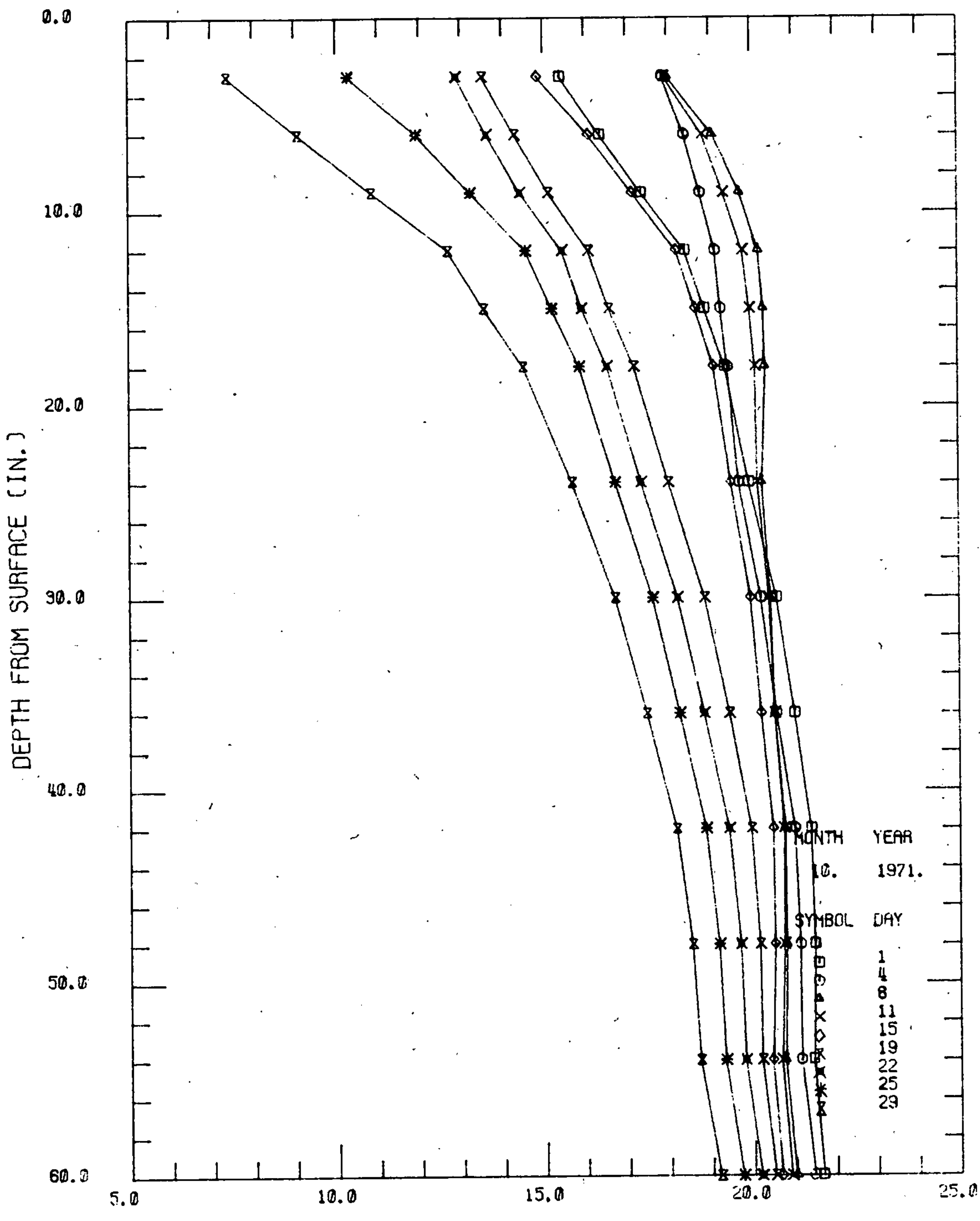


FIGURE 88

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR OCTOBER 1971

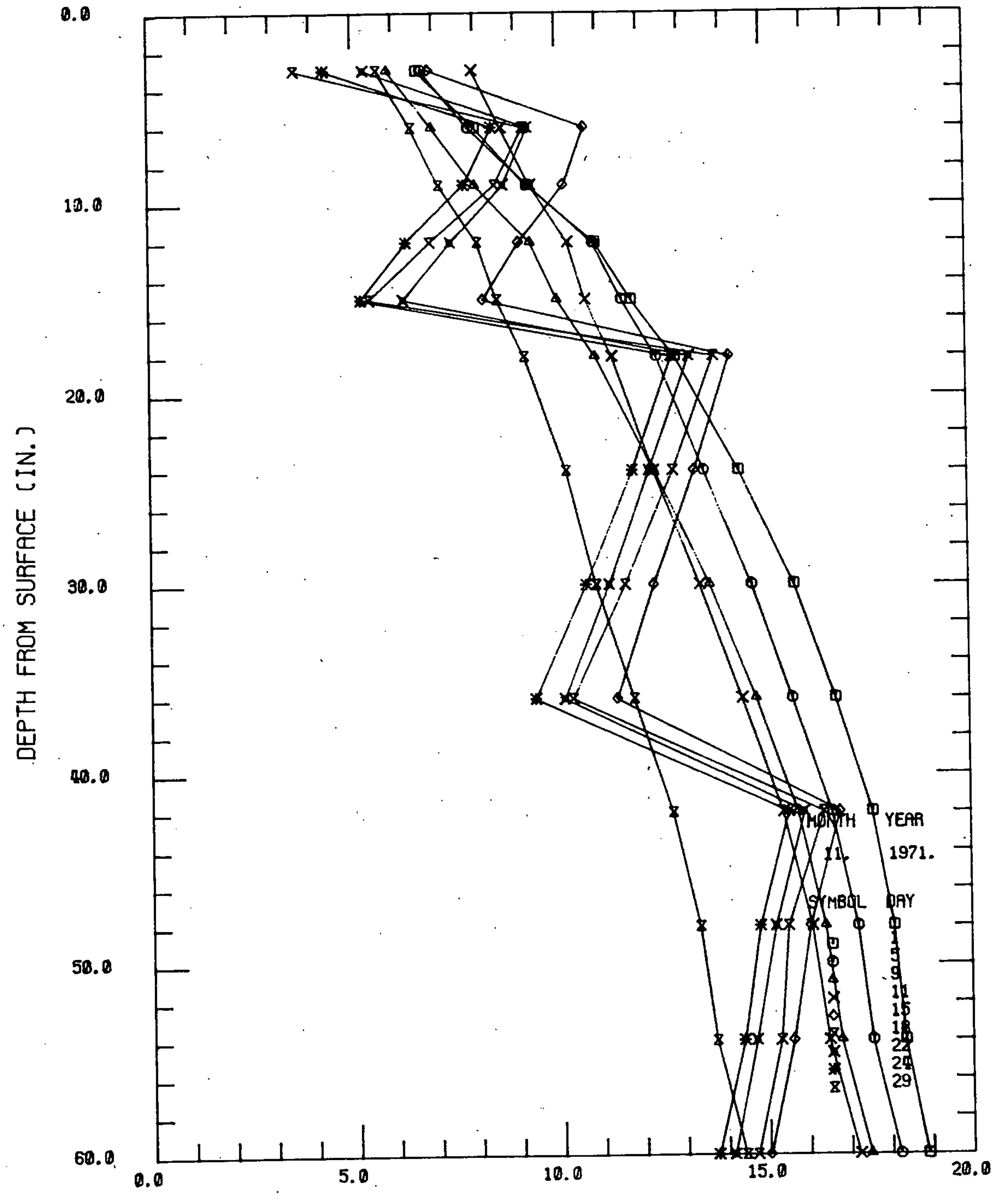


FIGURE 89

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR NOVEMBER 1971

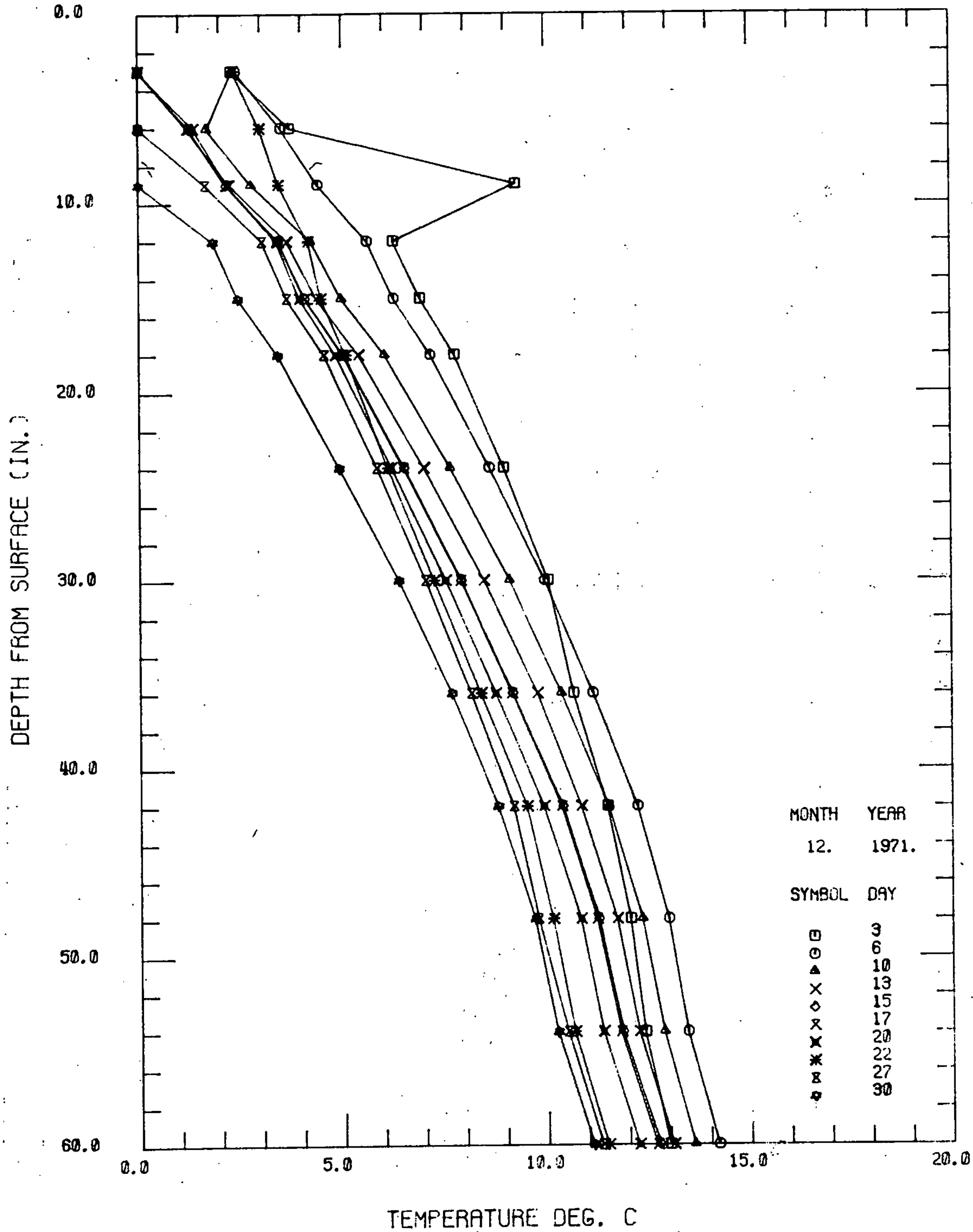


FIGURE 90

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR DECEMBER 1971

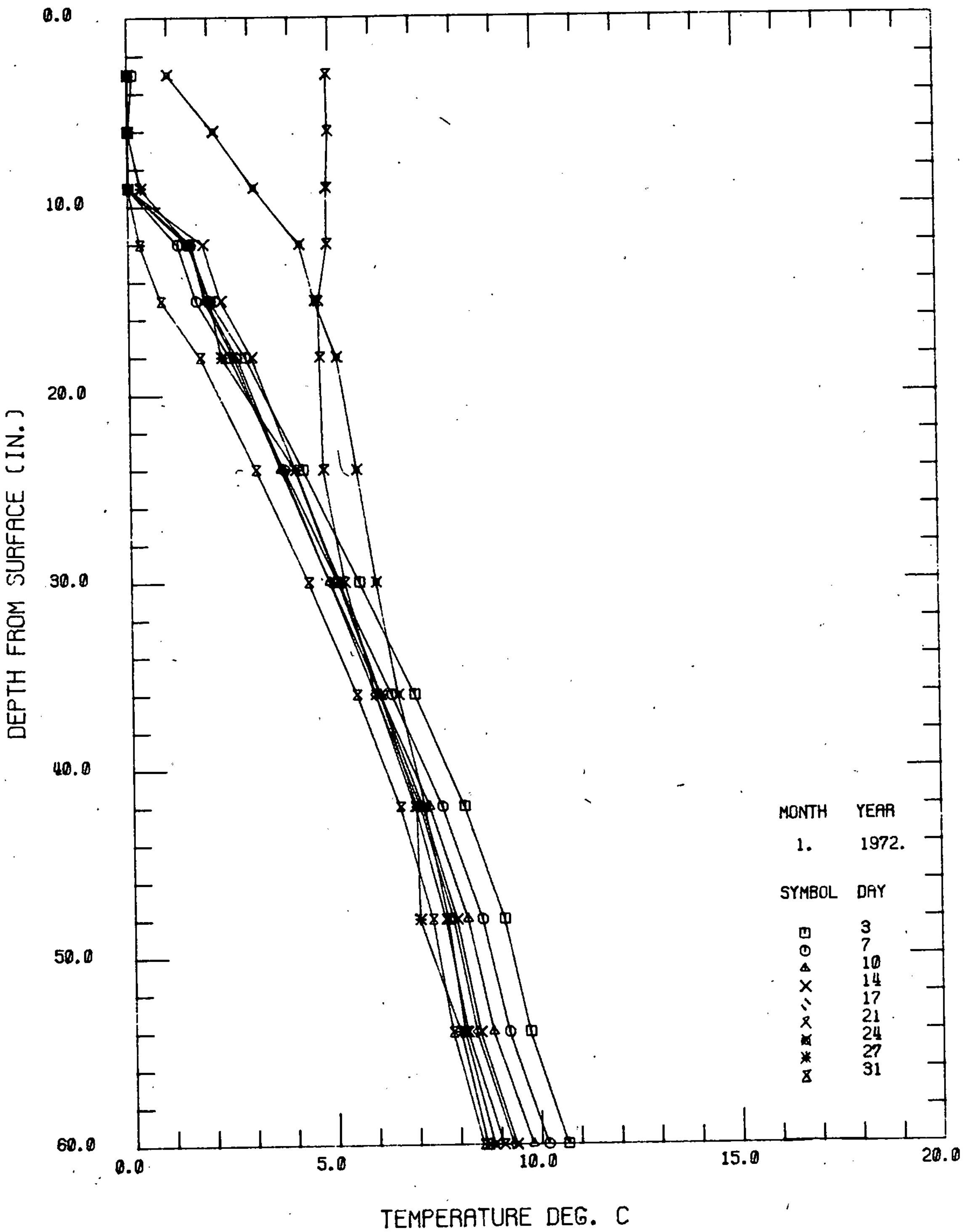


FIGURE 91

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JANUARY 1972

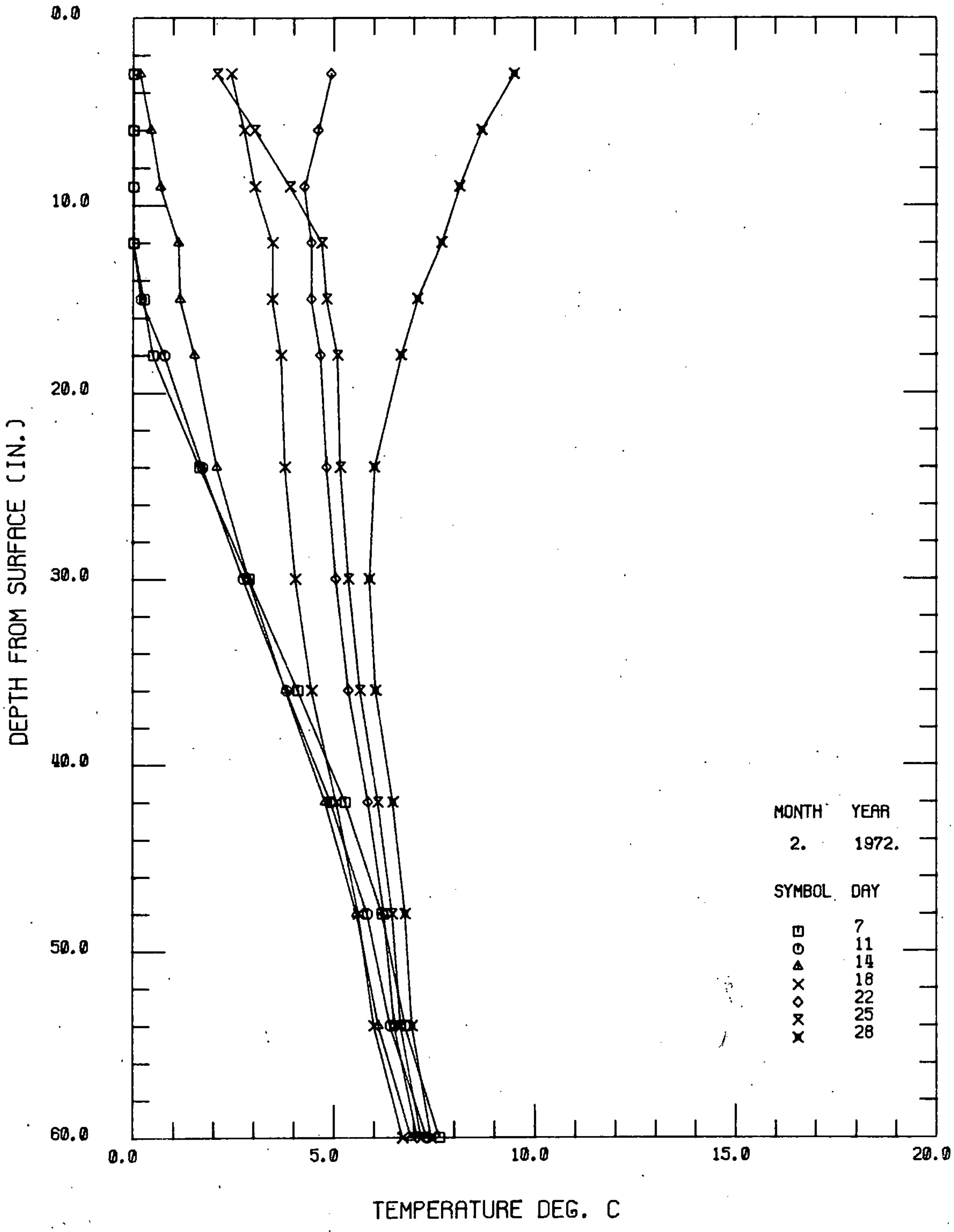


FIGURE 92

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR FEBRUARY 1972

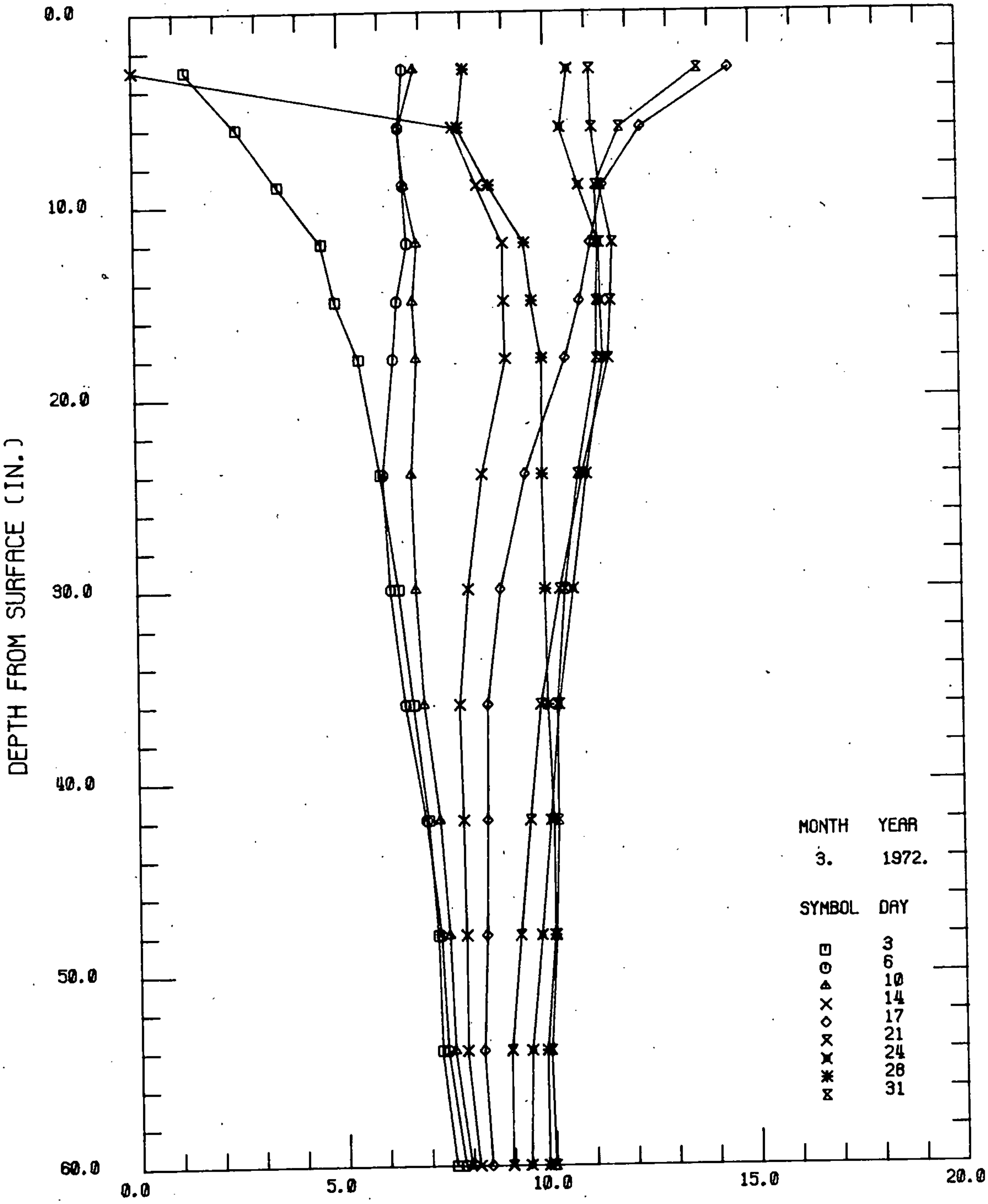


FIGURE 93

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR MARCH 1972

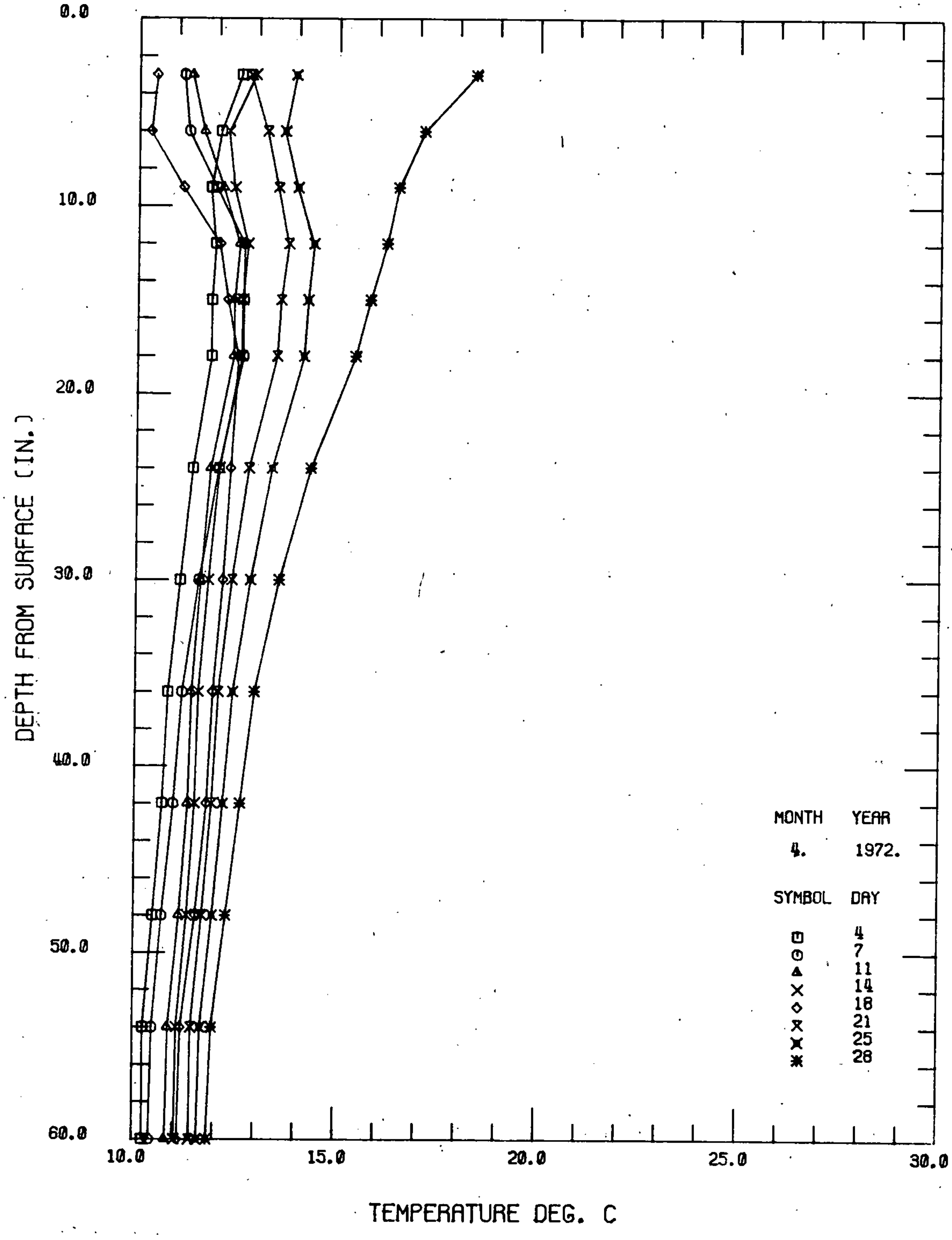


FIGURE 94

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINASTES FOR APRIL 1972

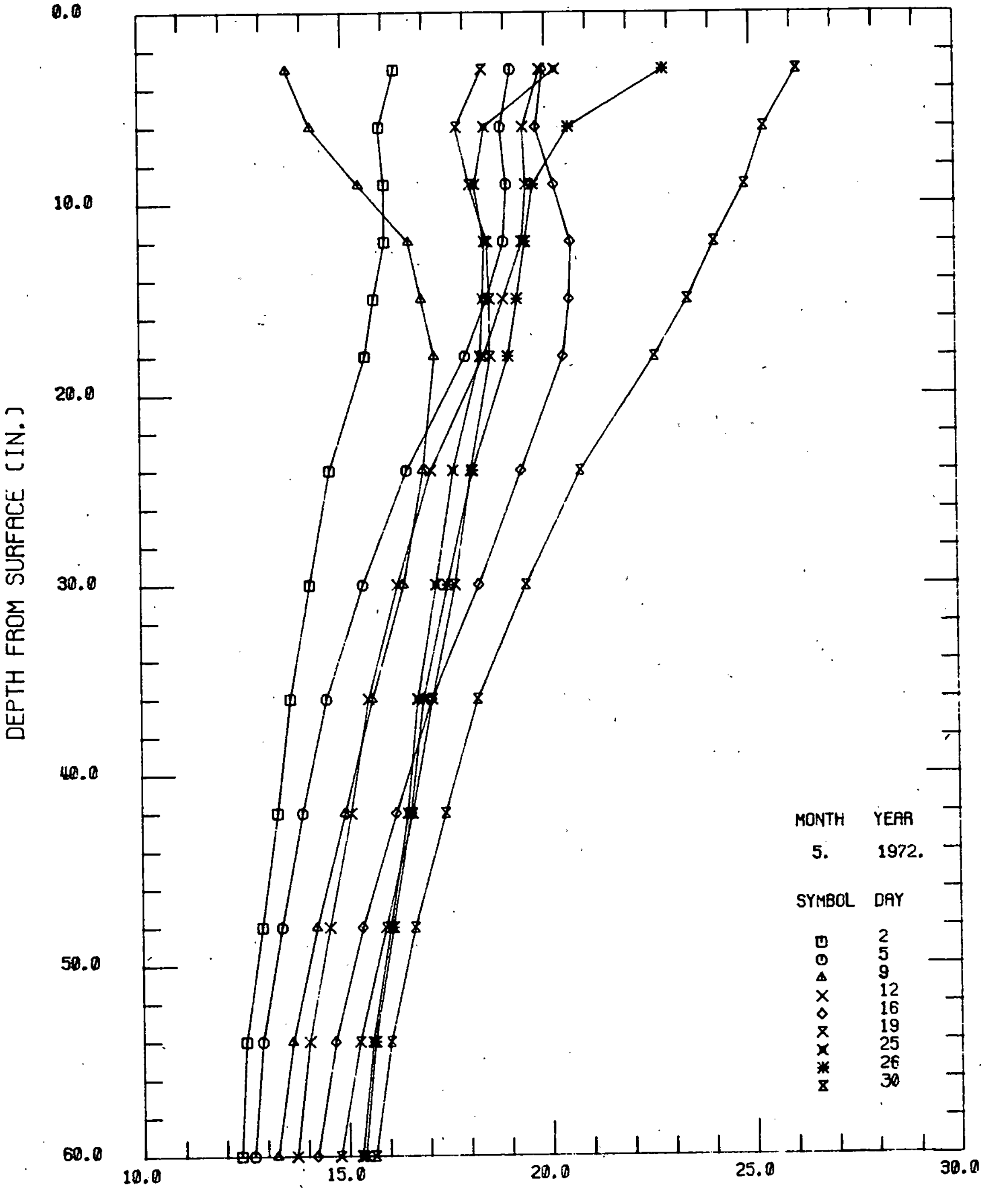


FIGURE 95

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR MAY 1972

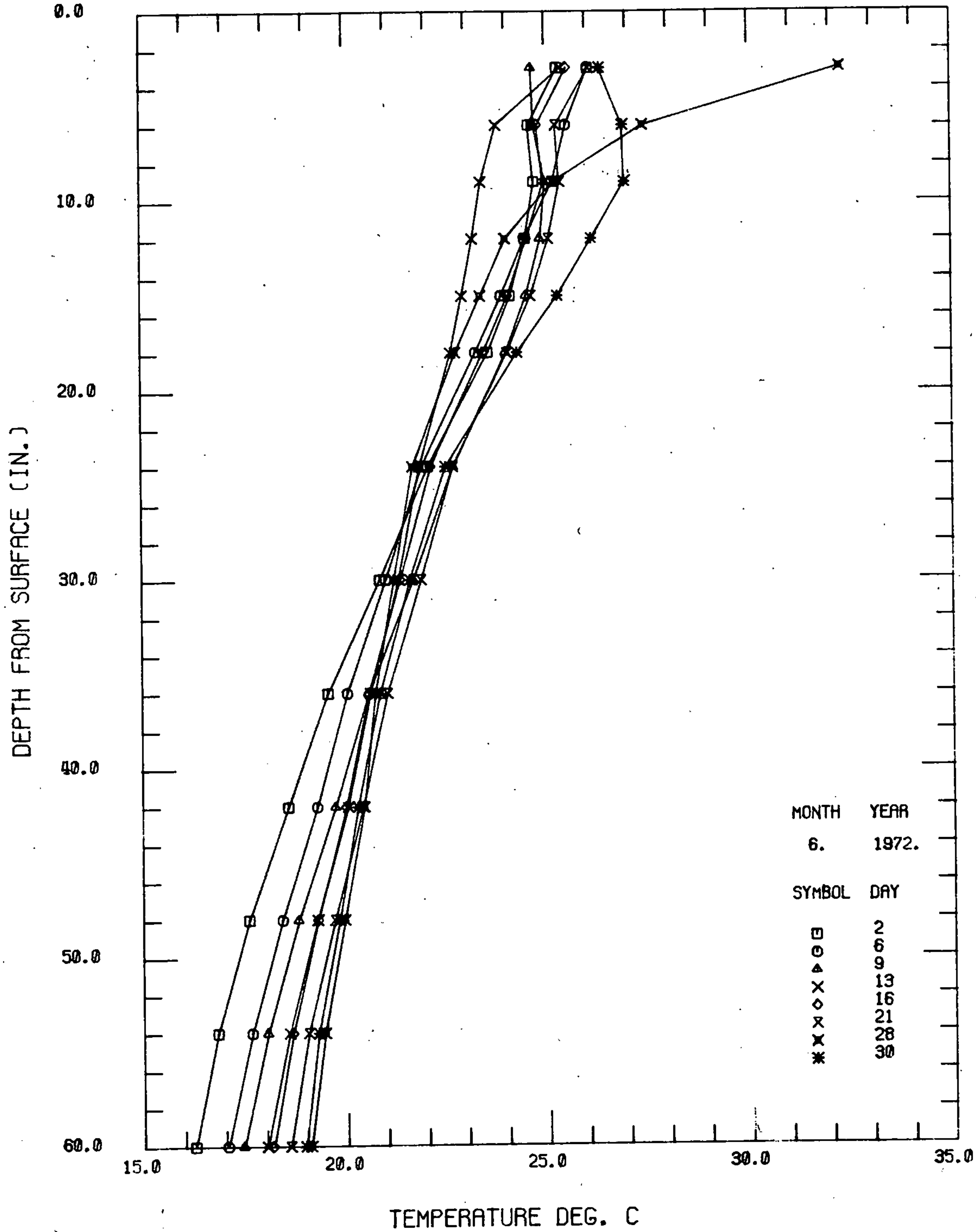


FIGURE 96

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JUNE 1972

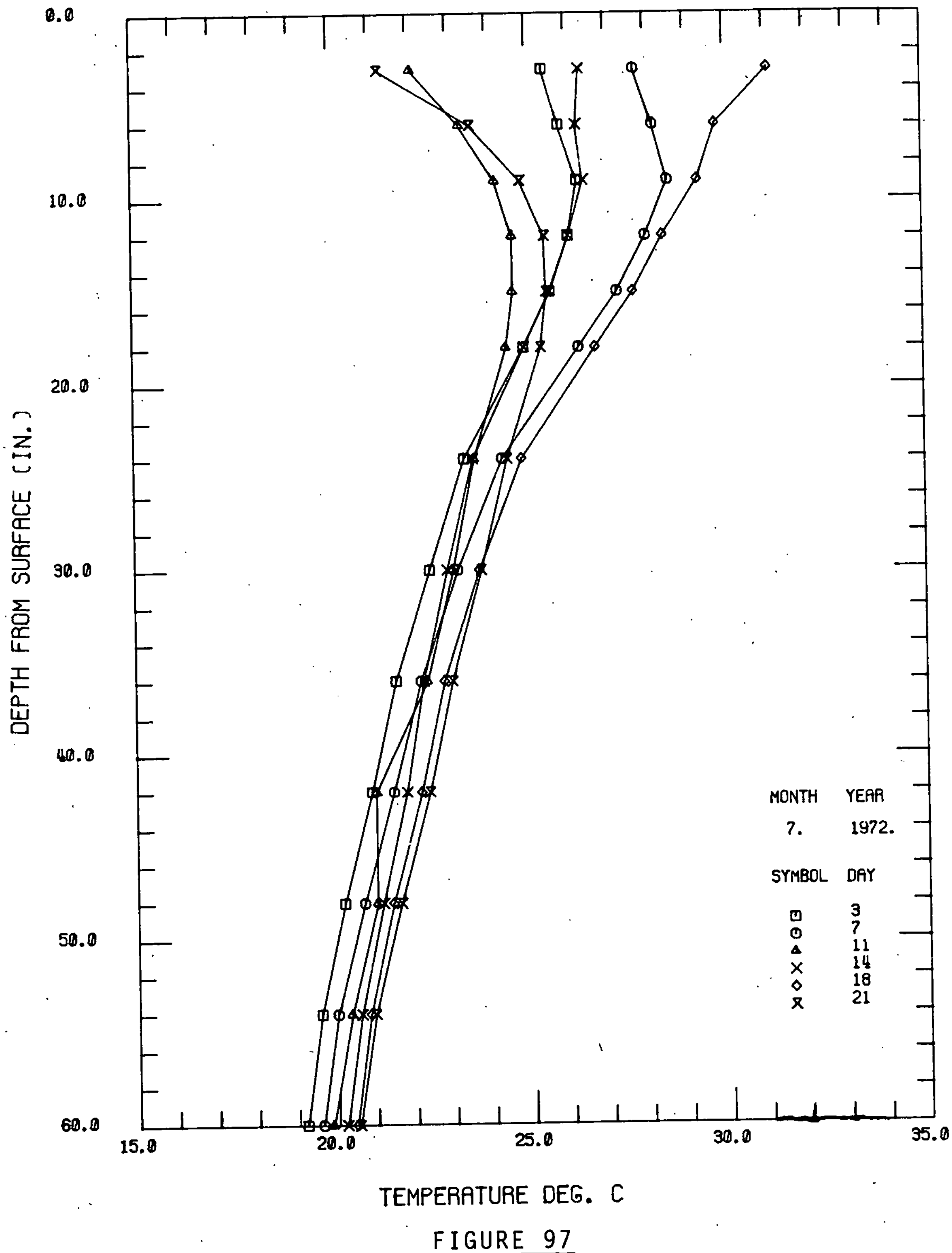


FIGURE 97

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JULY 1972

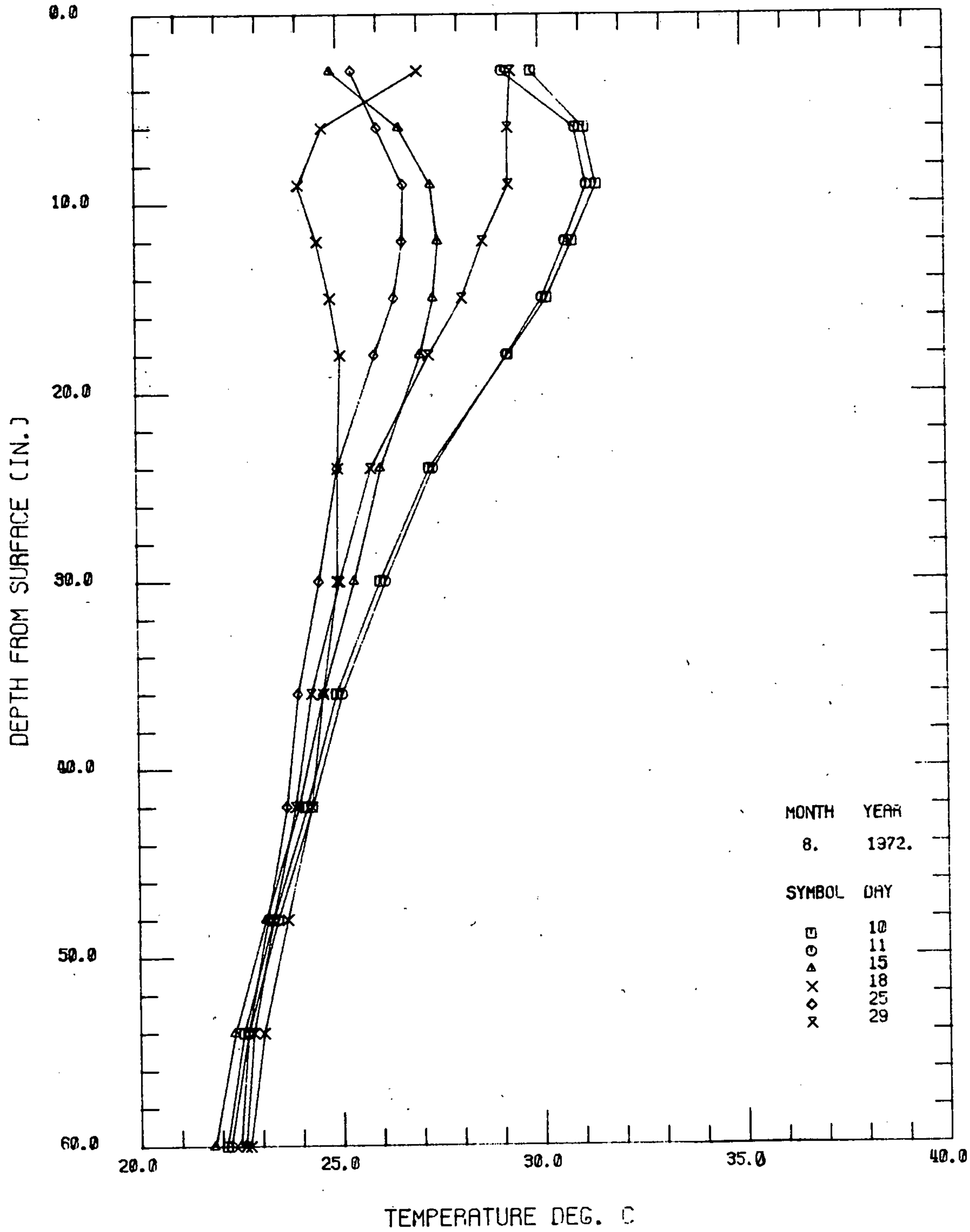


FIGURE 98

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR AUGUST 1972

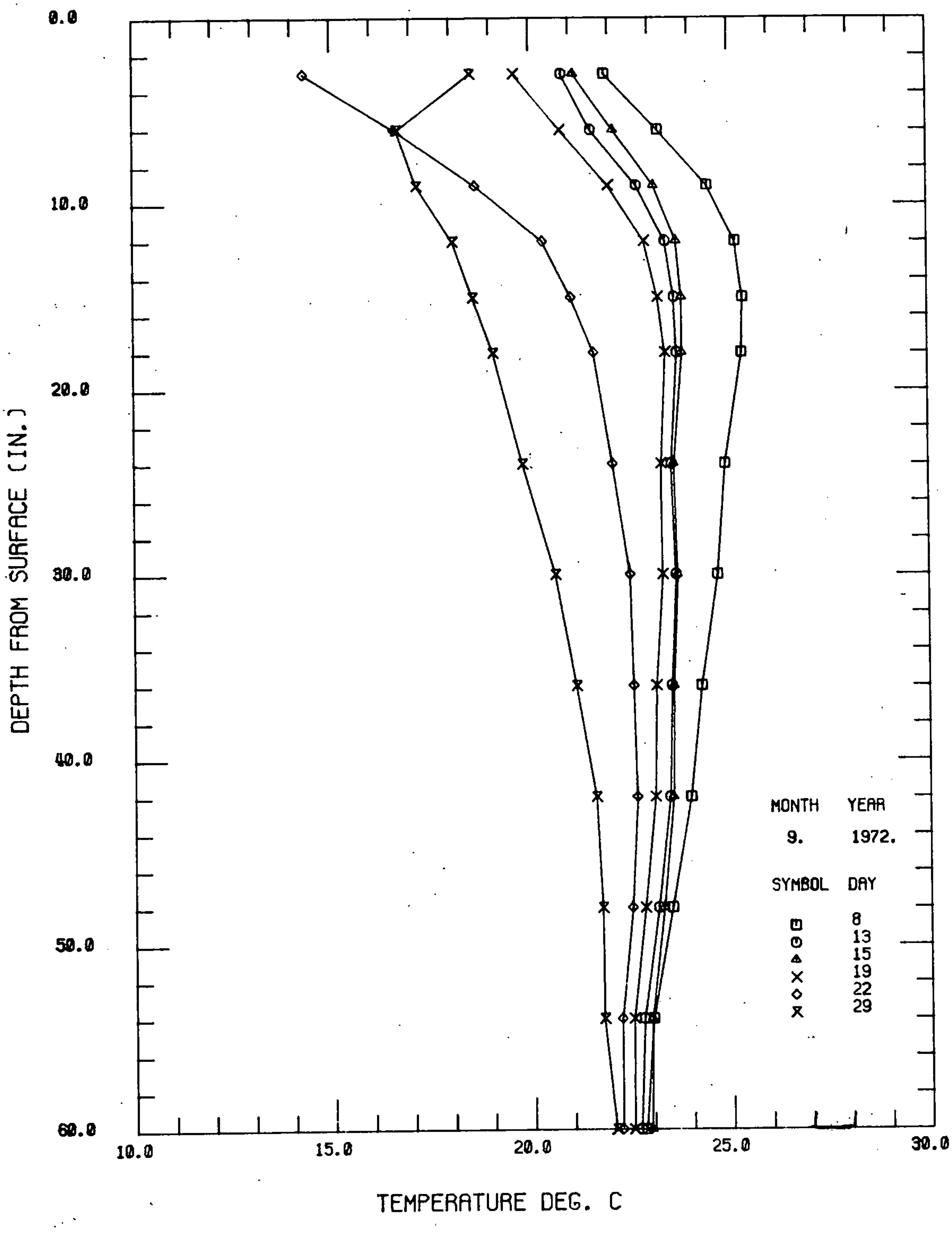


FIGURE 99

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR SEPTEMBER 1972

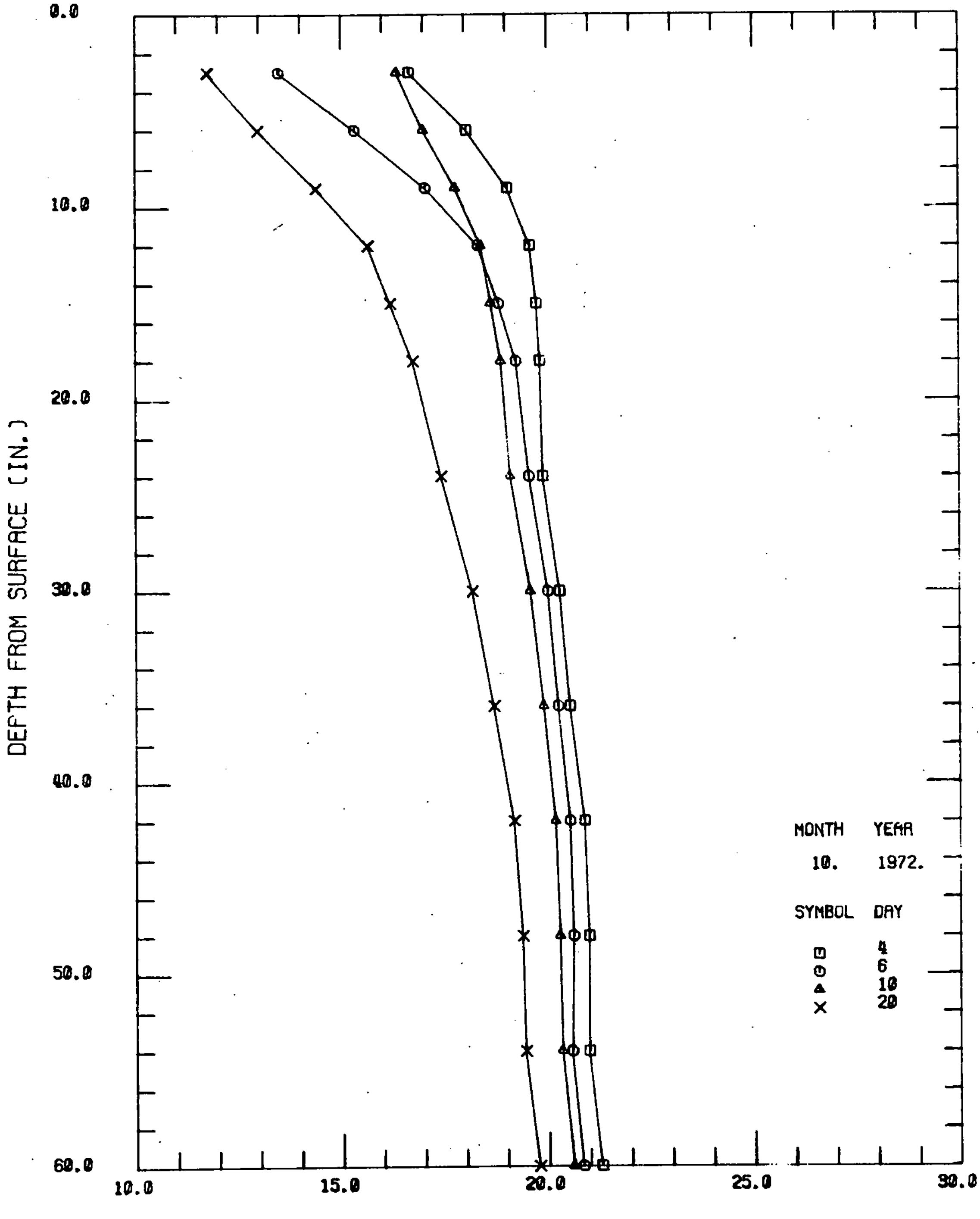


FIGURE 100

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR OCTOBER 1972

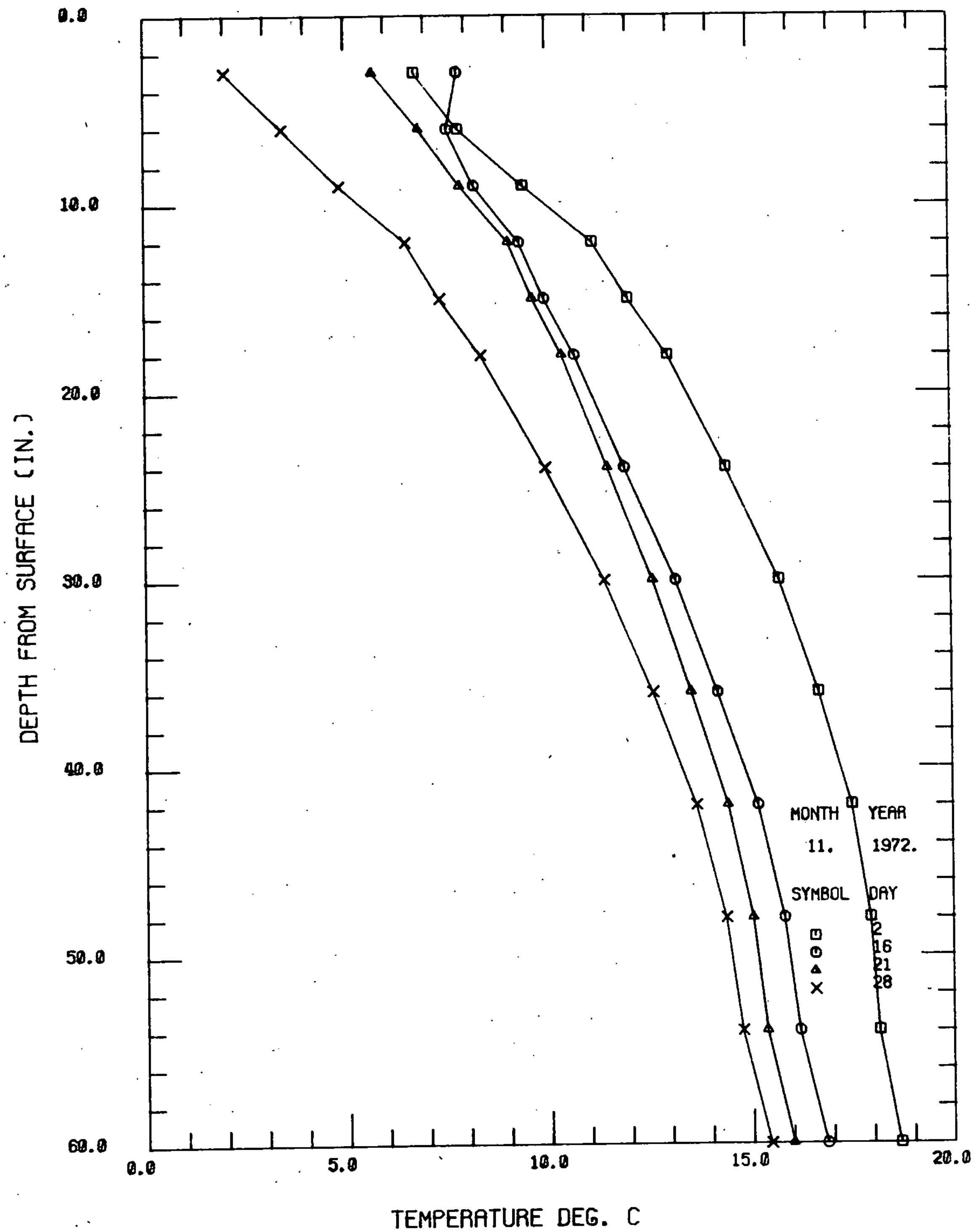


FIGURE 101

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR NOVEMBER 1972

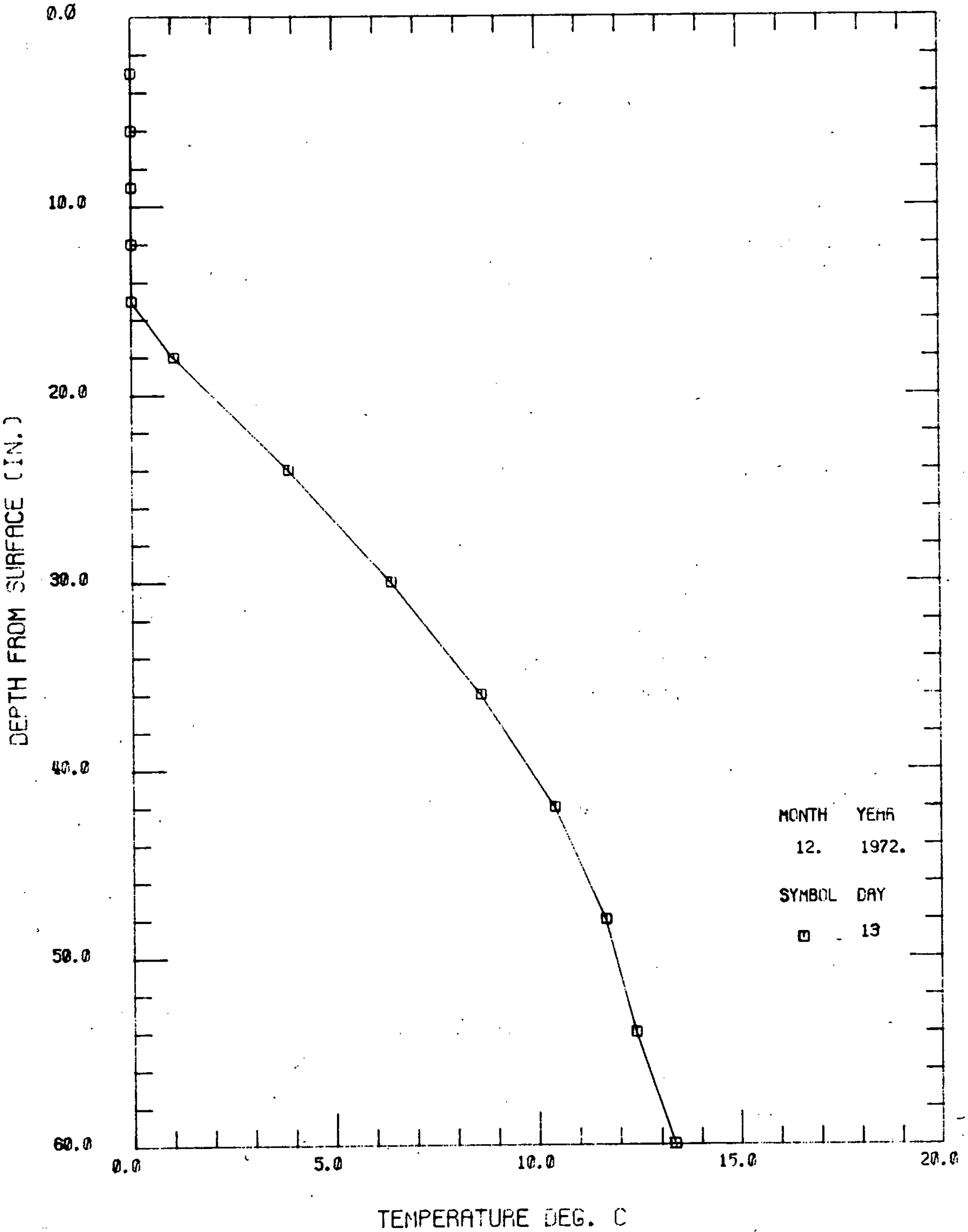


FIGURE 102

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR DECEMBER 1972

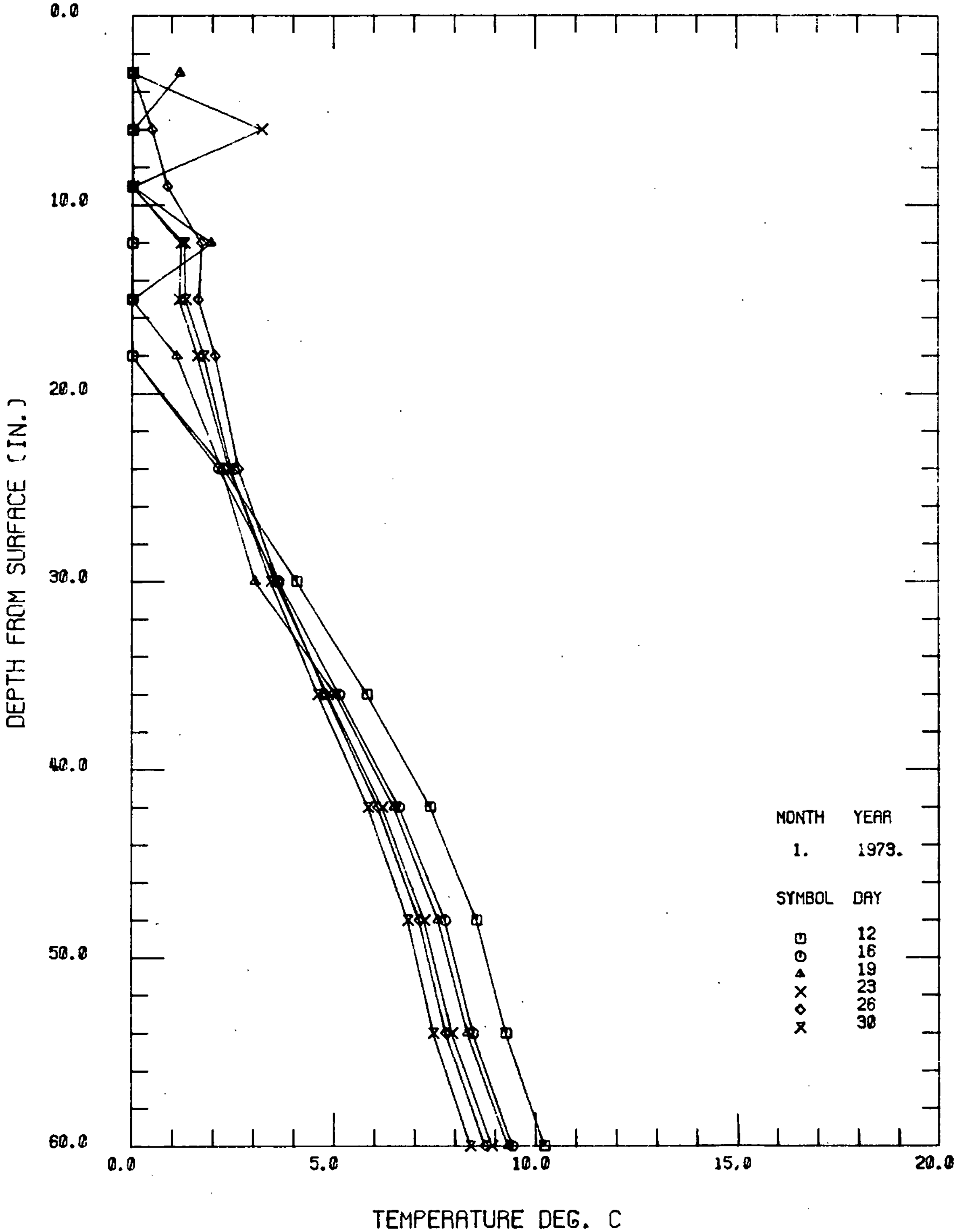


FIGURE 103

TEMPERATURE PROFILES FOR 1.52-METER DEPTH AT 32-49 COORDINATES FOR JANUARY 1973

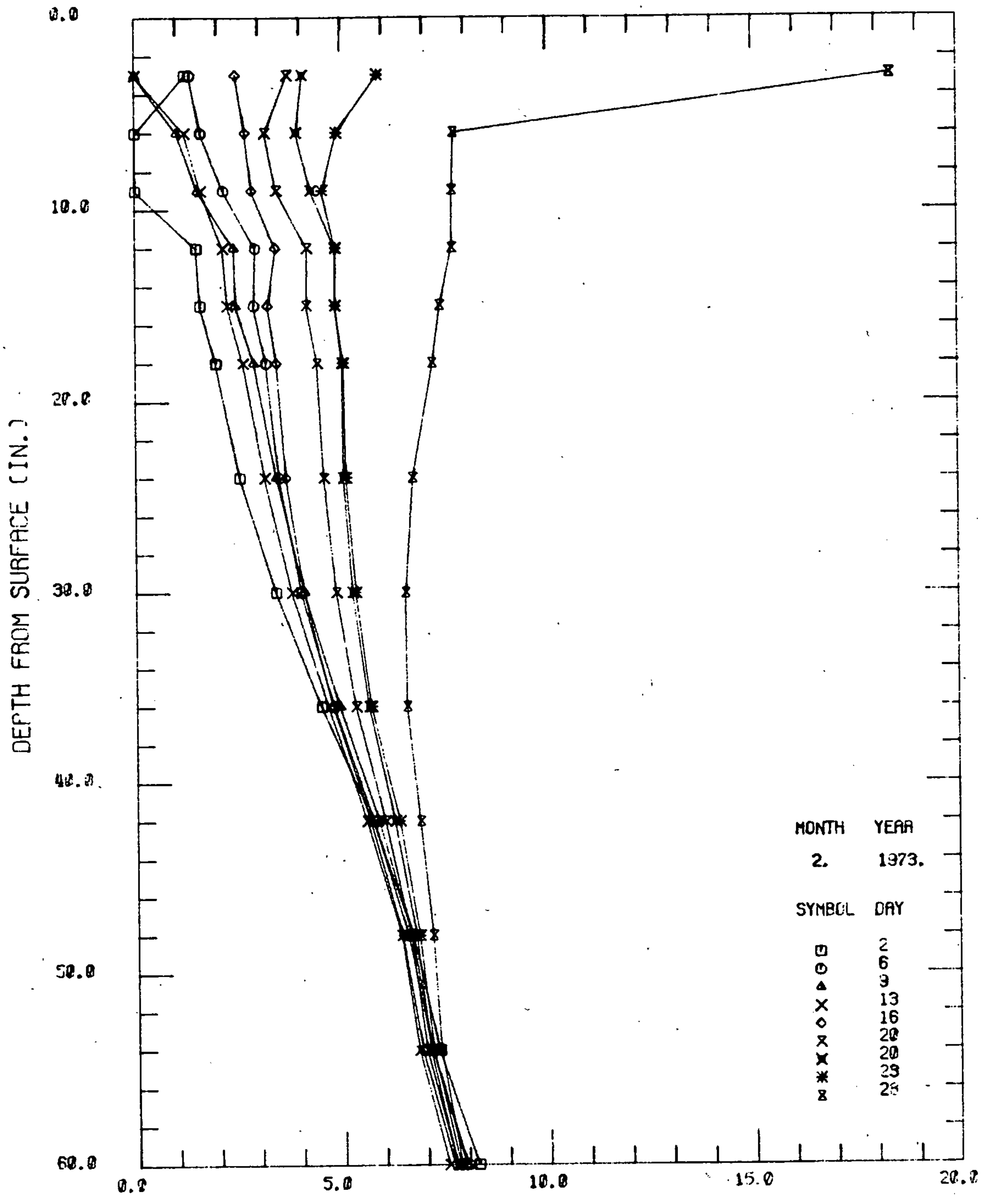


FIGURE 104

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR FEBRUARY 1973

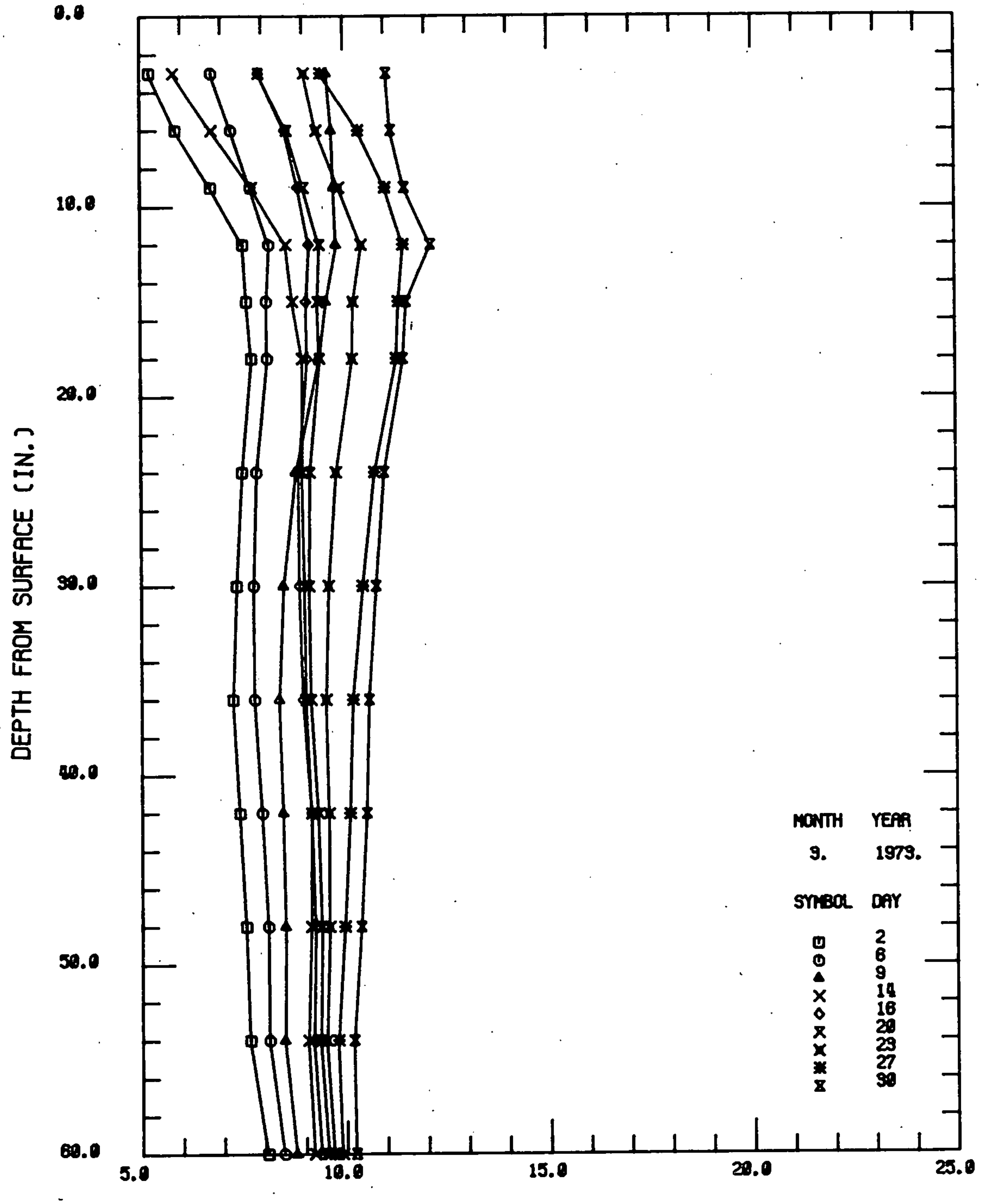


FIGURE 105

TEMPERATURE PROFILES FOR 1.52-METER DEPTH AT 32-49 COORDINATES FOR MARCH 1973

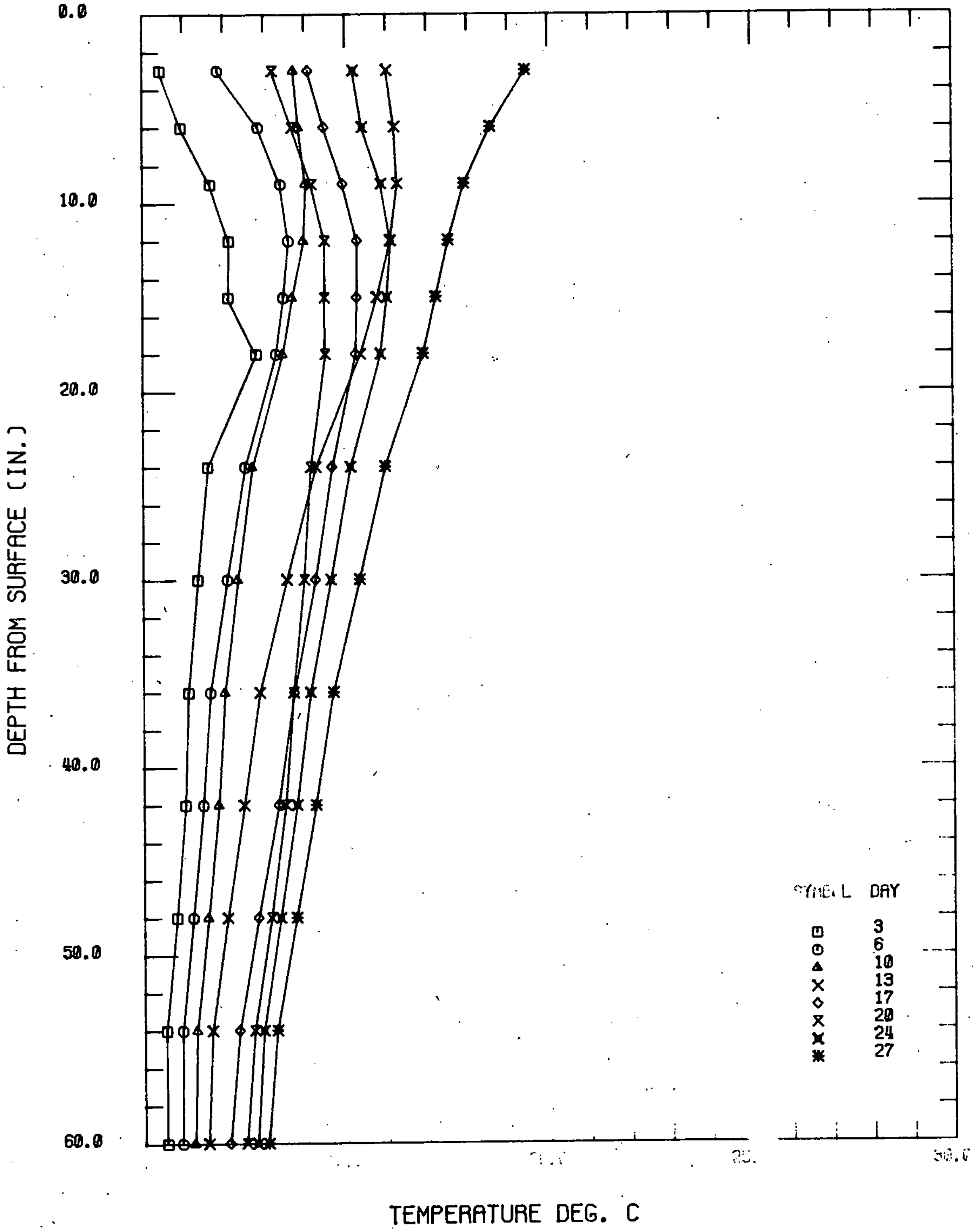


FIGURE 106

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR APRIL 1973

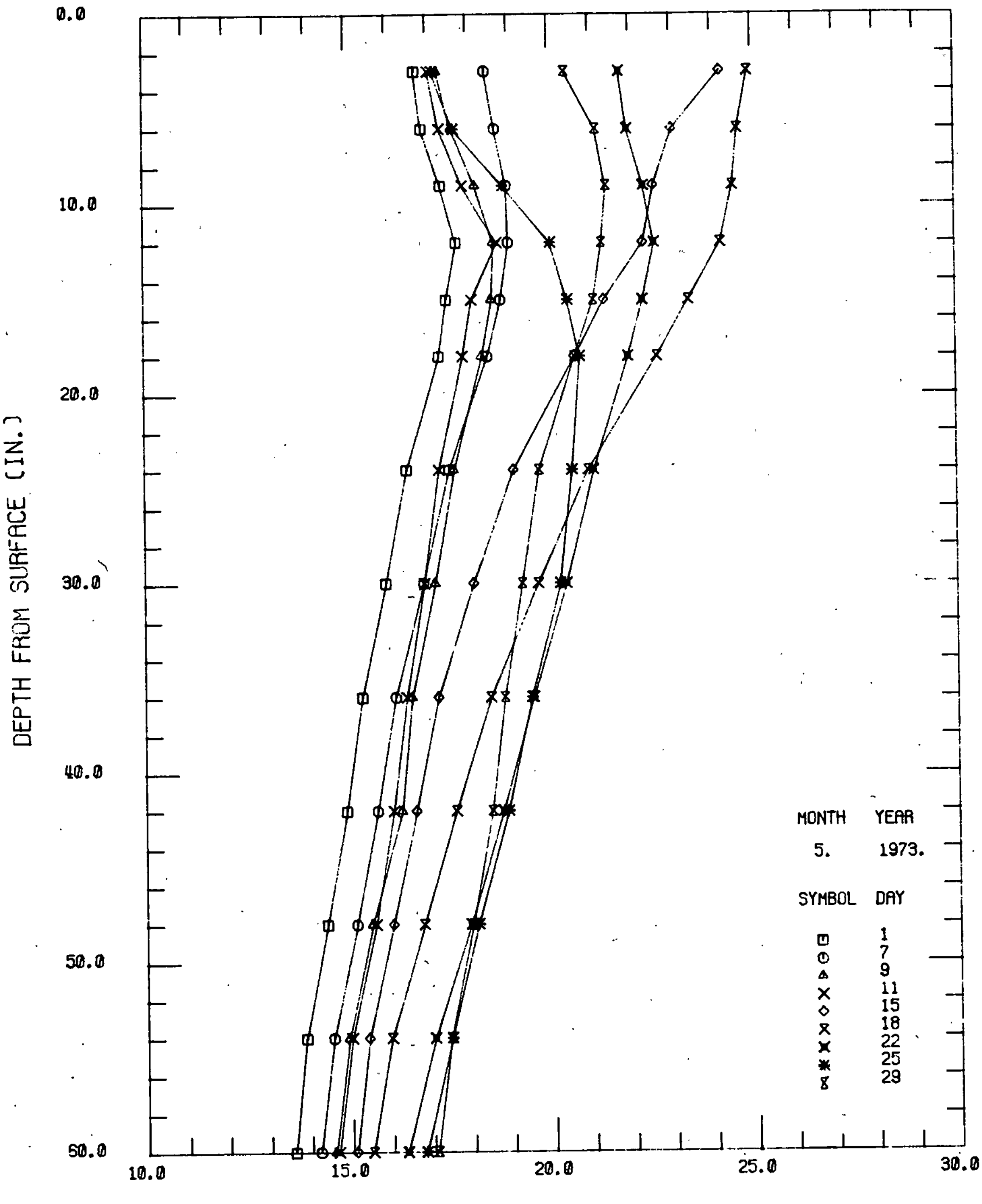


FIGURE 107

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR MAY 1973

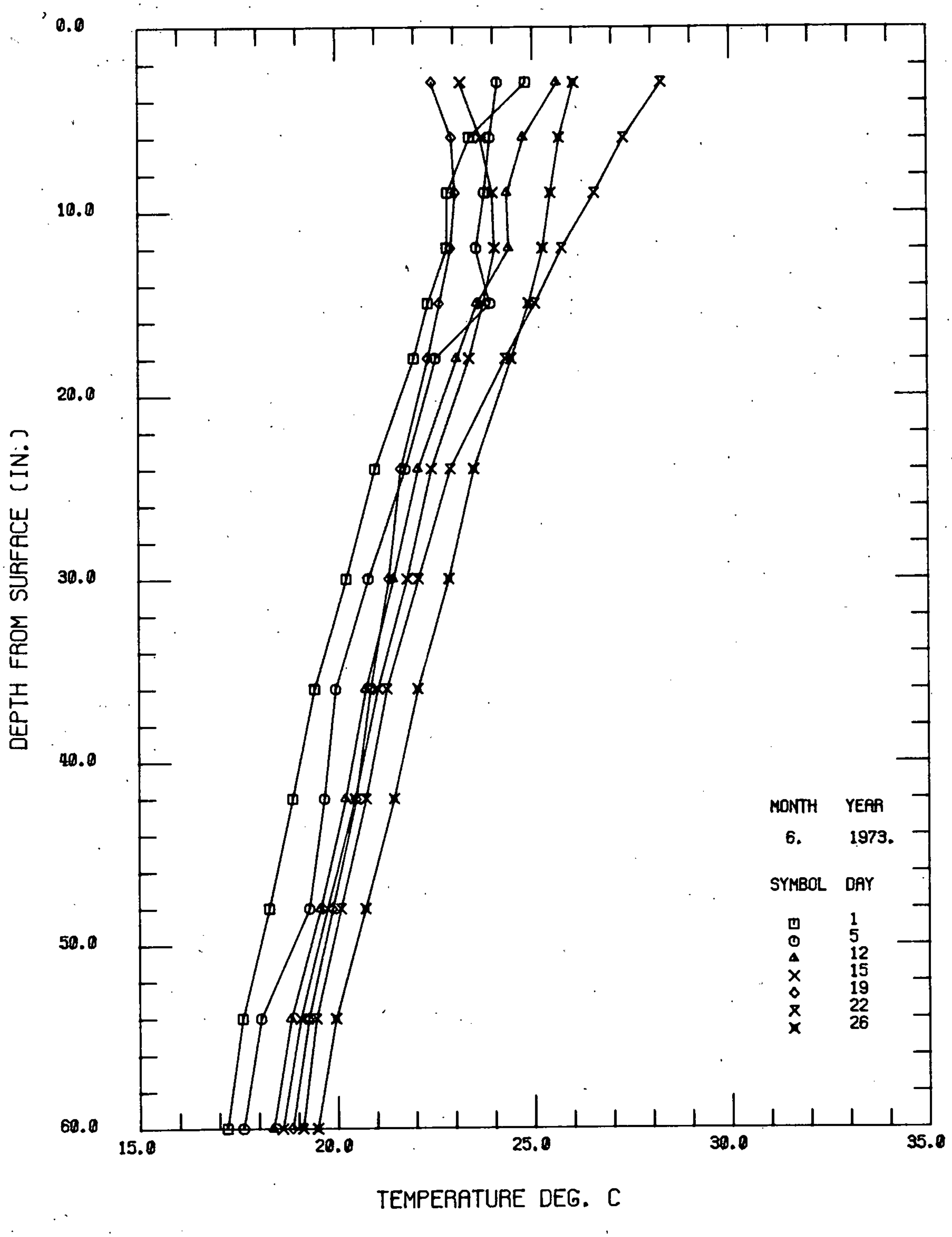


FIGURE 108

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JUNE 1973

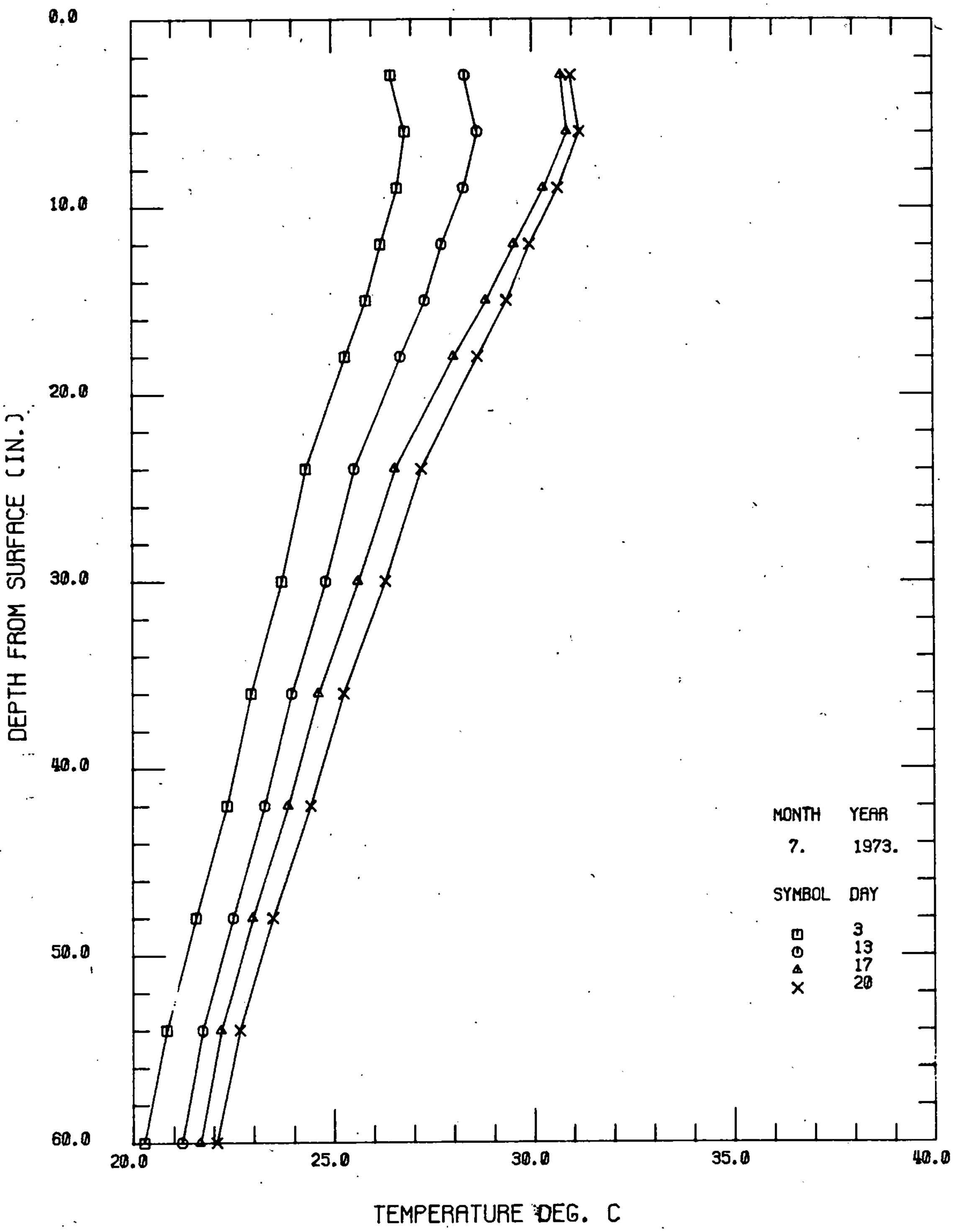


FIGURE 109

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JULY 1973

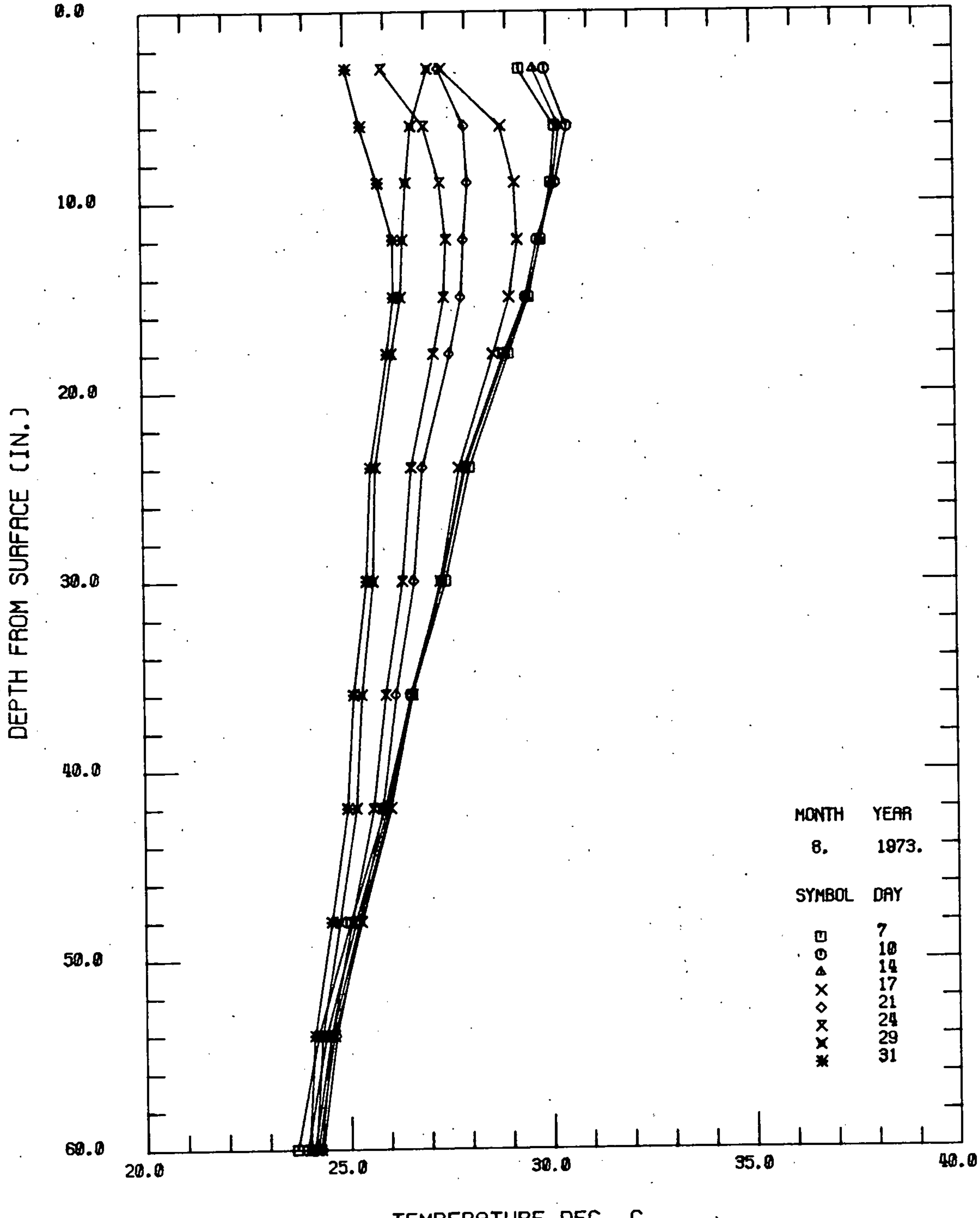


FIGURE 110

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR AUGUST 1973

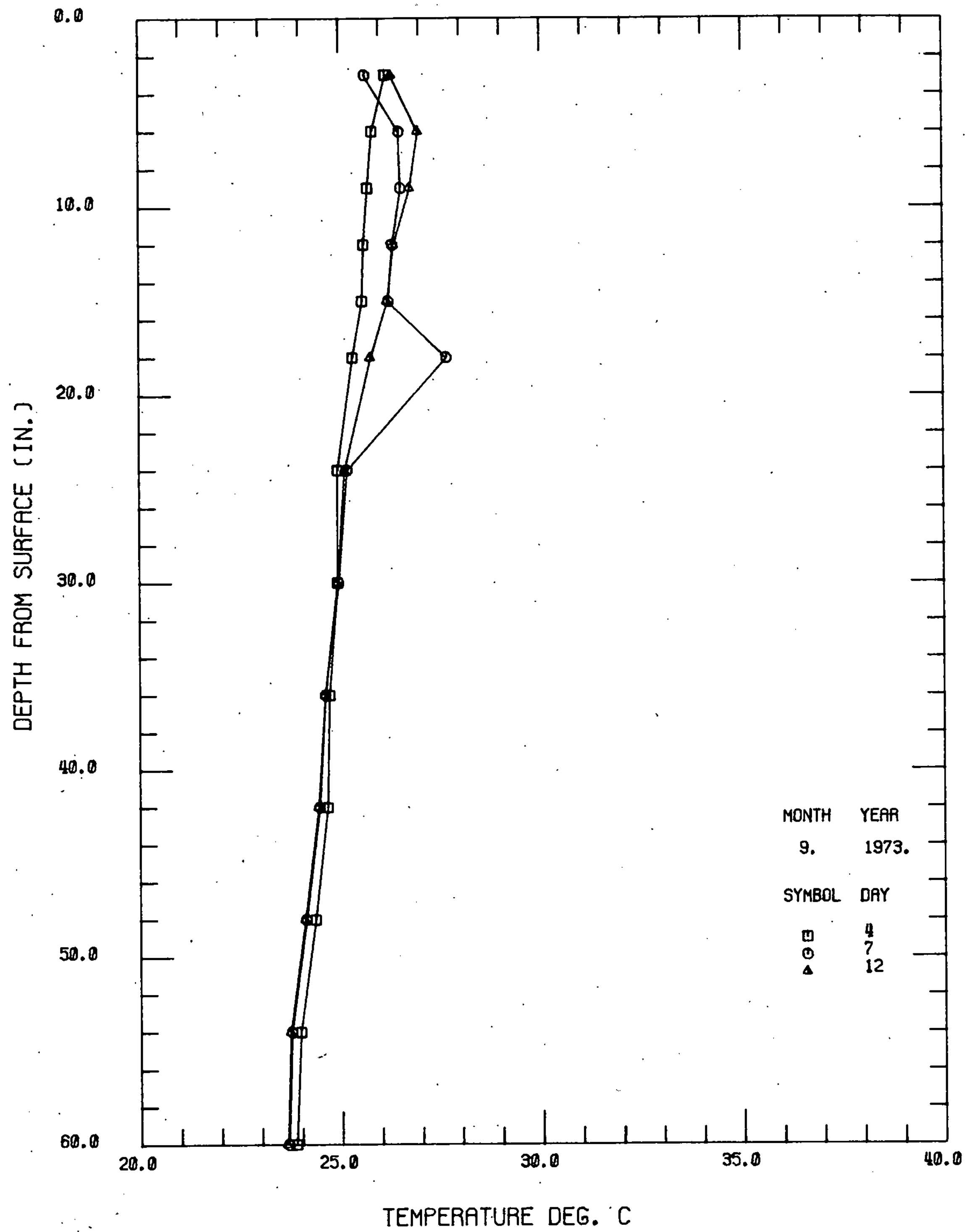


FIGURE 111

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR SEPTEMBER 1973

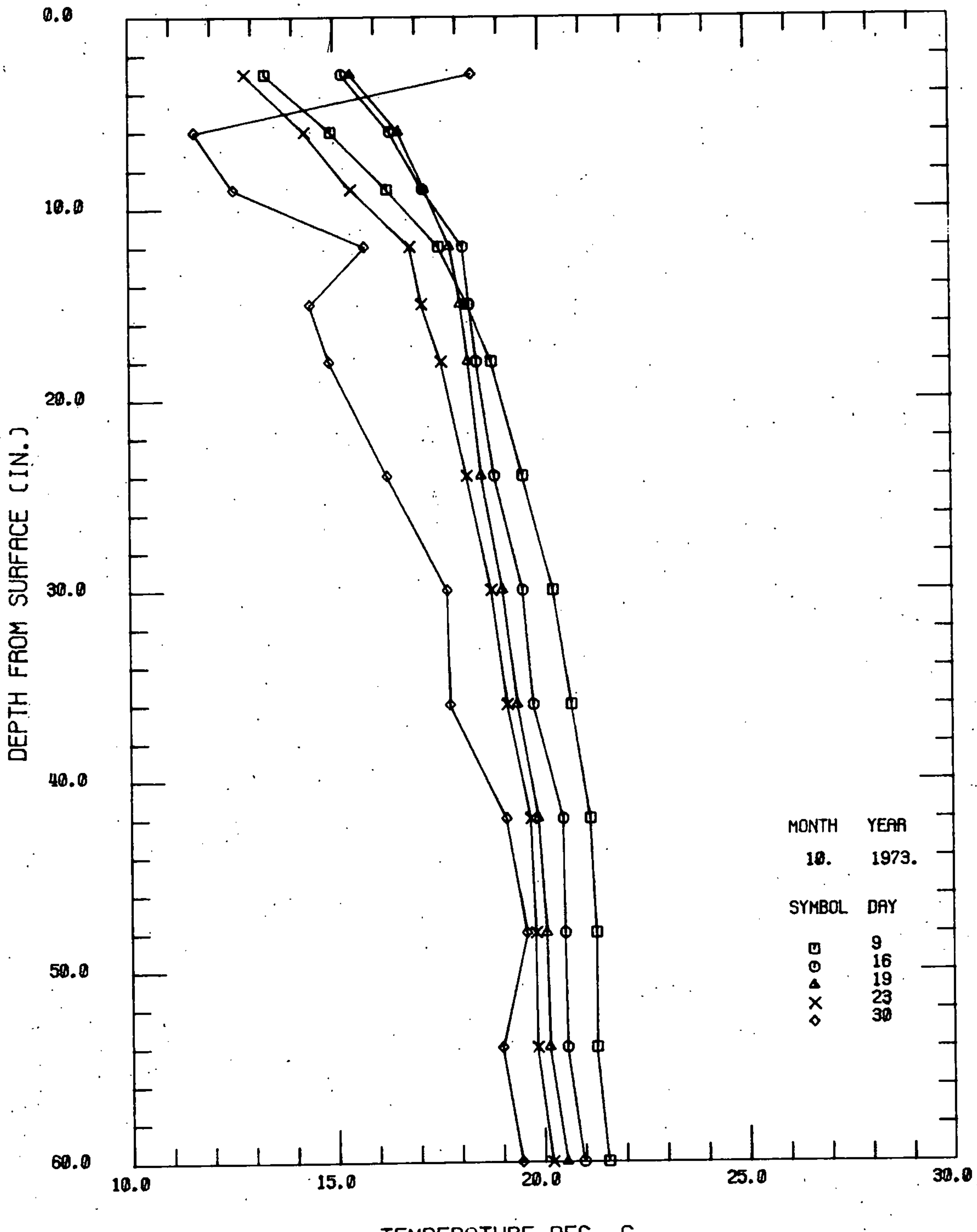


FIGURE 112

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR OCTOBER 1973

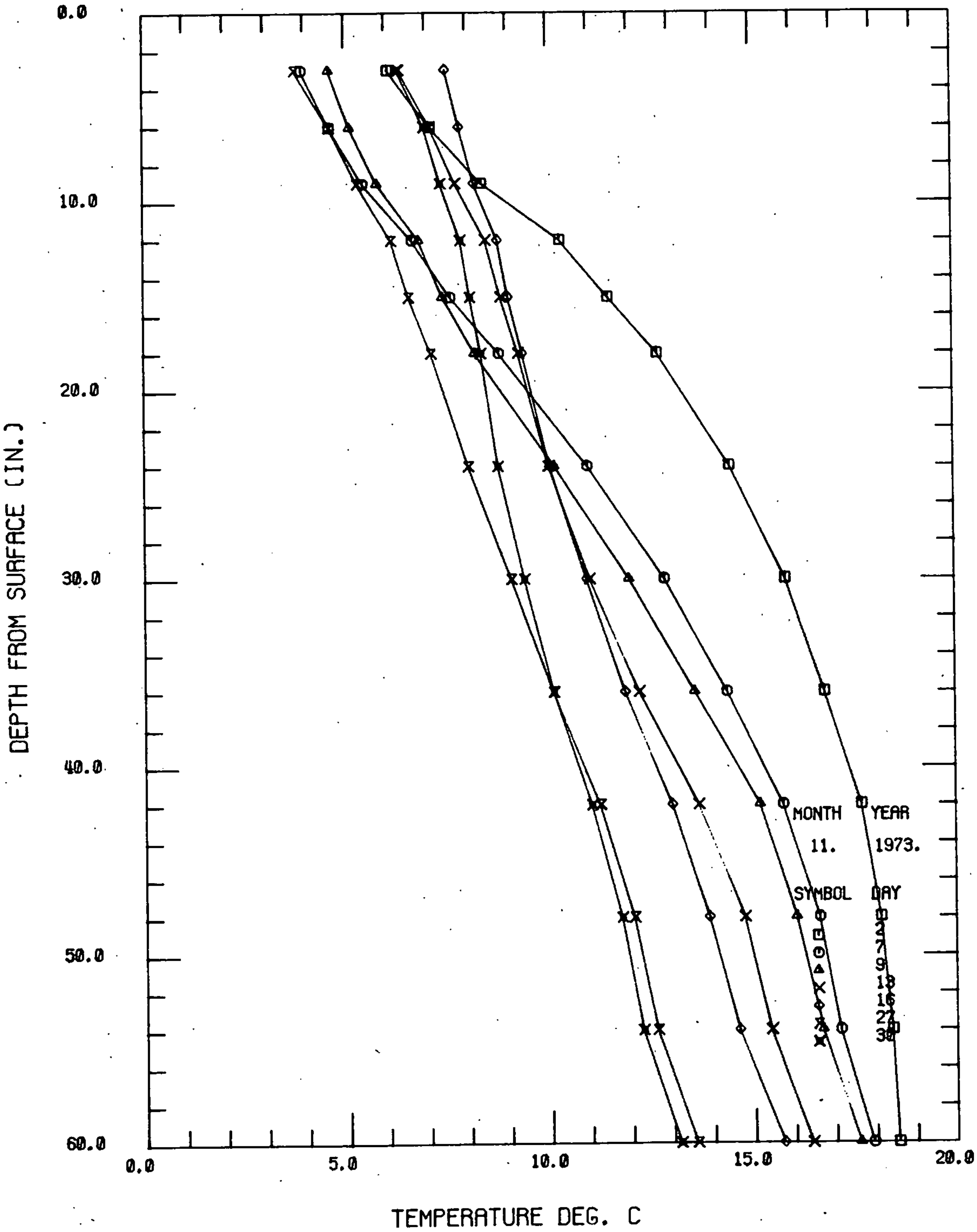


FIGURE 113

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR NOVEMBER 1973

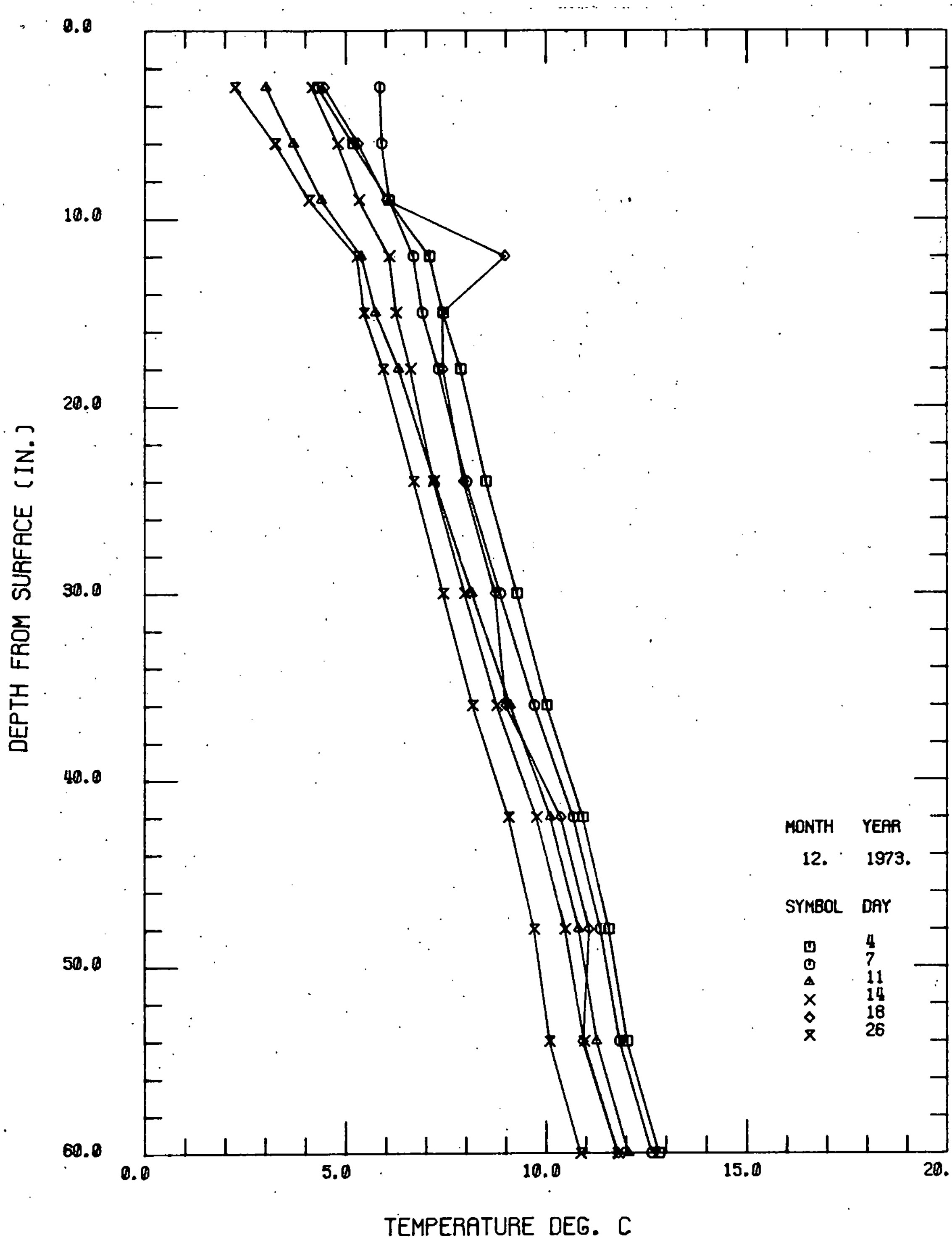


FIGURE 114

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR DECEMBER 1973

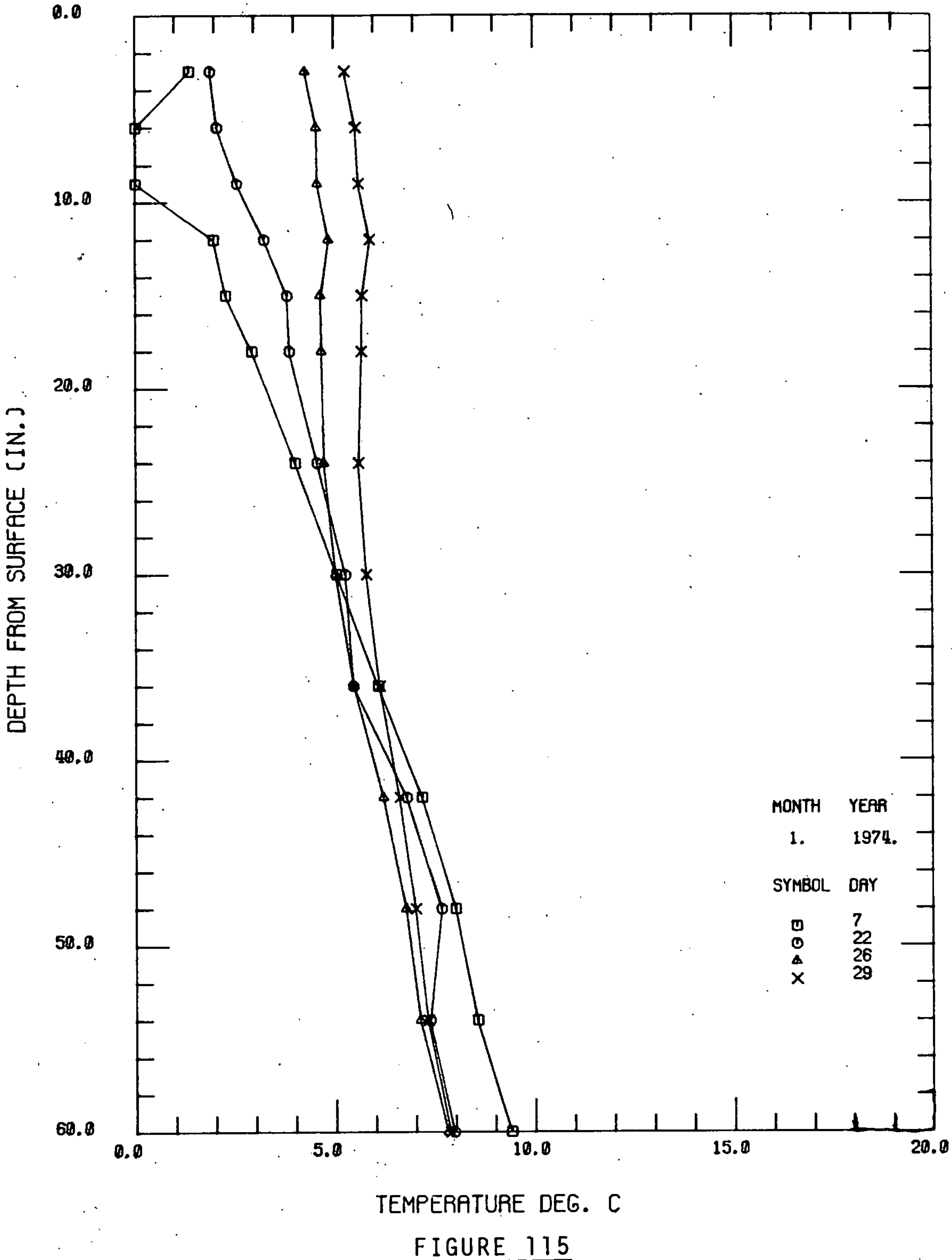


FIGURE 115

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JANUARY 1974

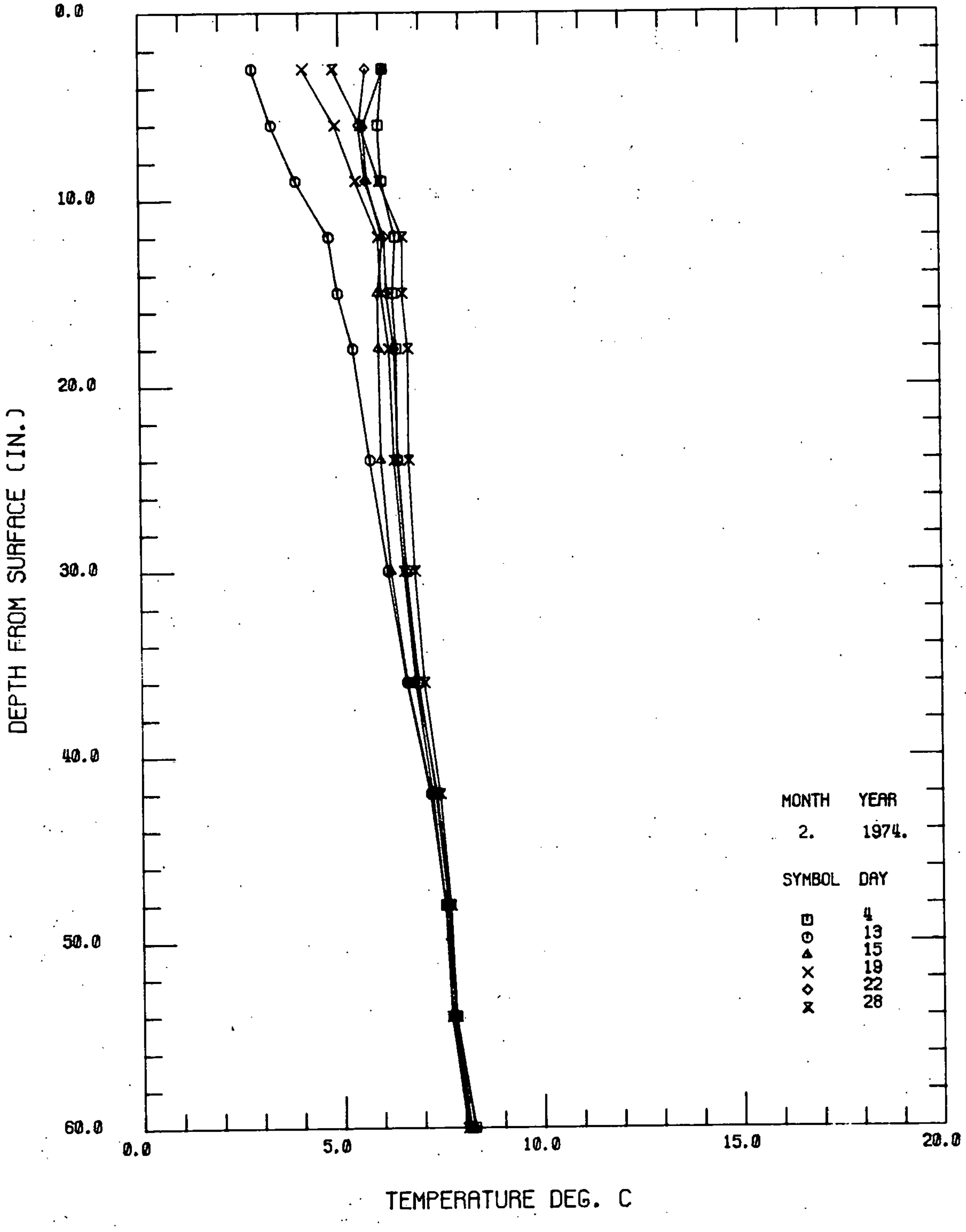


FIGURE 116

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR FEBRUARY 1974

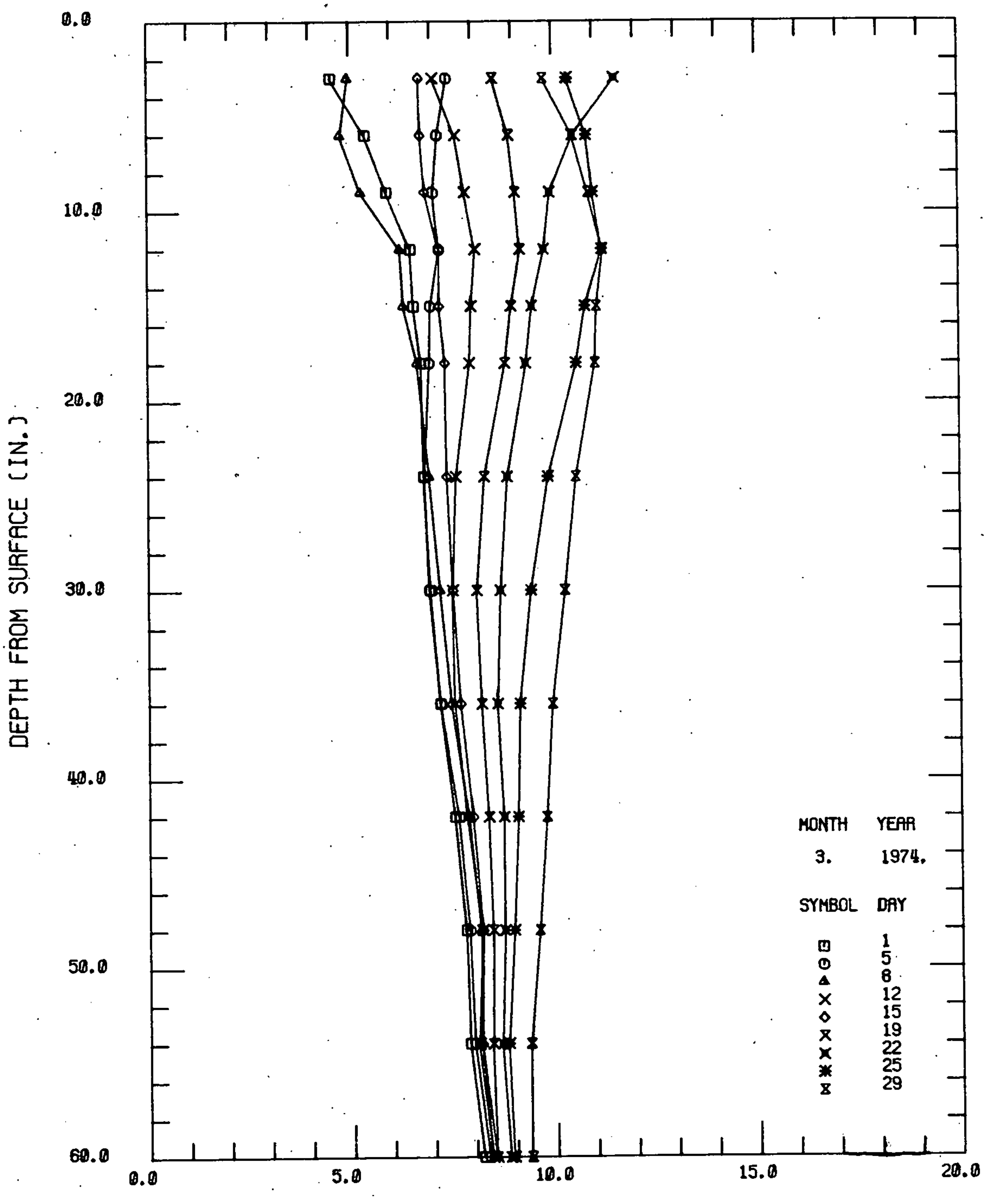


FIGURE 117

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR MARCH 1974

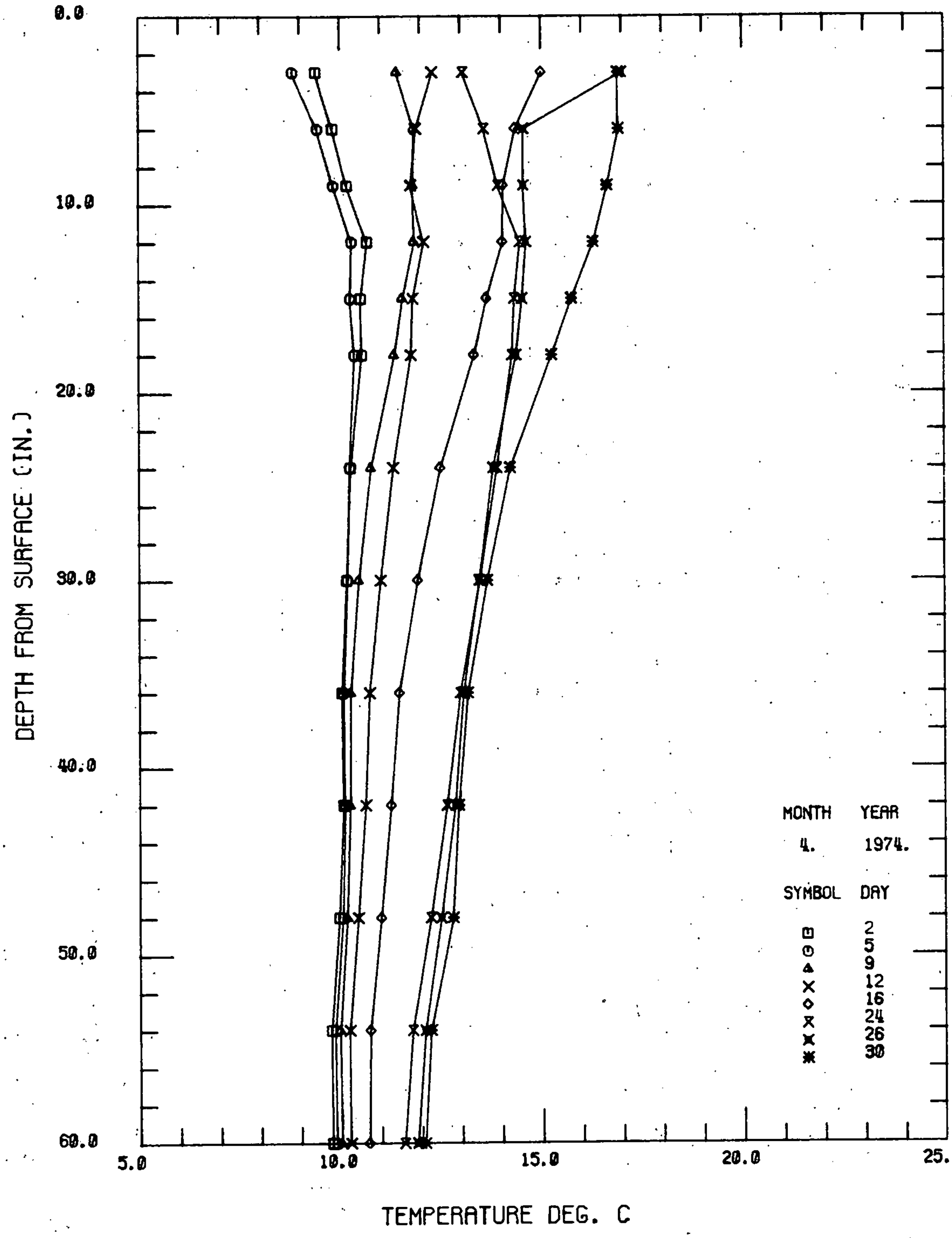


FIGURE 118

TEMPERTURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR APRIL 1974

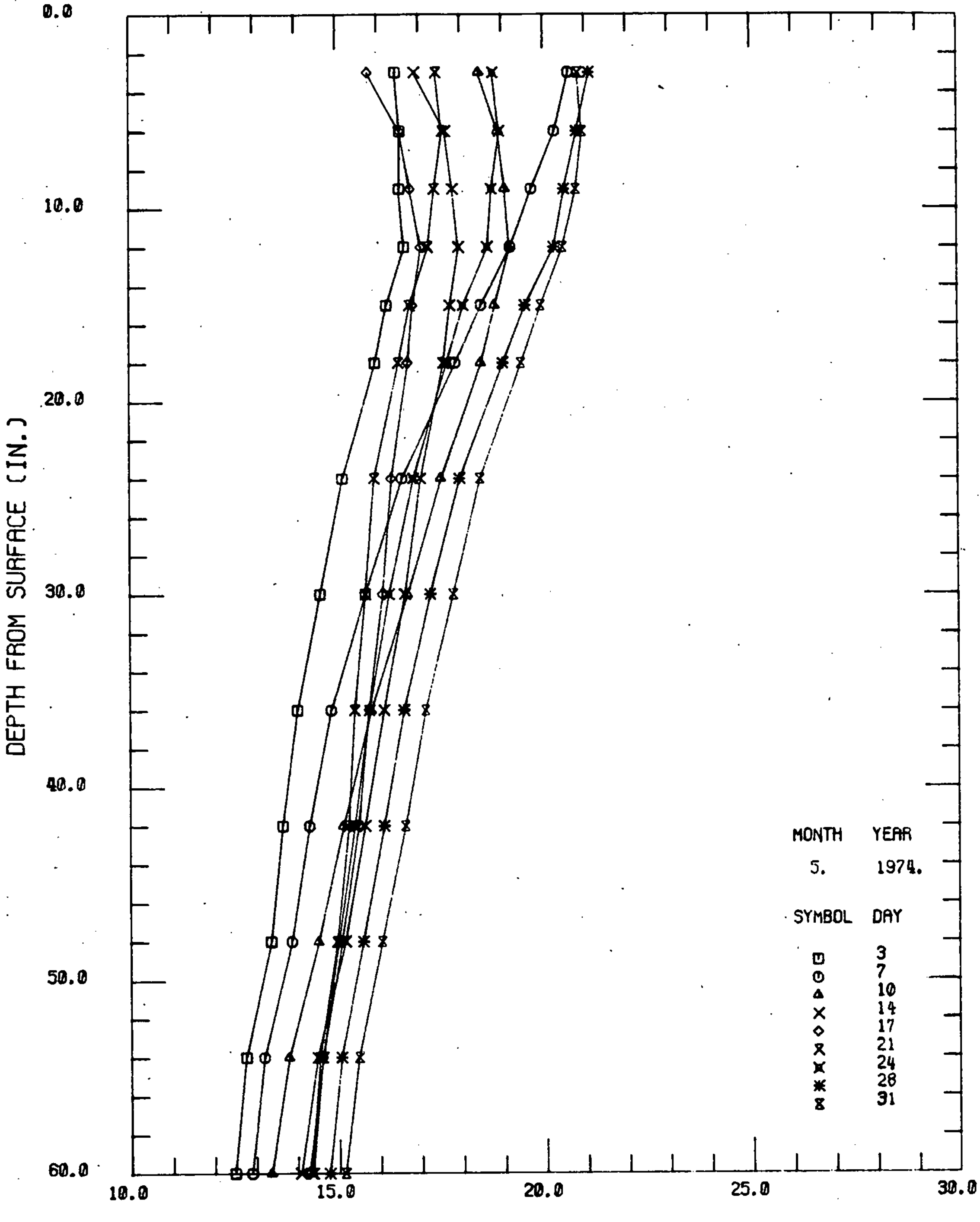


FIGURE 119

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR MAY 1974

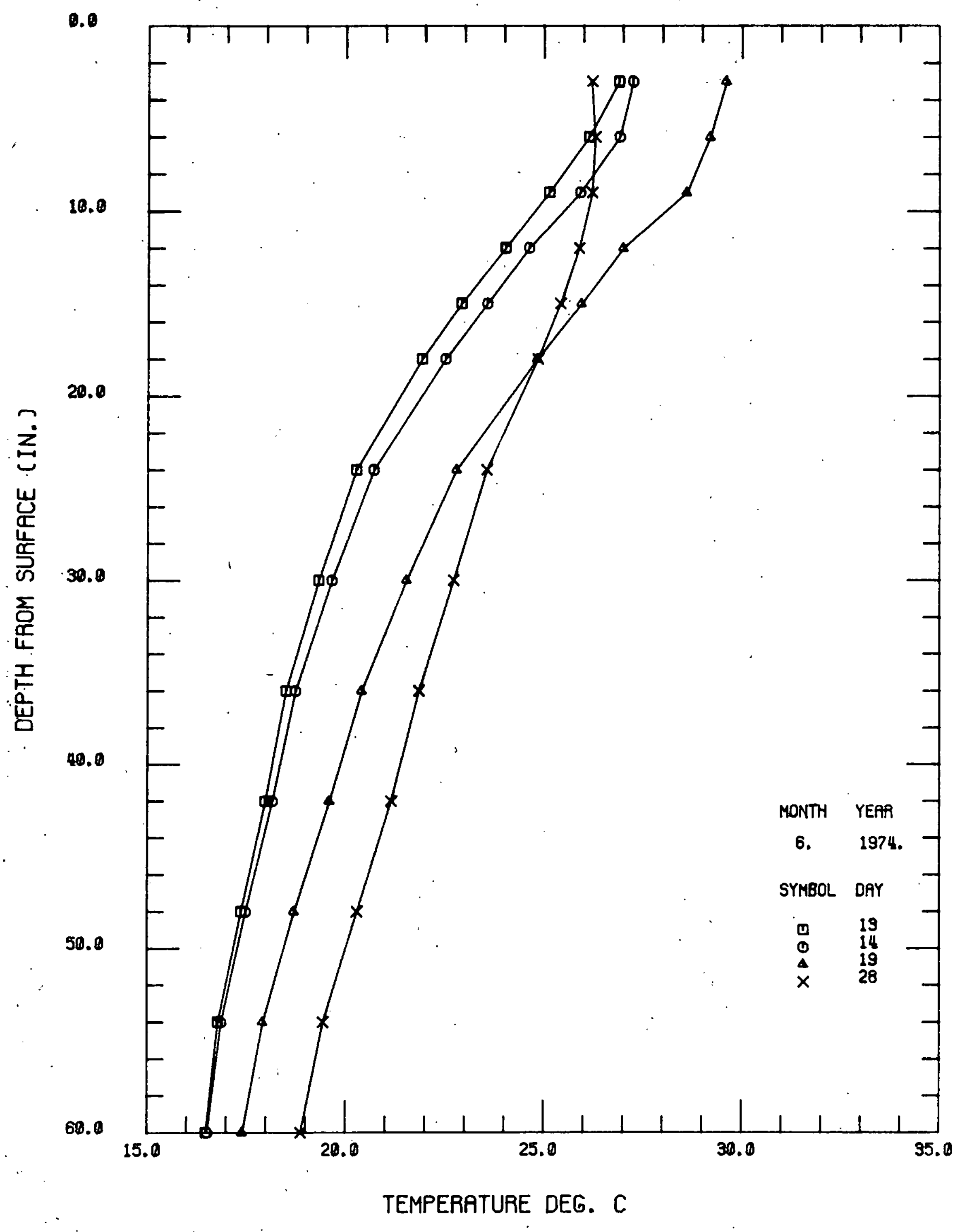


FIGURE 120

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JUNE 1974

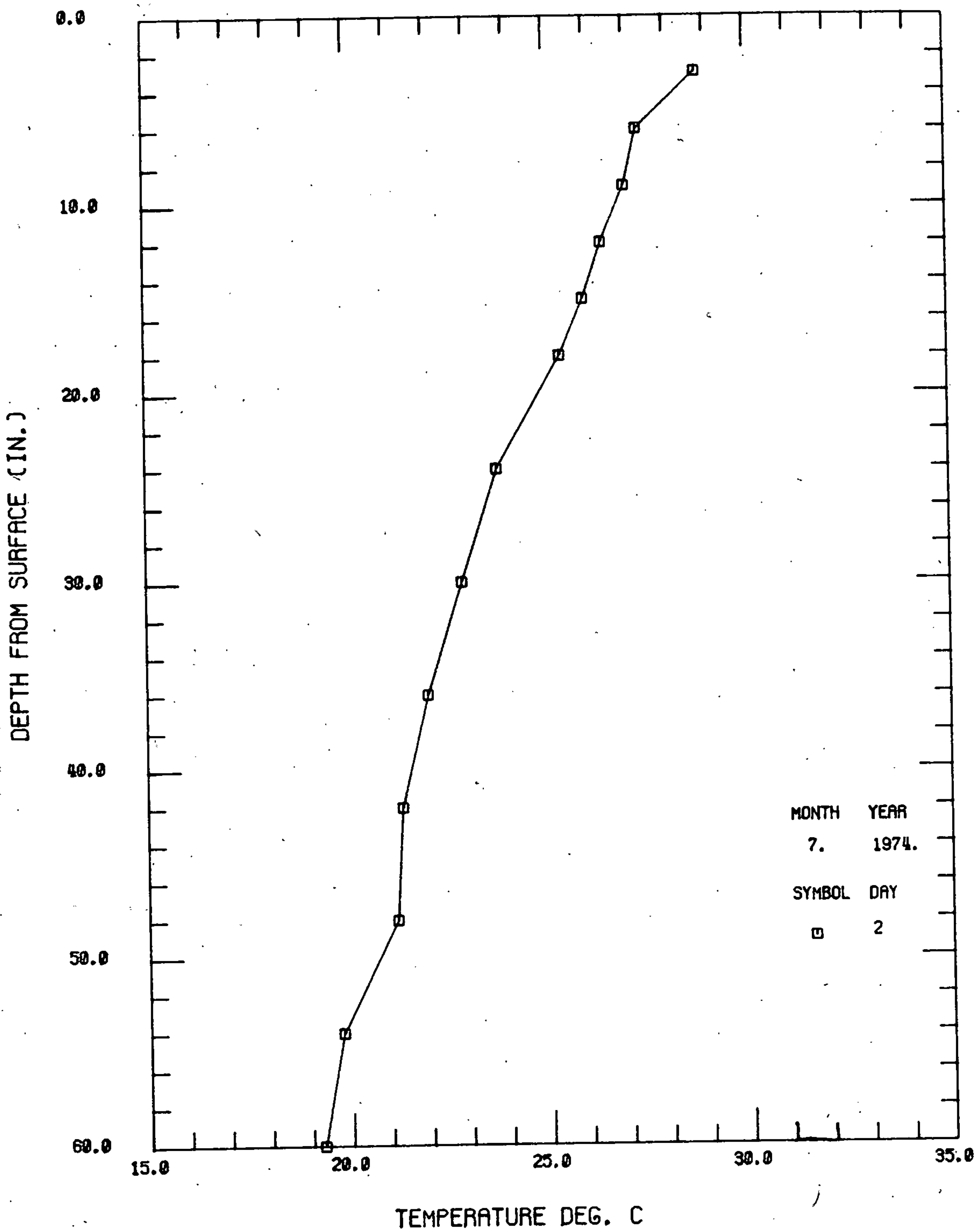


FIGURE 121

TEMPERATURE PROFILES TO 1.52-METER DEPTH AT 32-49 COORDINATES FOR JULY 1974

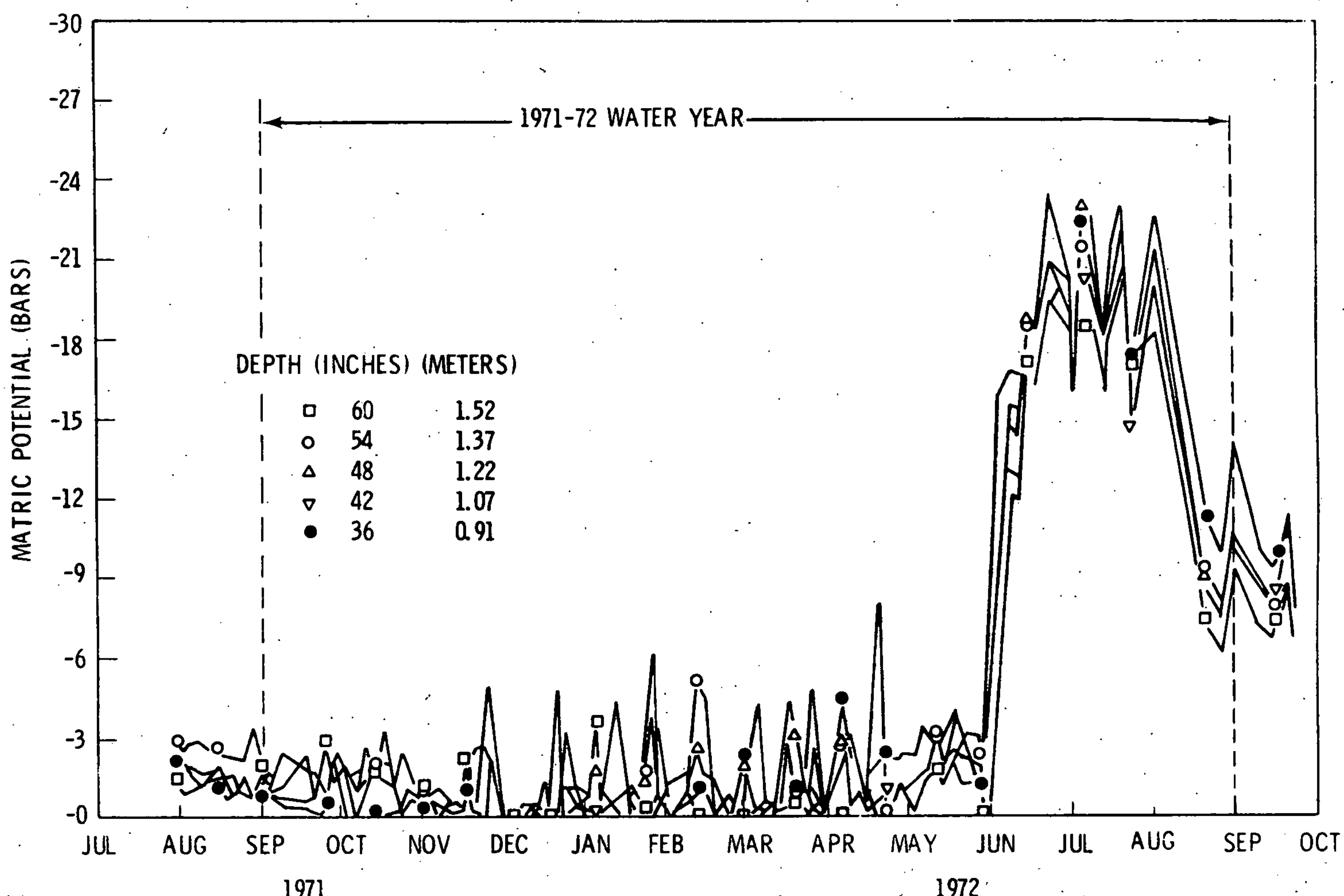


FIGURE 122

MATRIC POTENTIAL VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

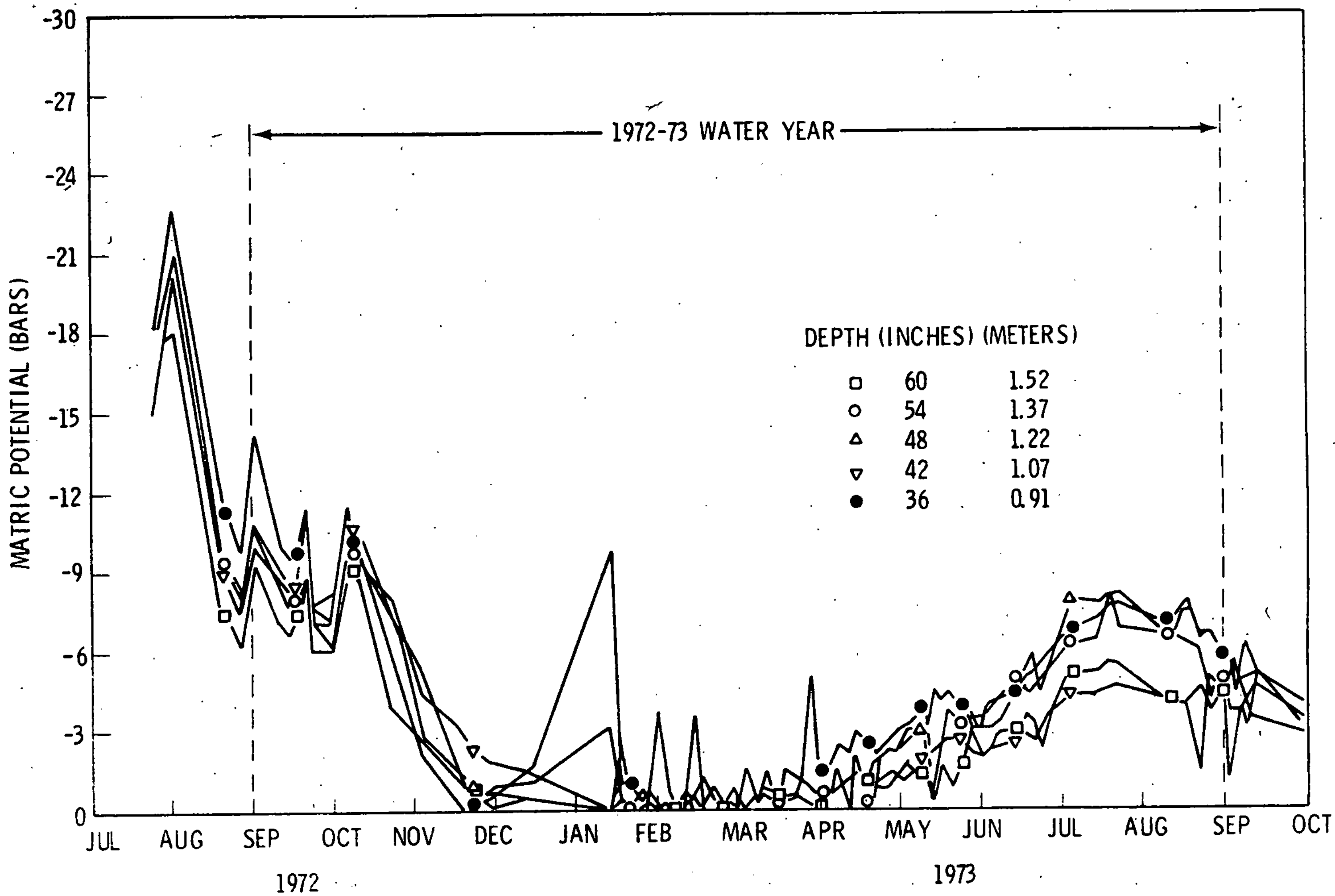


FIGURE 123

MATRIC POTENTIAL VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

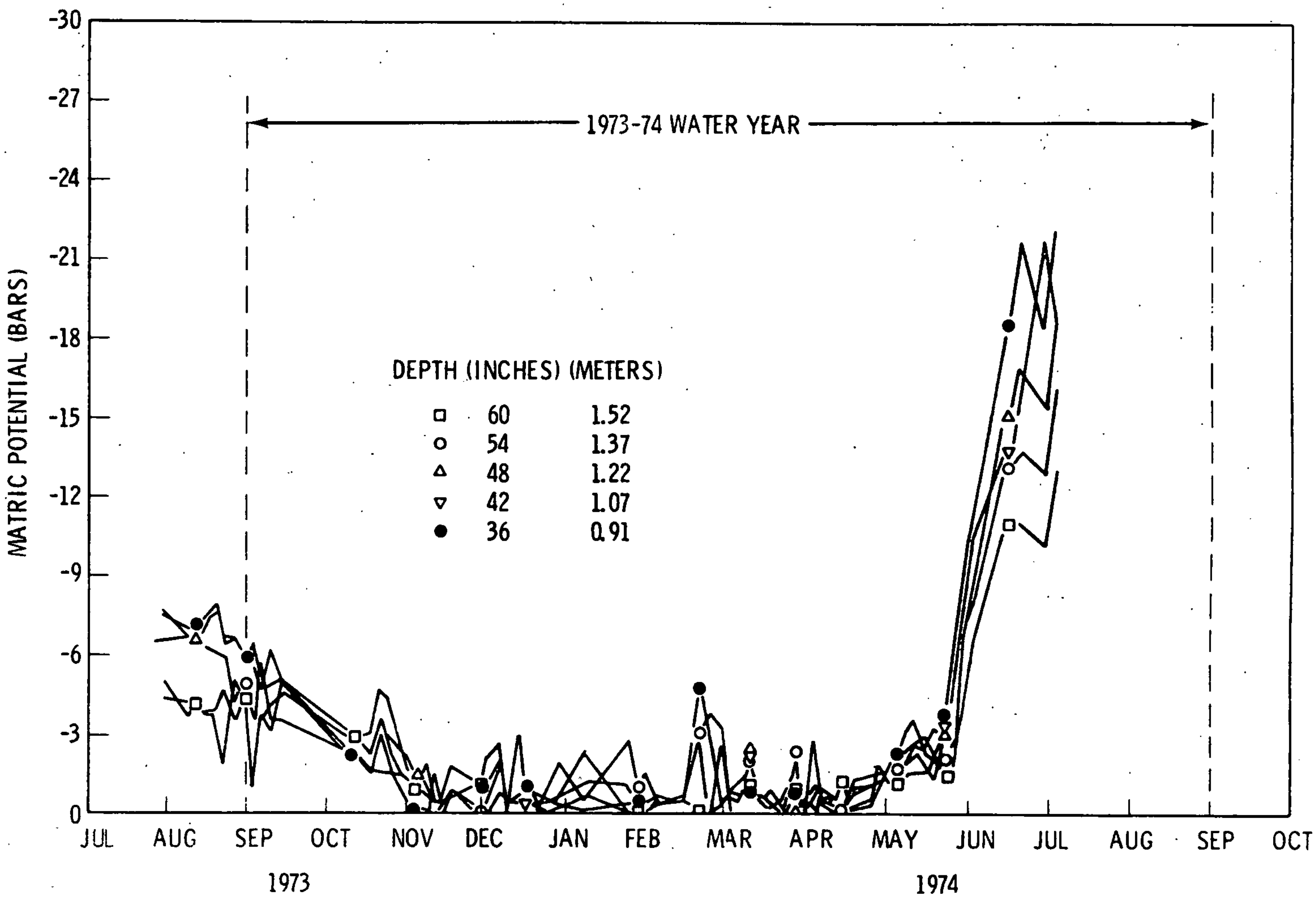


FIGURE 124

MATRIC POTENTIAL VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.91- TO 1.52-METER (36- to 60-Inch) DEPTHS AT 32-49 COORDINATES

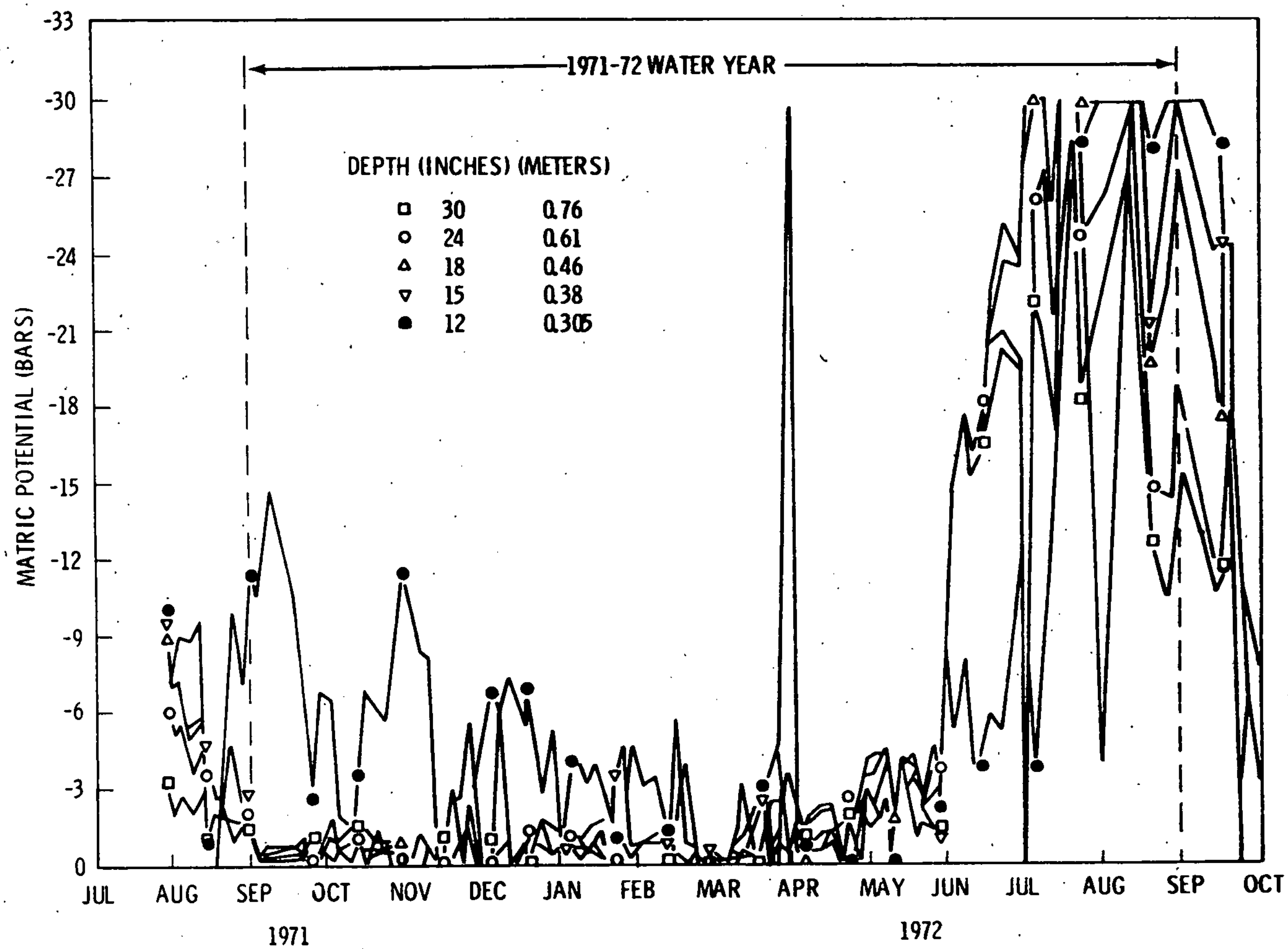


FIGURE 125

MATRIC POTENTIAL VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPTHS AT 32-49 COORDINATES

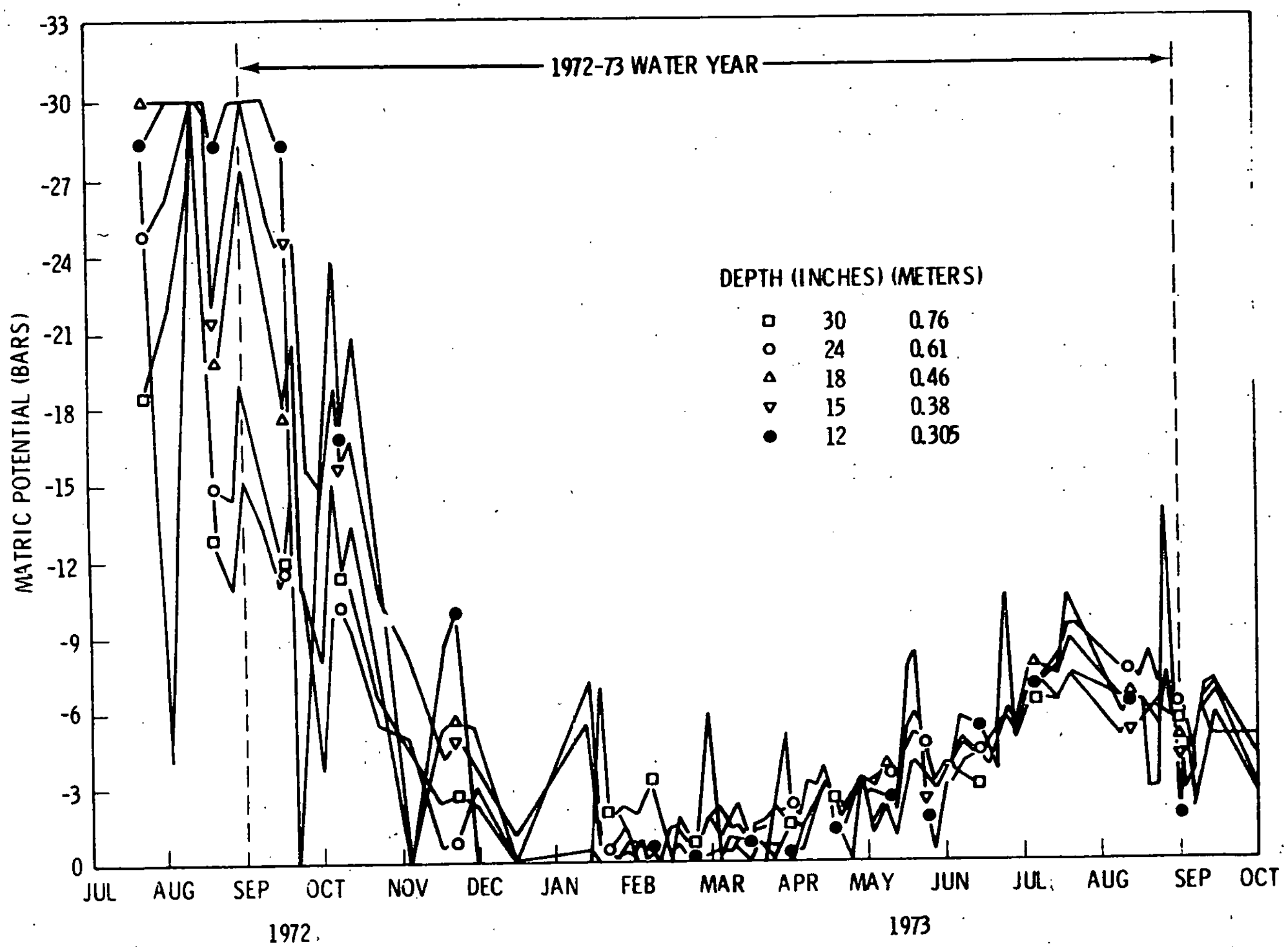


FIGURE 126

MATRIC POTENTIAL VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPTHS AT 32-49 COORDINATES

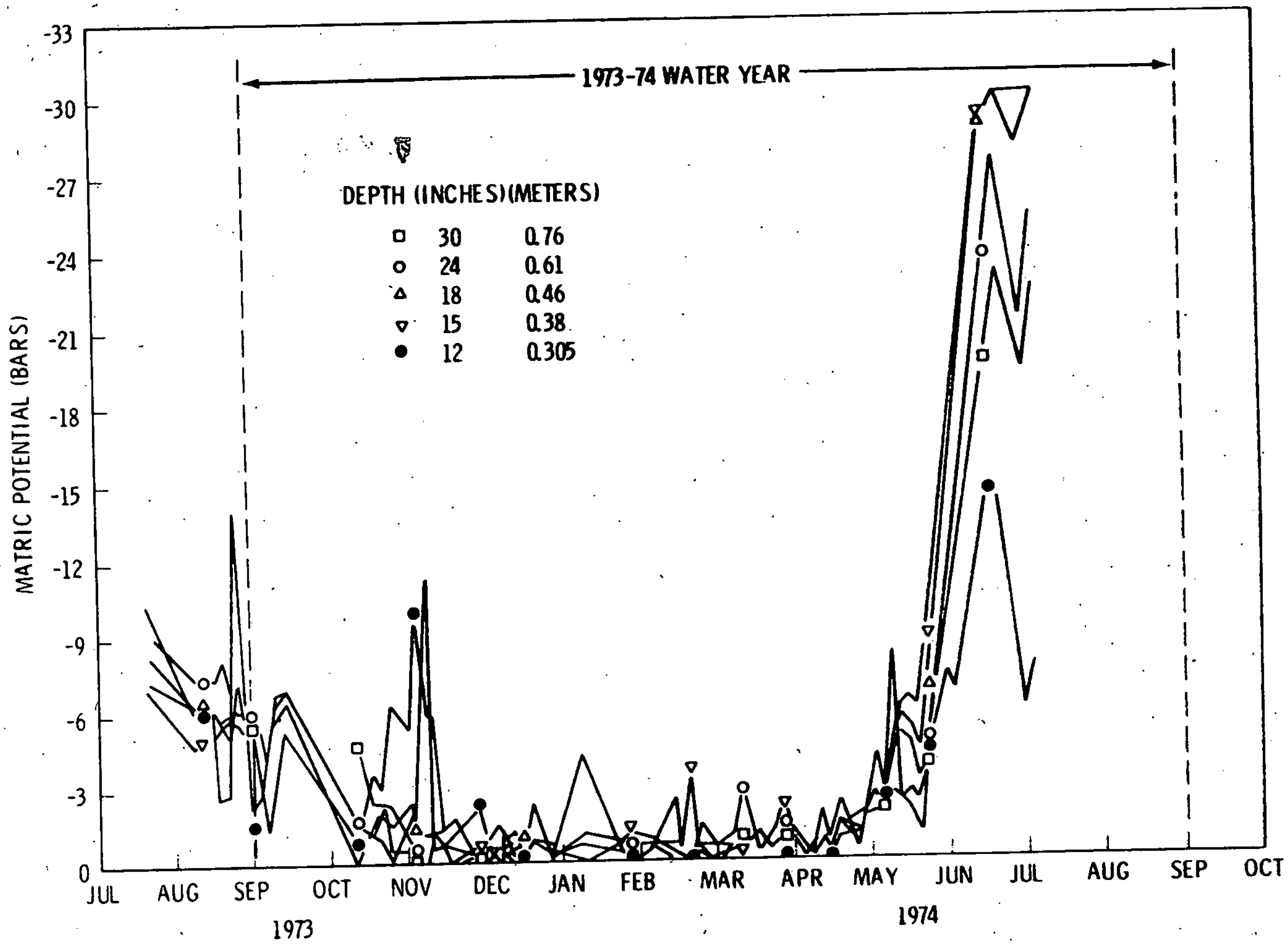


FIGURE 127

MATRIC POTENTIAL VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.305- TO 0.76-METER (12- to 30-Inch) DEPHTS AT 32-49 COORDINATES

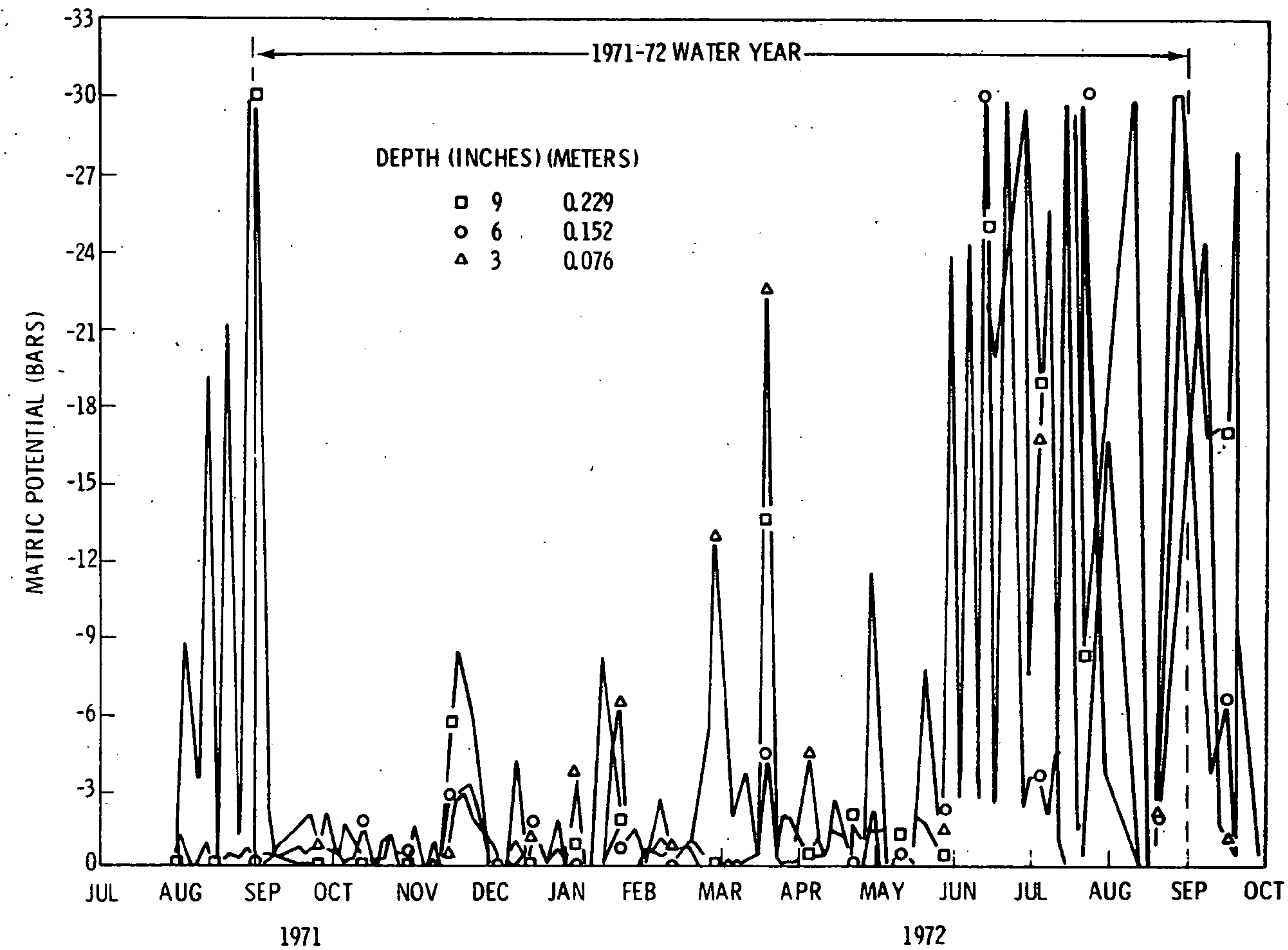


FIGURE 128

MATRIC POTENTIAL VERSUS TIME FOR 1971-1972 WATER YEAR AND 0.076- 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

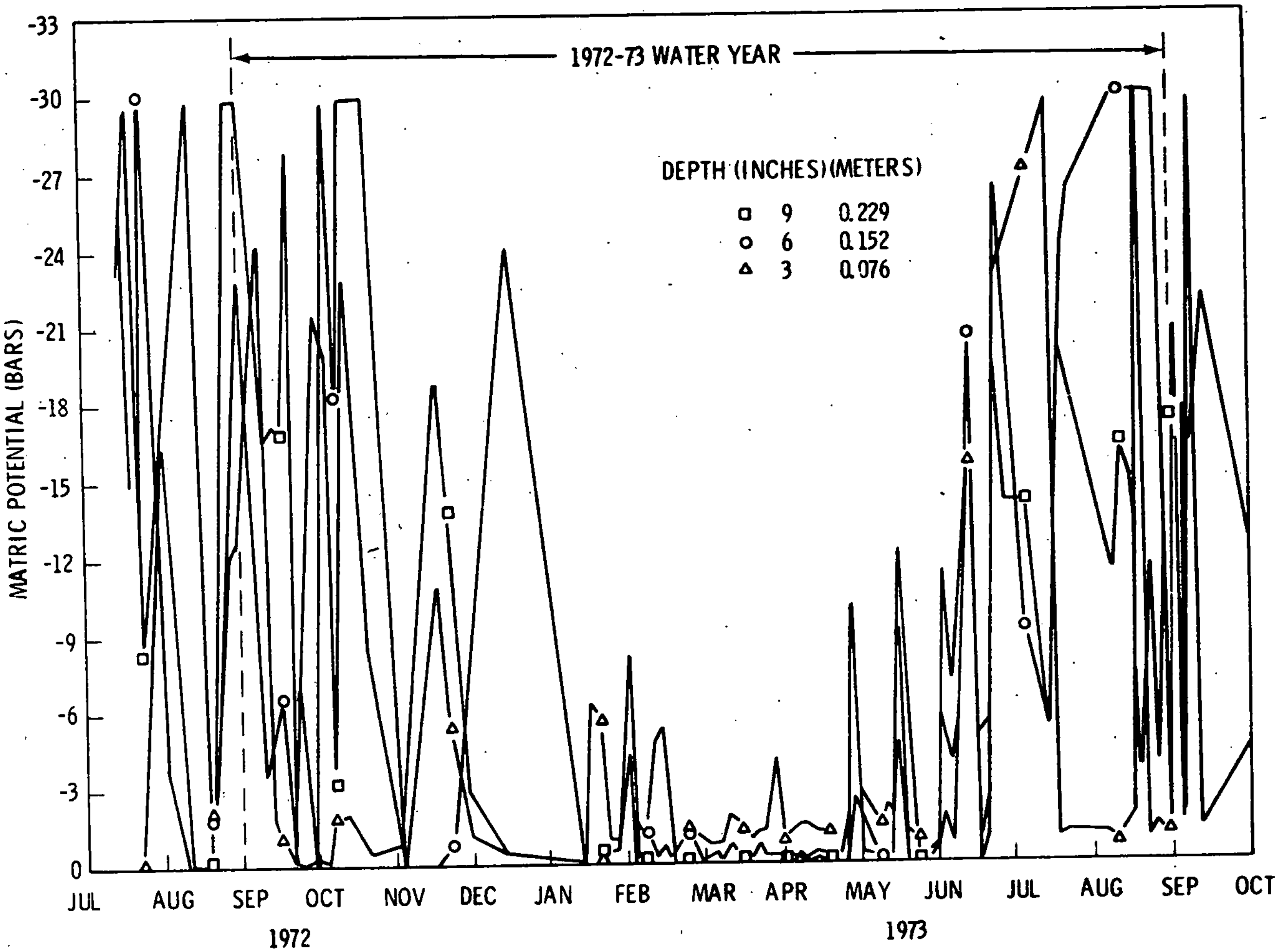


FIGURE 129

MATRIC POTENTIAL VERSUS TIME FOR 1972-1973 WATER YEAR AND 0.076- 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

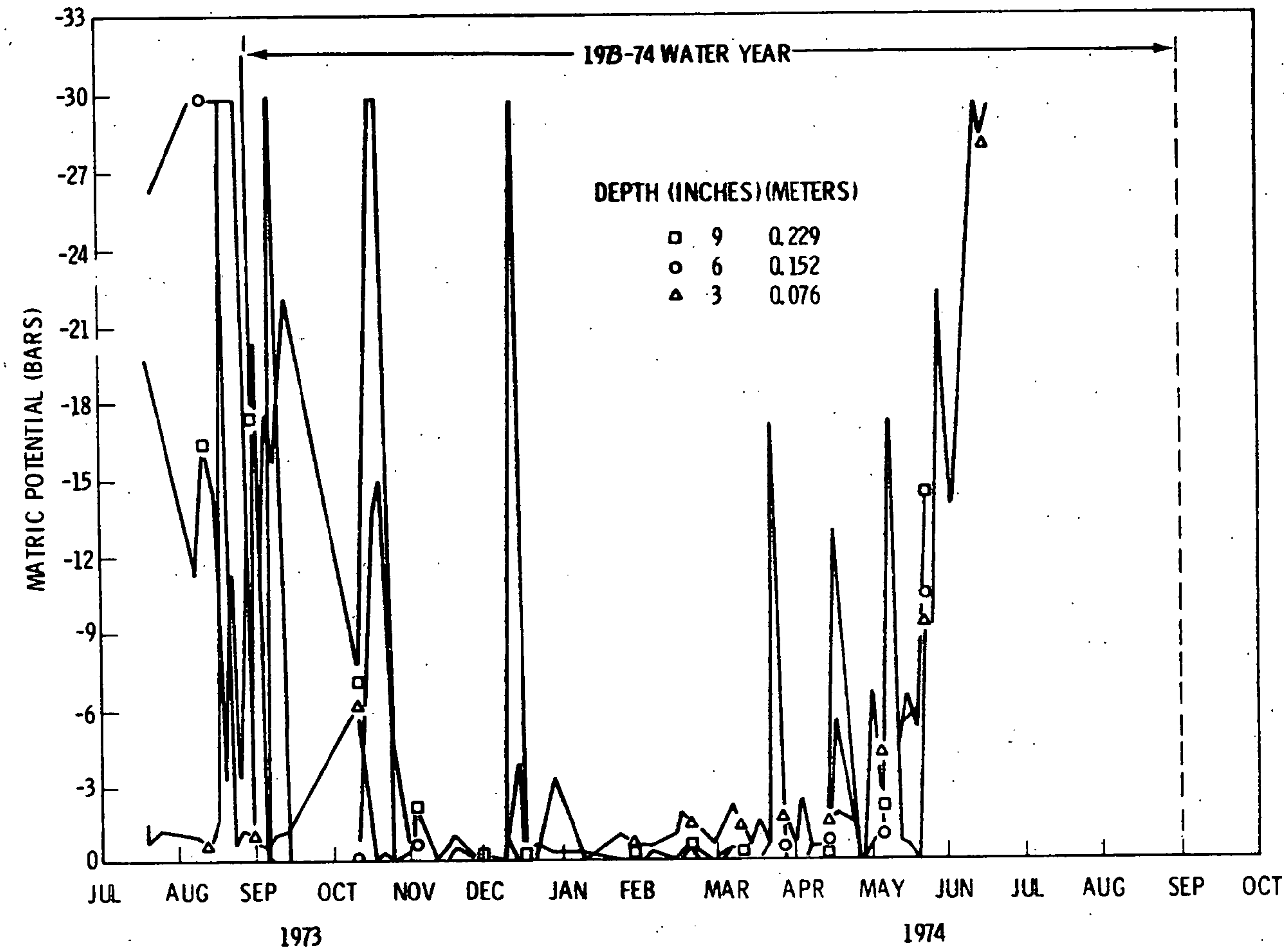


FIGURE 130

MATRIC POTENTIAL VERSUS TIME FOR 1973-1974 WATER YEAR AND 0.076- 0.229-METER (3- to 9-Inch) DEPTHS AT 32-49 COORDINATES

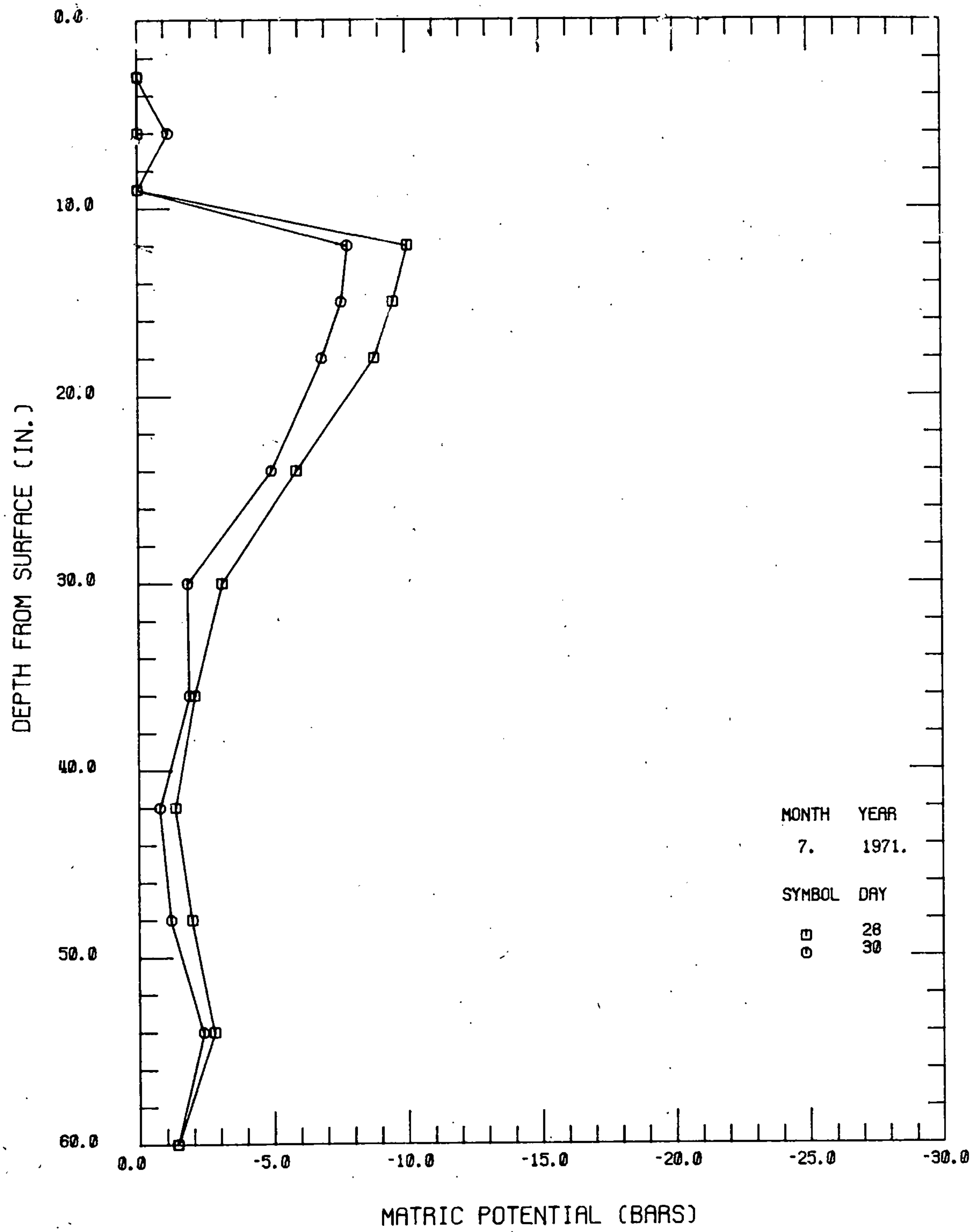


FIGURE 131

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (50-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JULY 1971

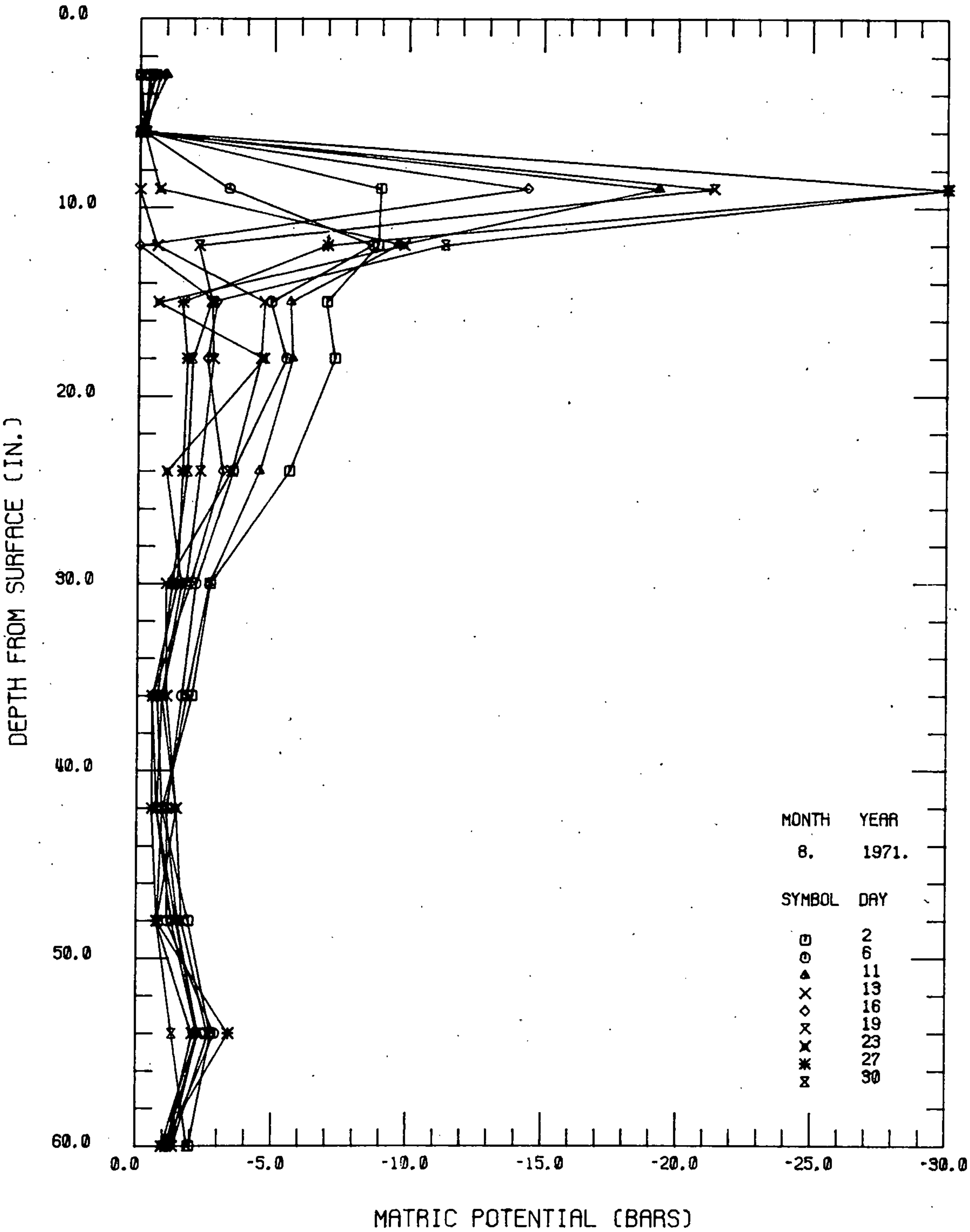


FIGURE 132

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR AUGUST 1971

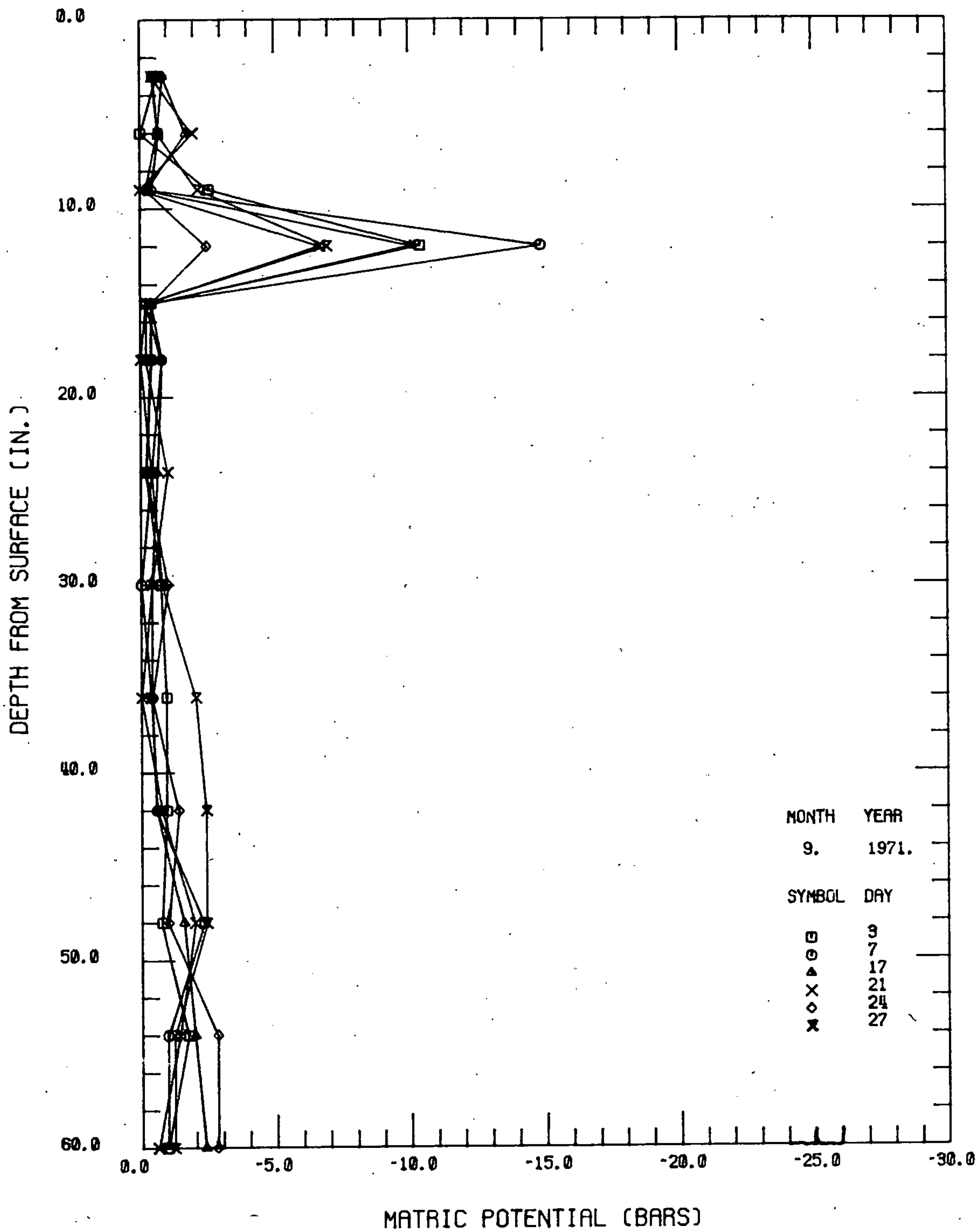


FIGURE 133

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR SEPTEMBER 1971

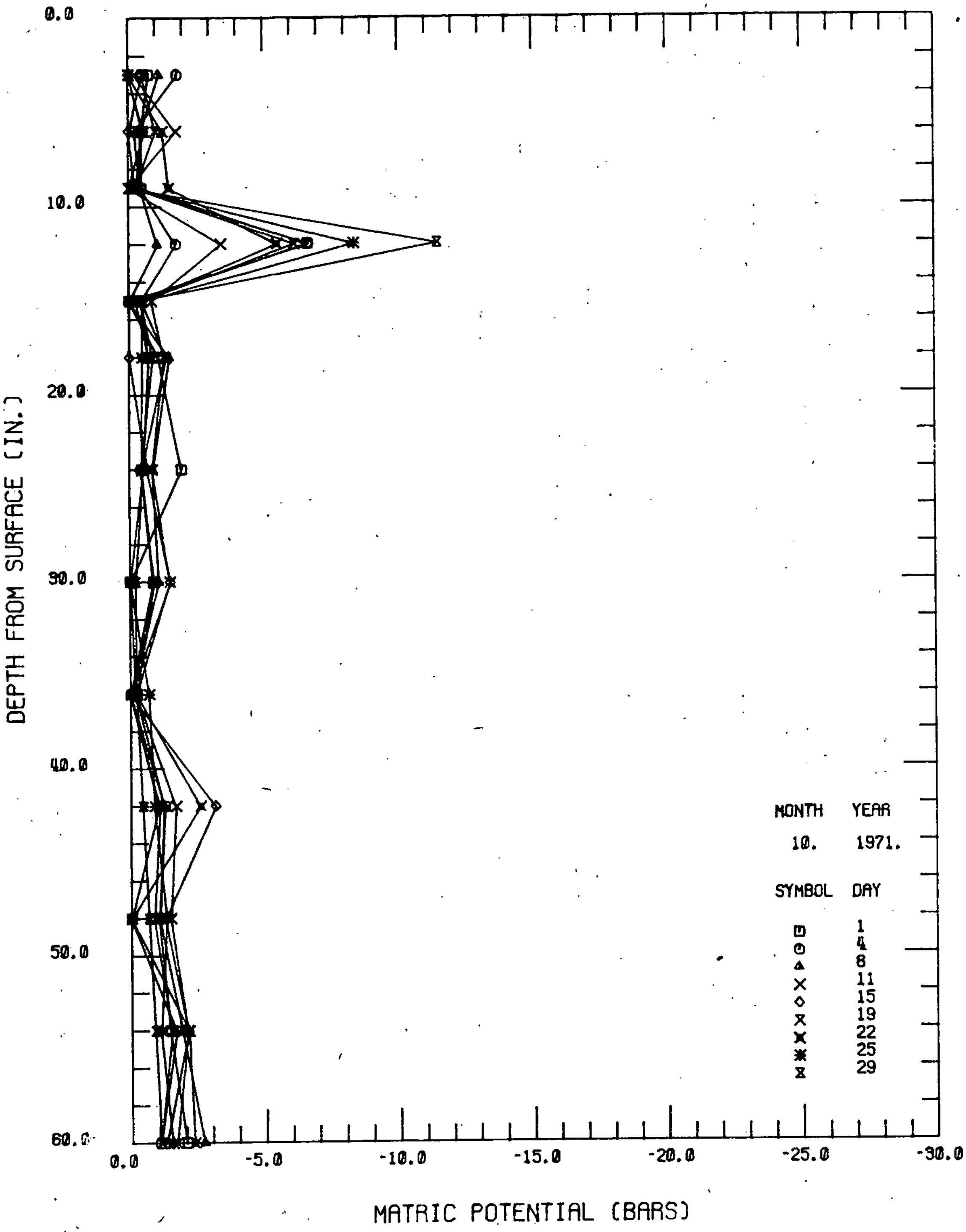


FIGURE 134

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR OCTOBER 1971

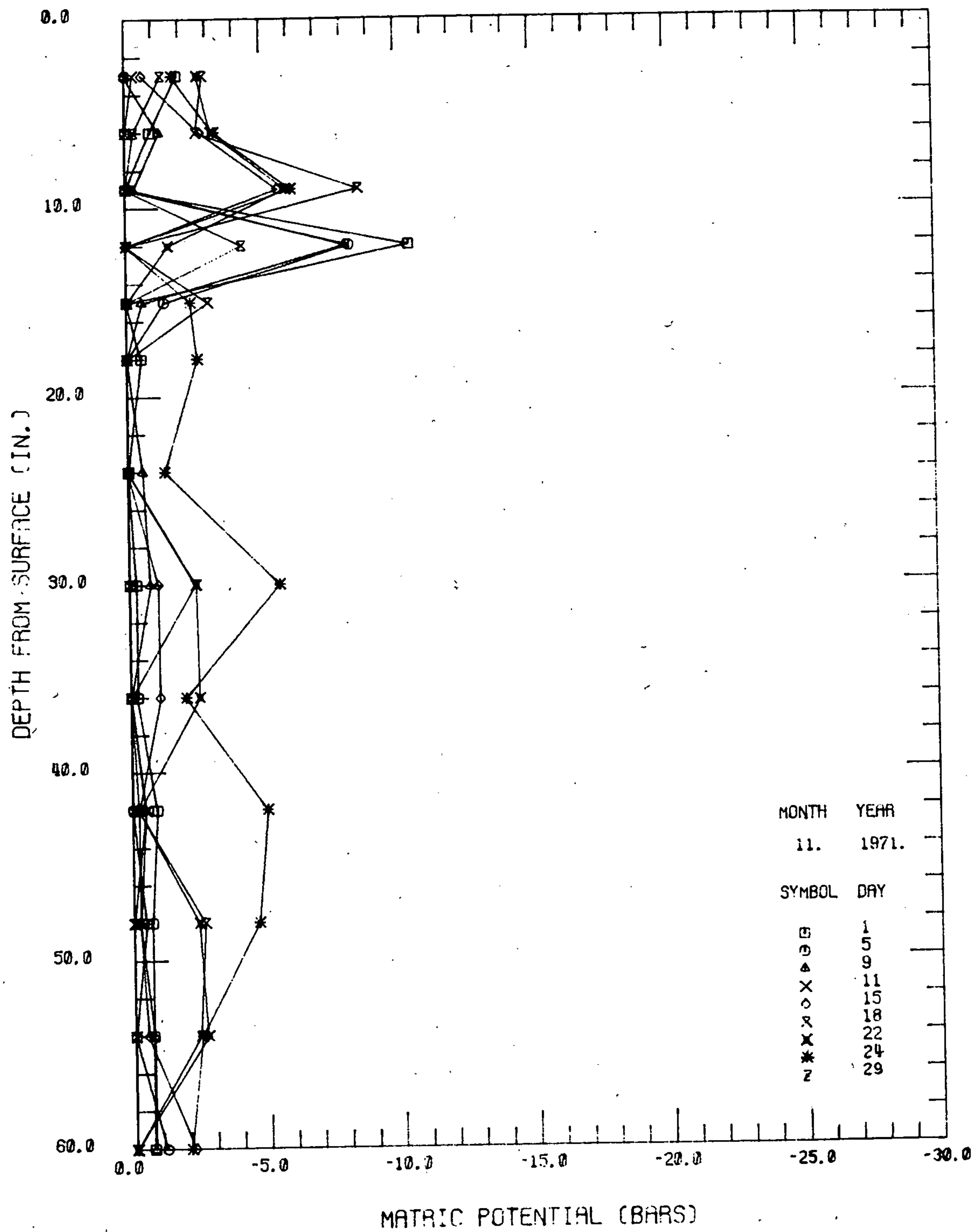


FIGURE 135

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR NOVEMBER 1971

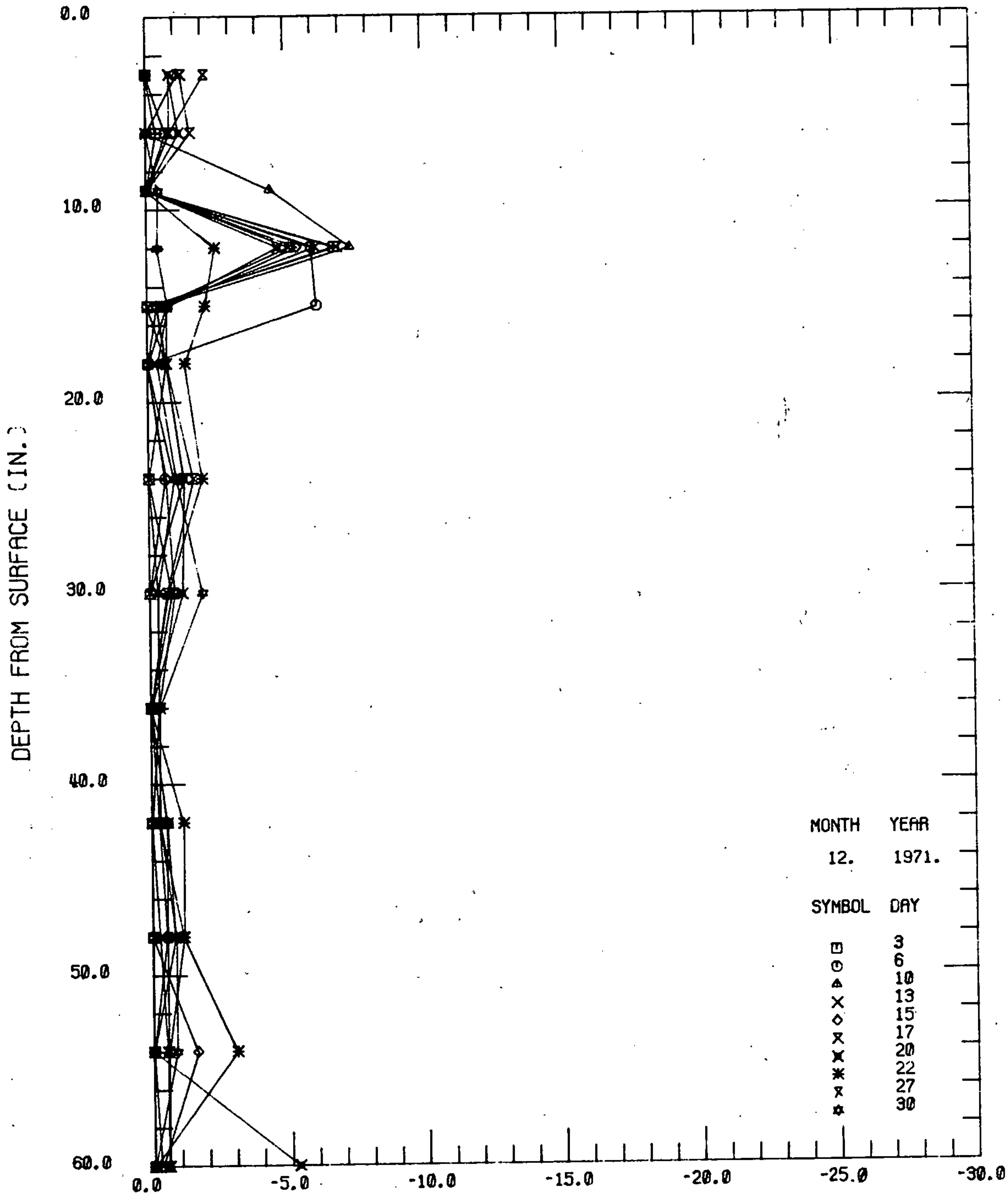


FIGURE 136

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR DECEMBER 1971

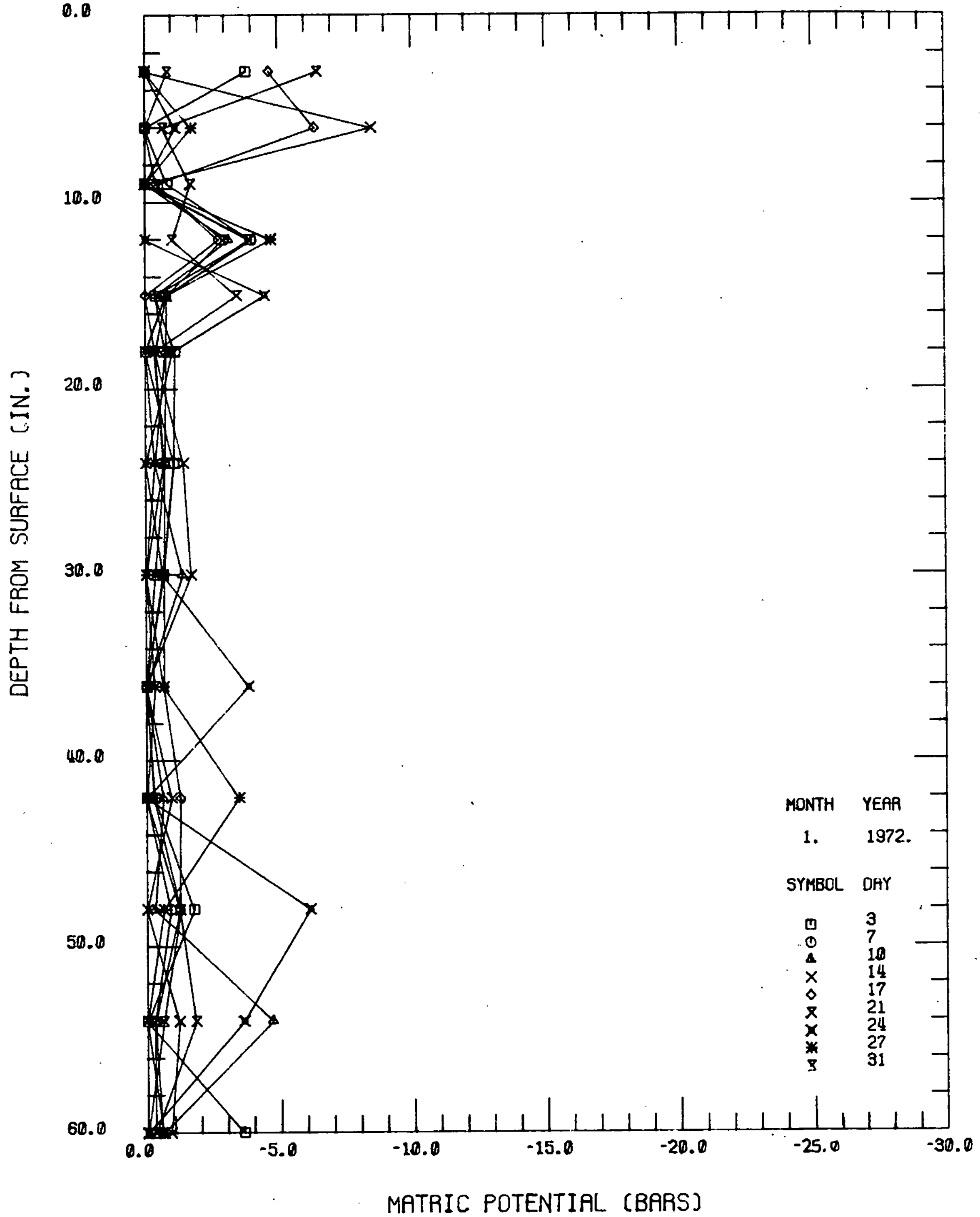


FIGURE 137

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JANUARY 1972

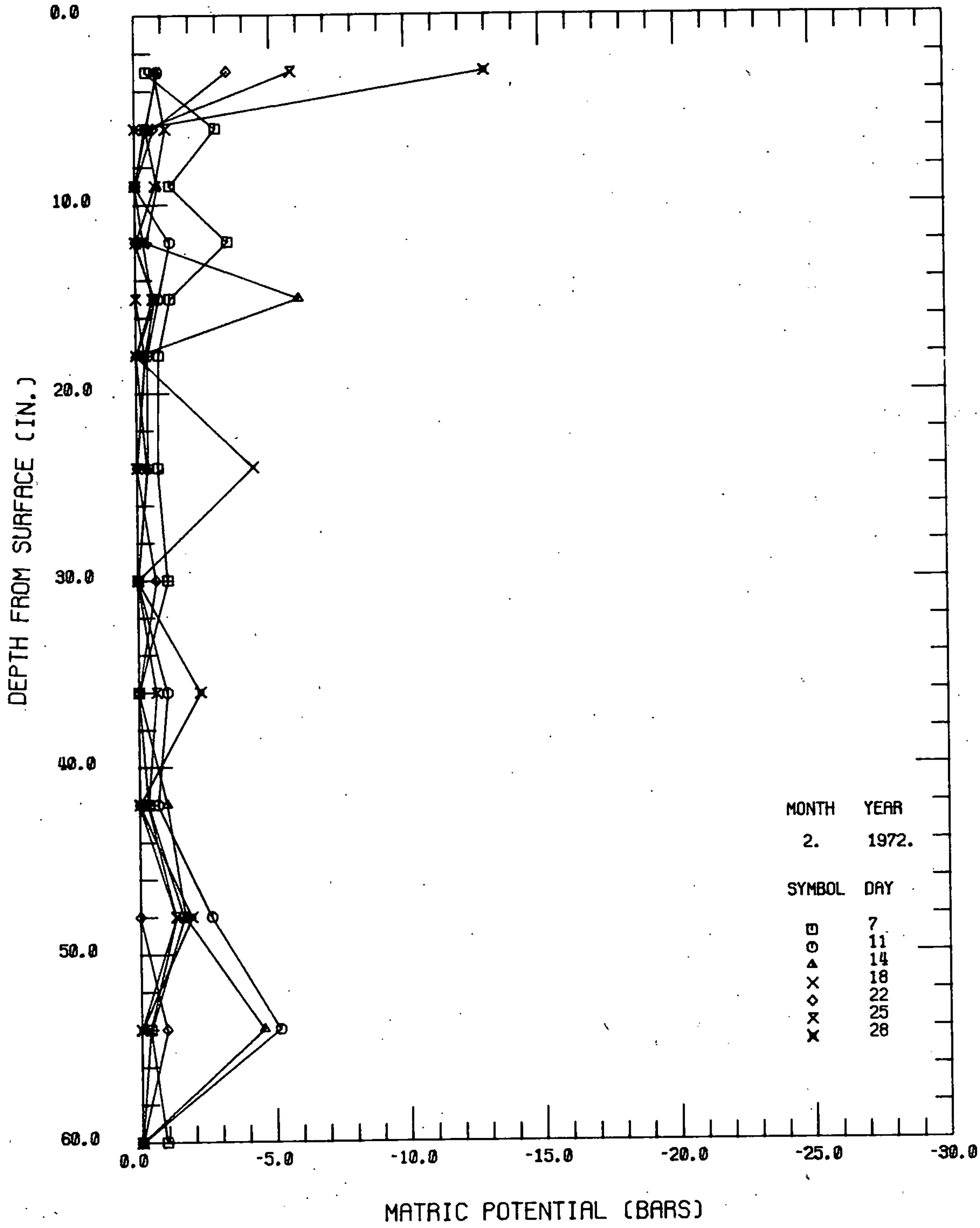


FIGURE 138

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR FEBRUARY 1972

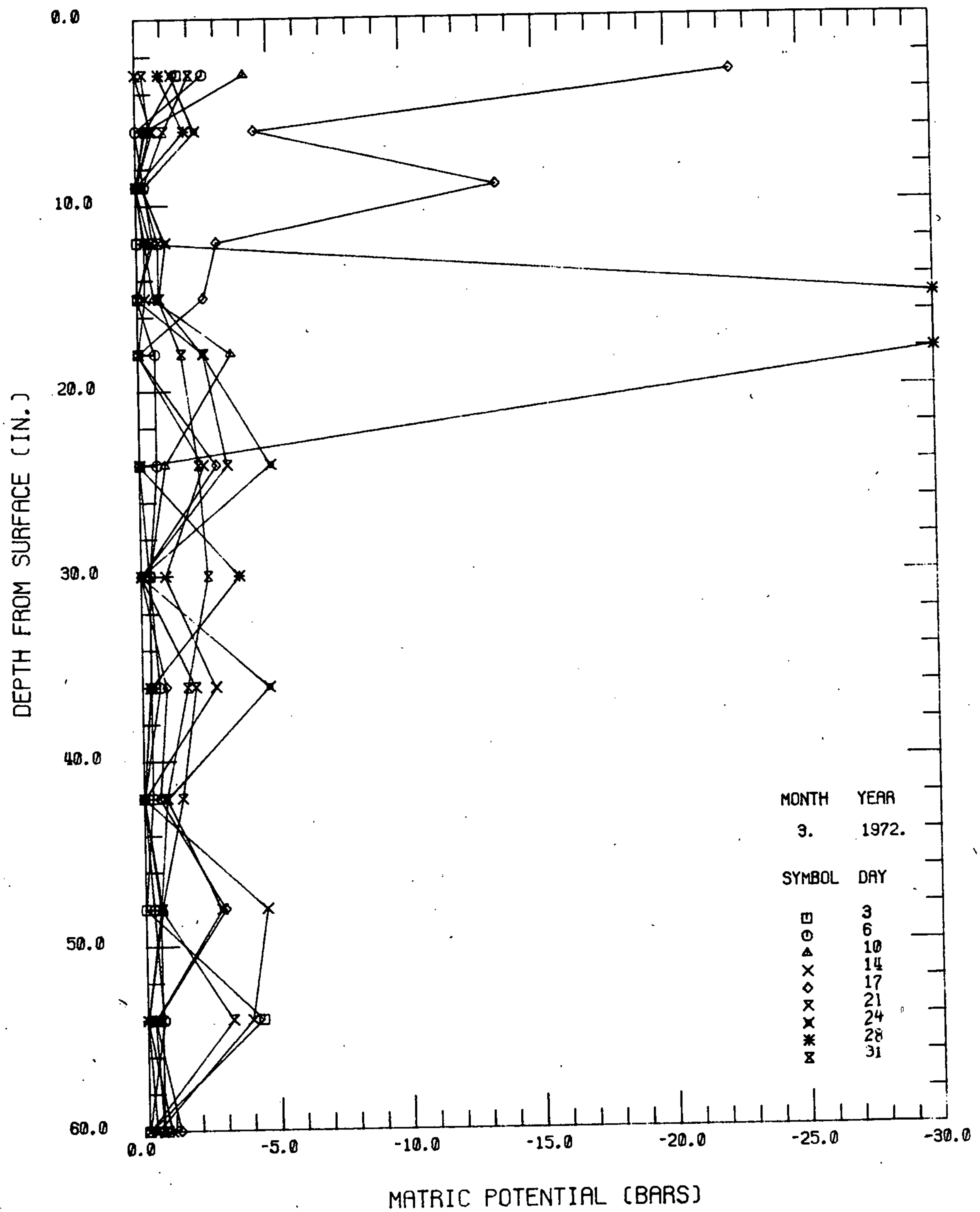


FIGURE 139

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MARCH 1972

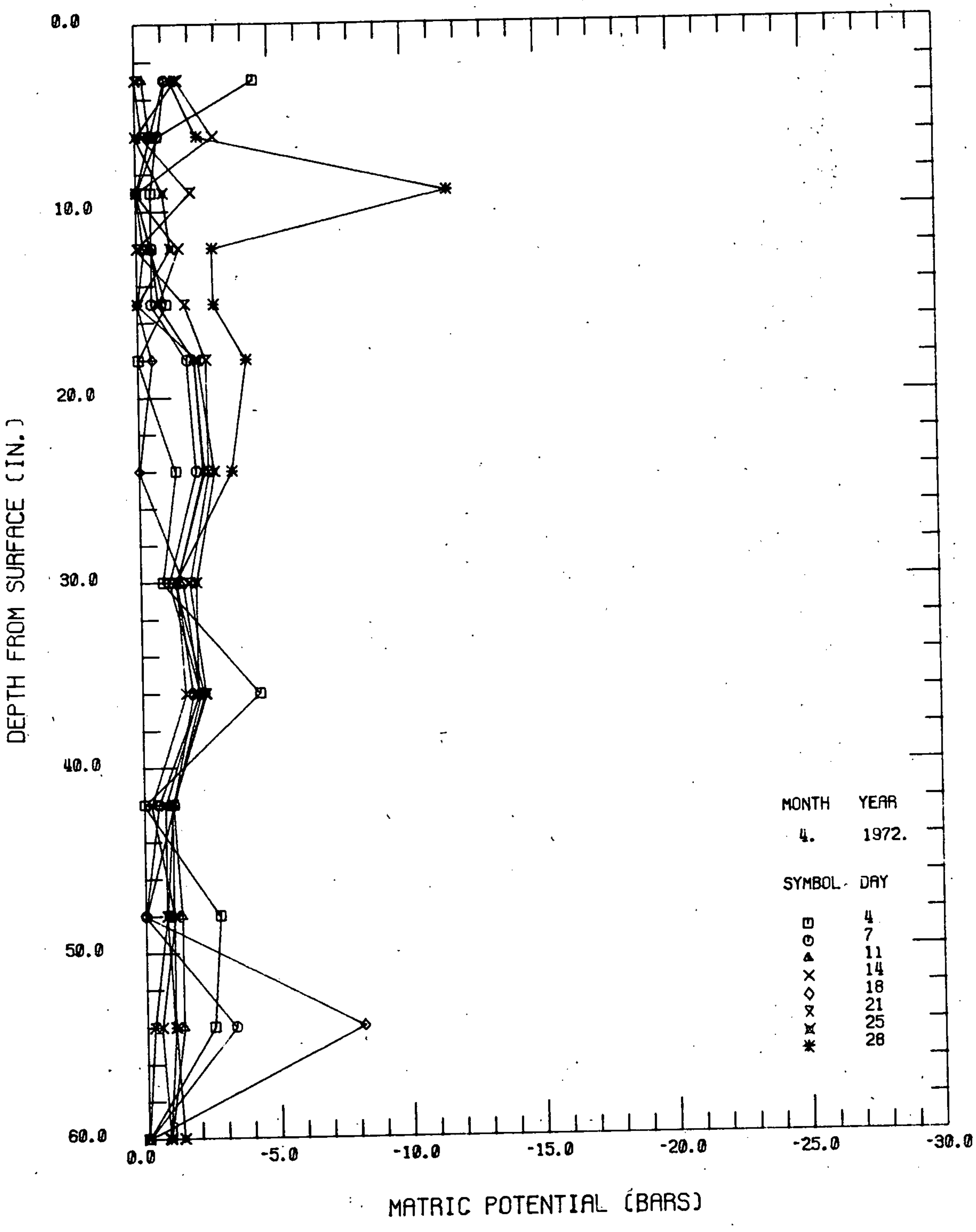


FIGURE 140

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR APRIL 1972

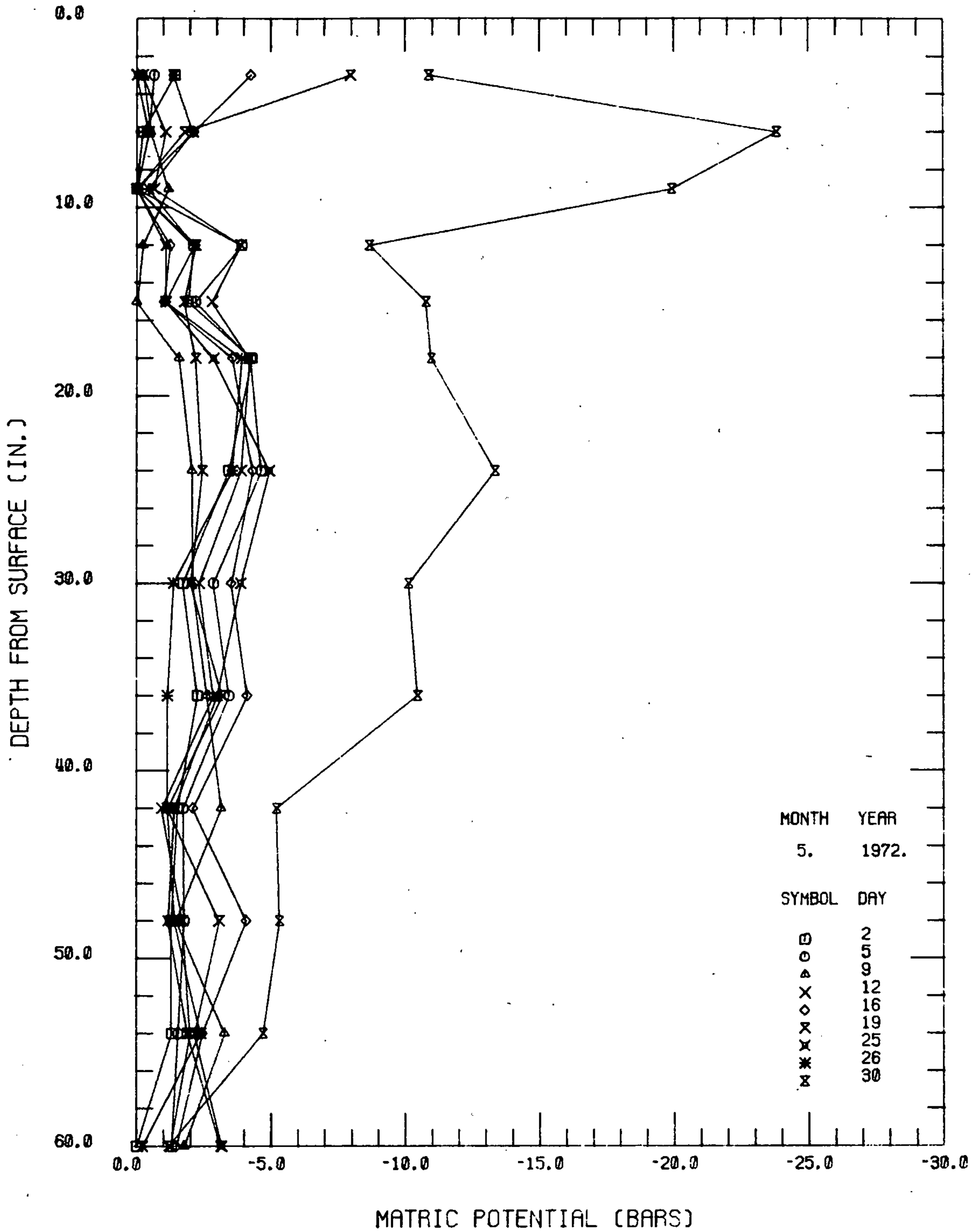


FIGURE 141

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MAY 1972

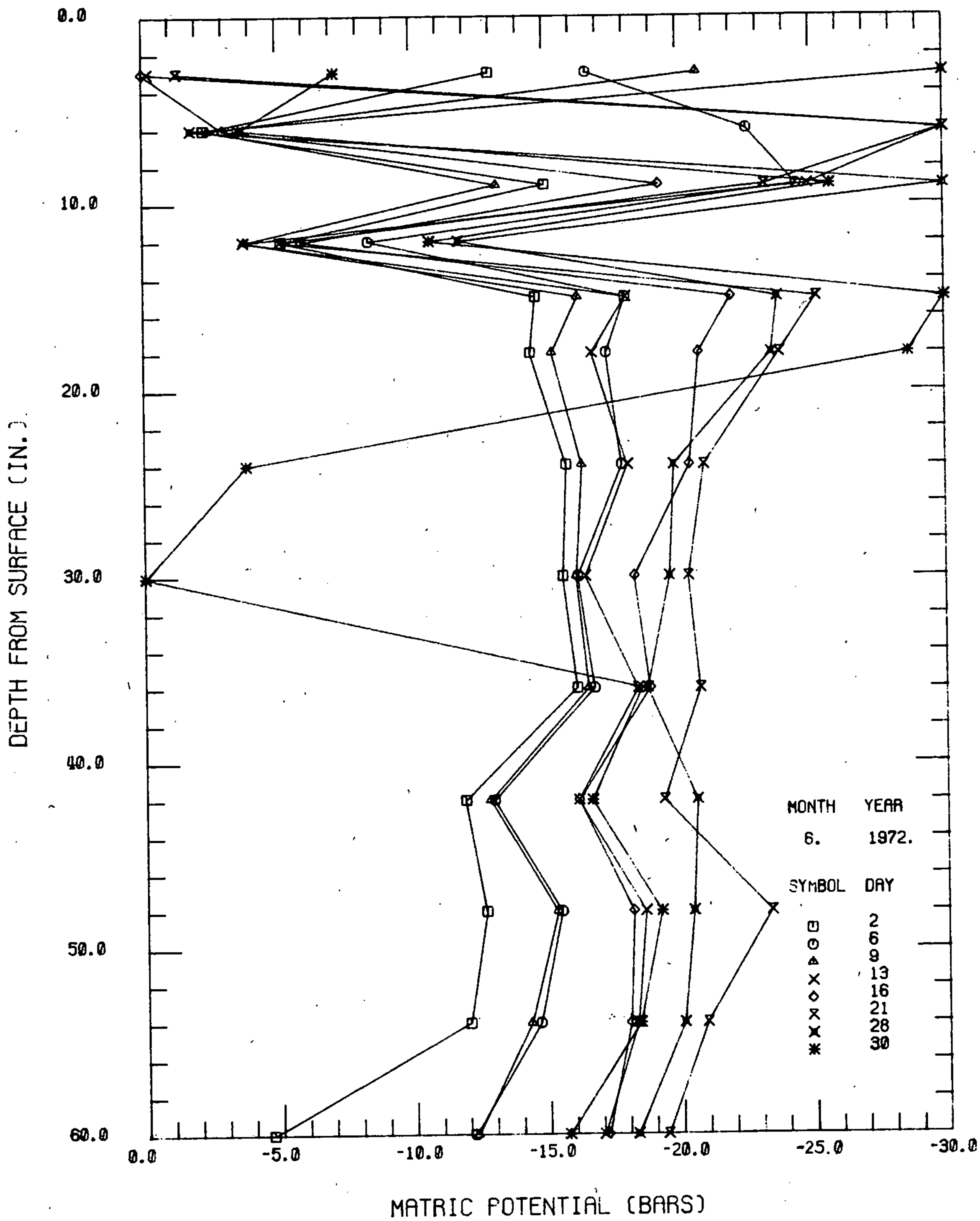


FIGURE 142

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JUNE 1972

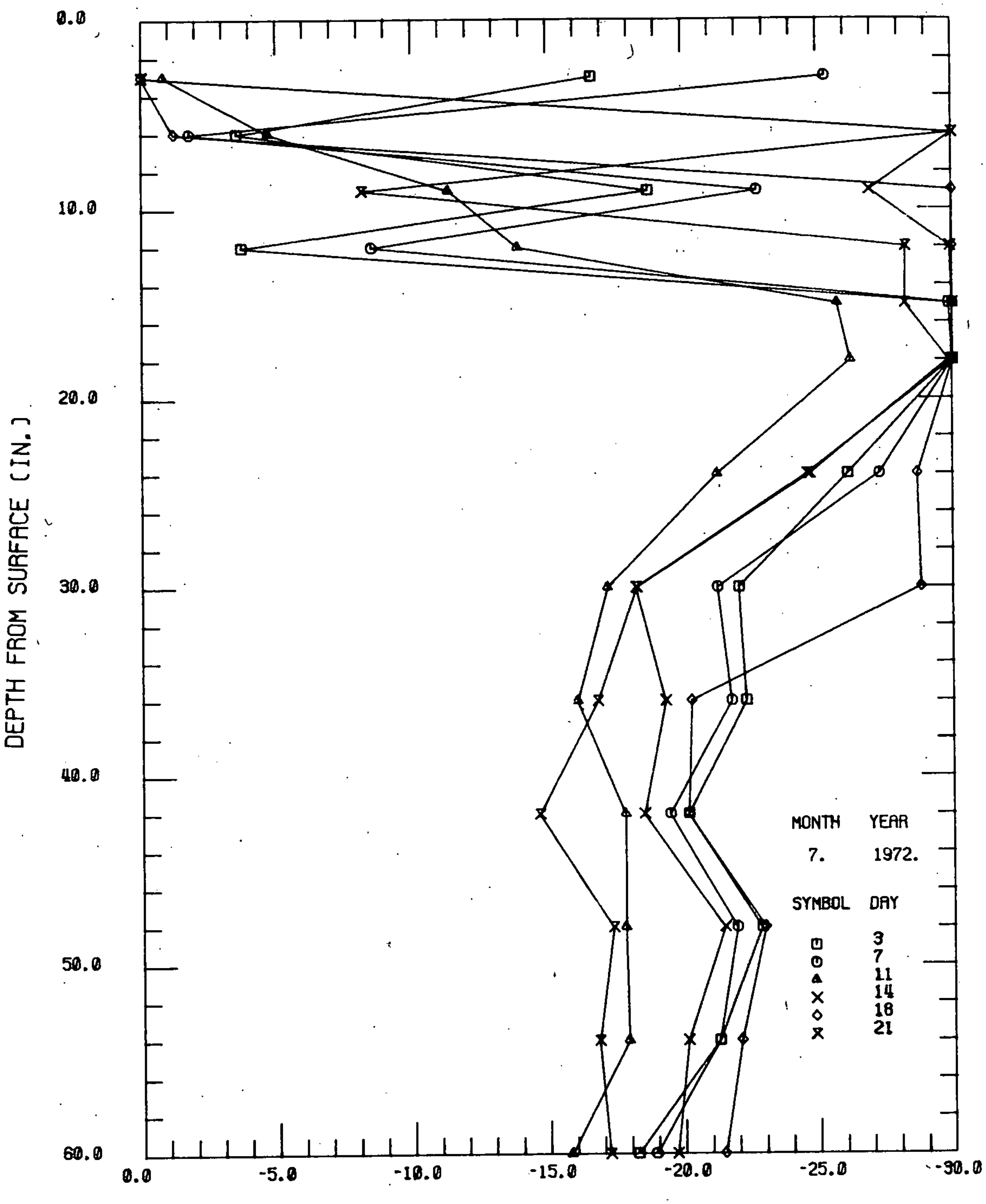


FIGURE 143

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JULY 1972

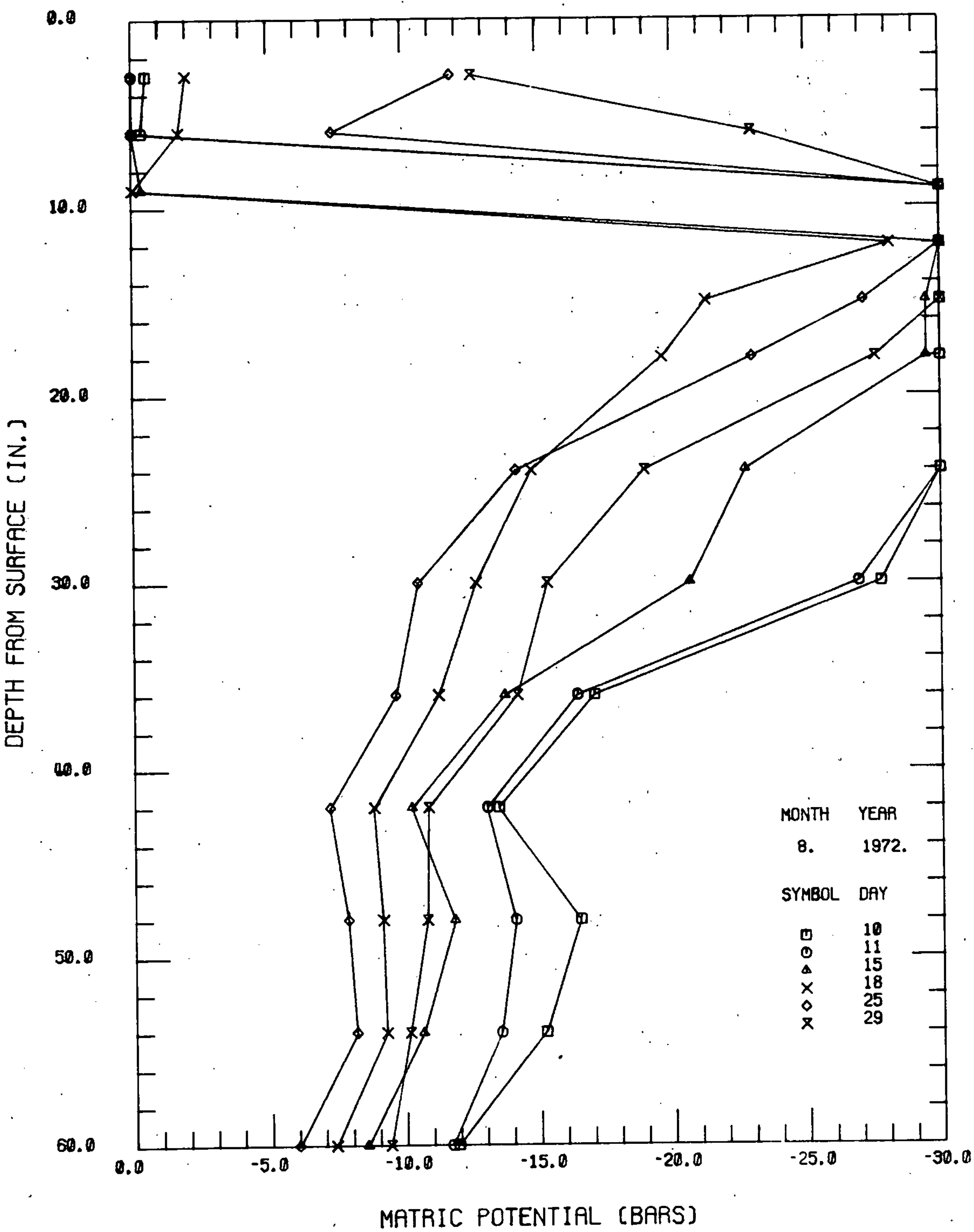


FIGURE 144

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR AUGUST 1972

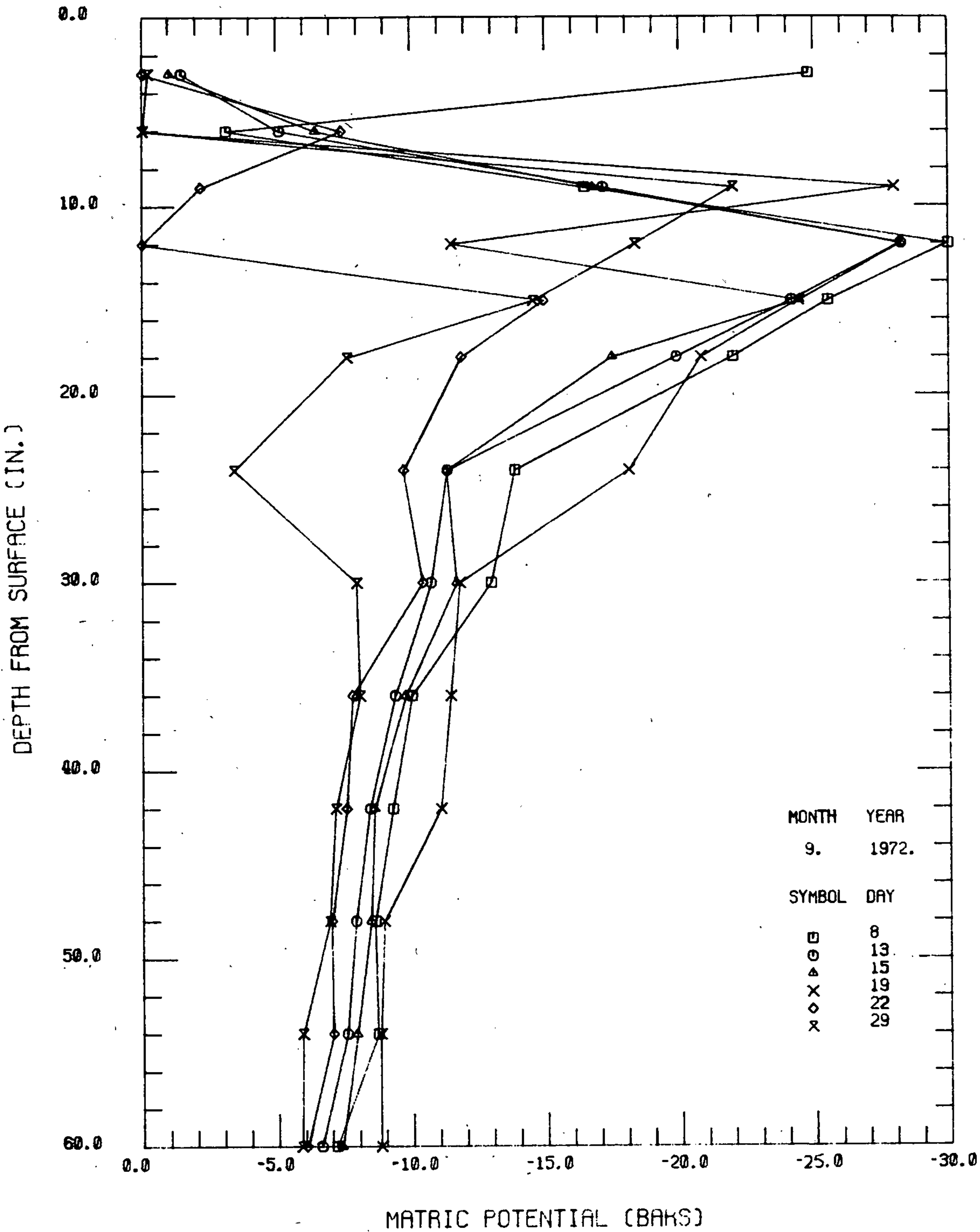


FIGURE 145

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR SEPTEMBER 1972

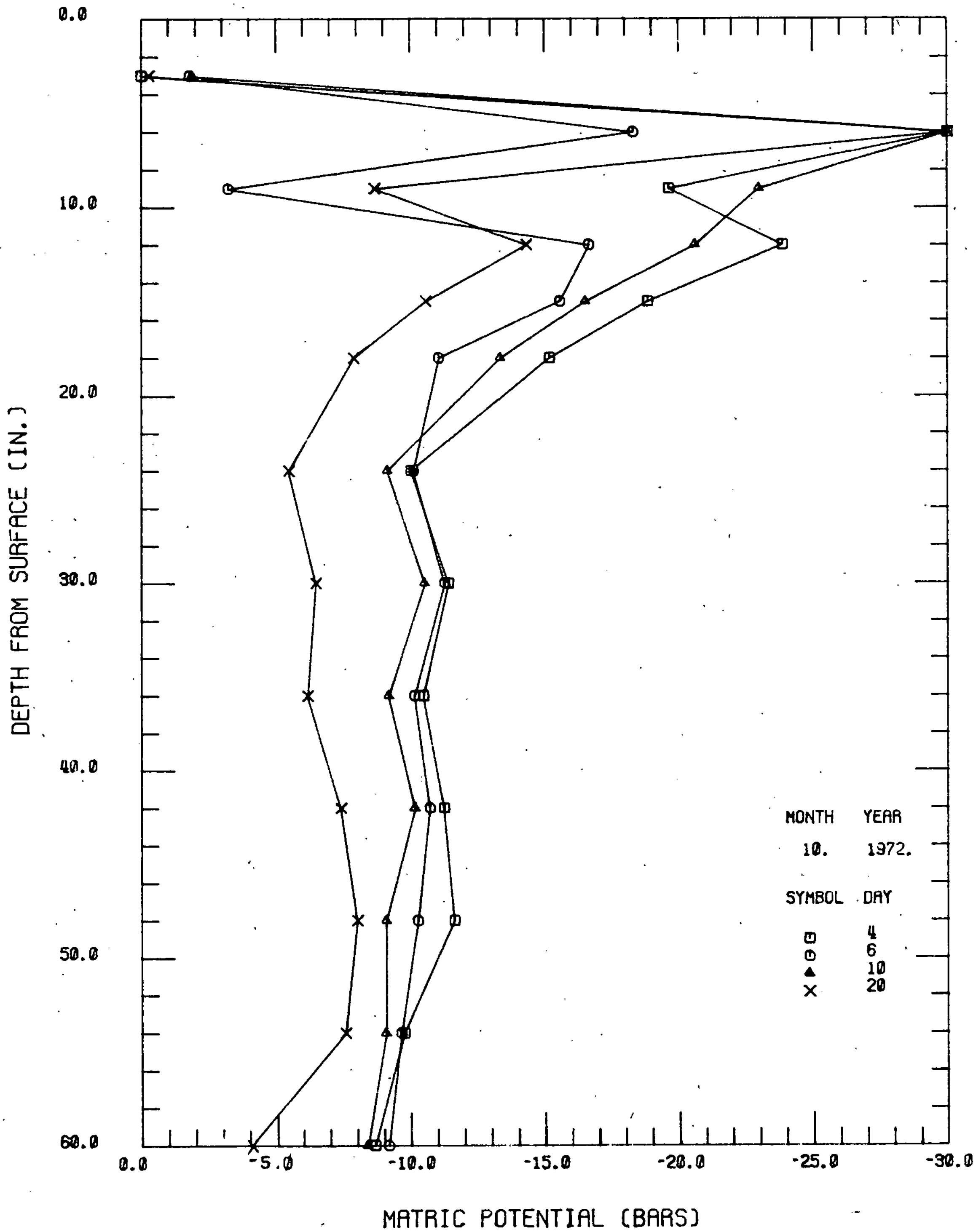


FIGURE 146

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR OCTOBER 1972

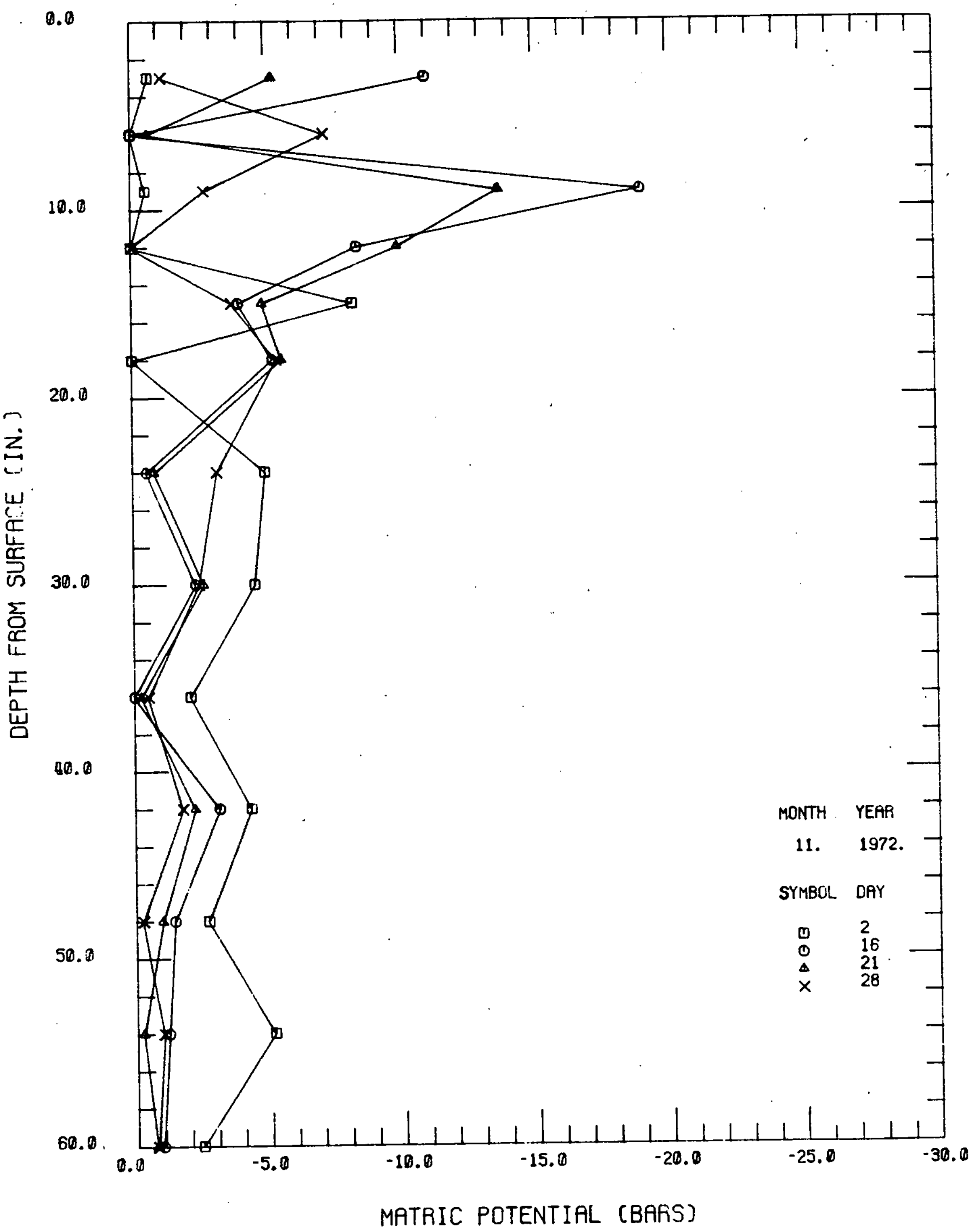


FIGURE 147

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR NOVEMBER 1972

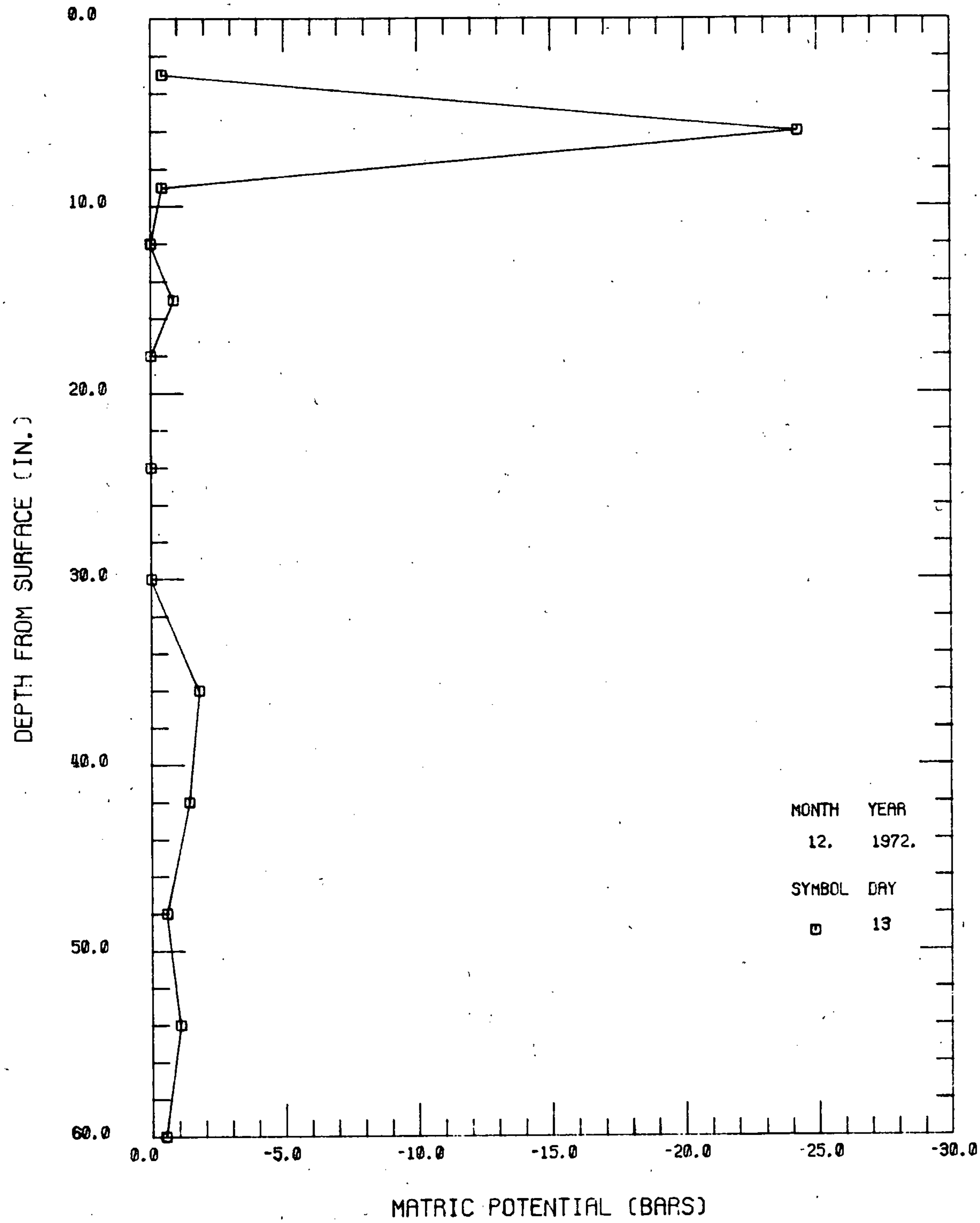


FIGURE 148

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR DECEMBER 1972

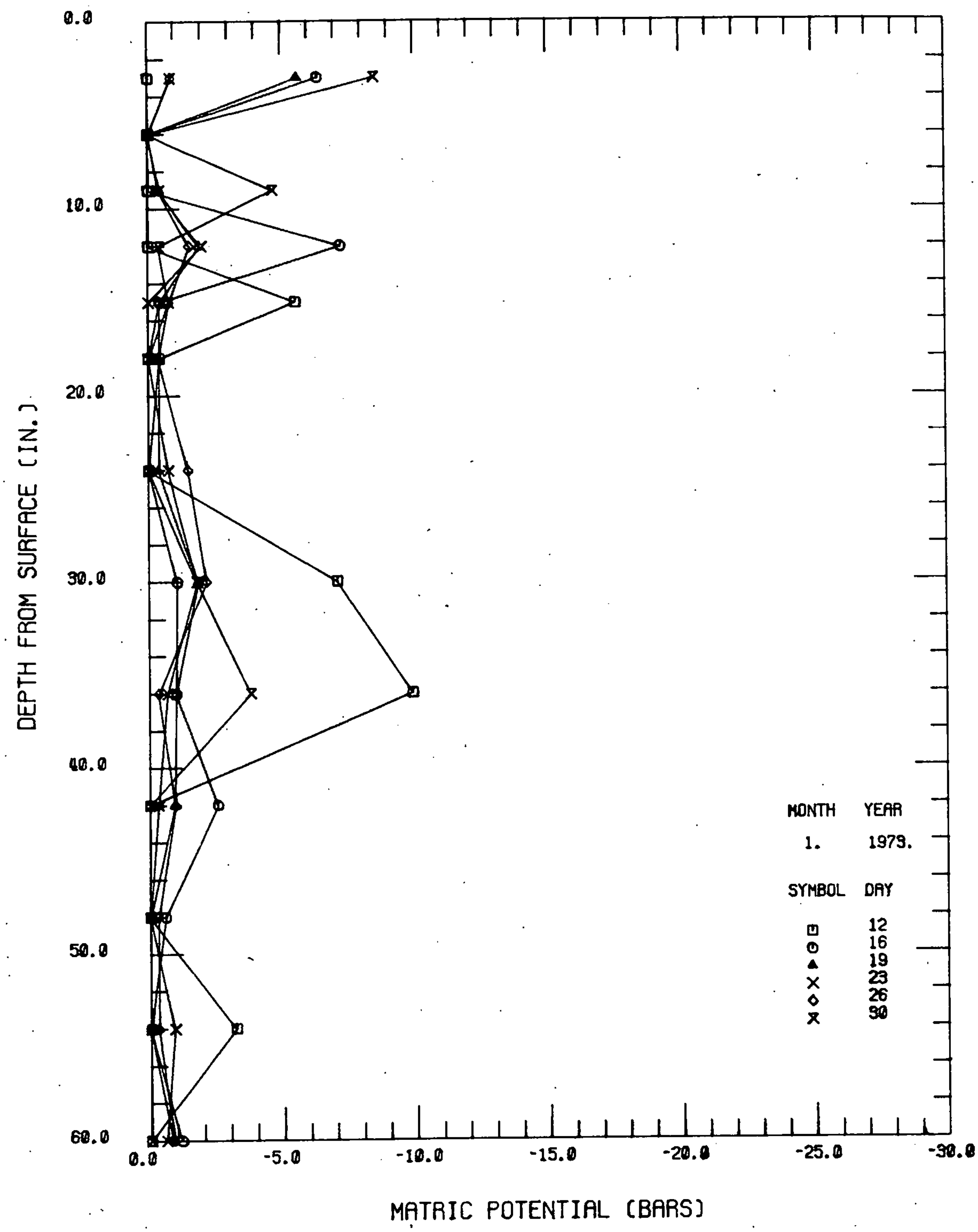


FIGURE 149

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JANUARY 1973

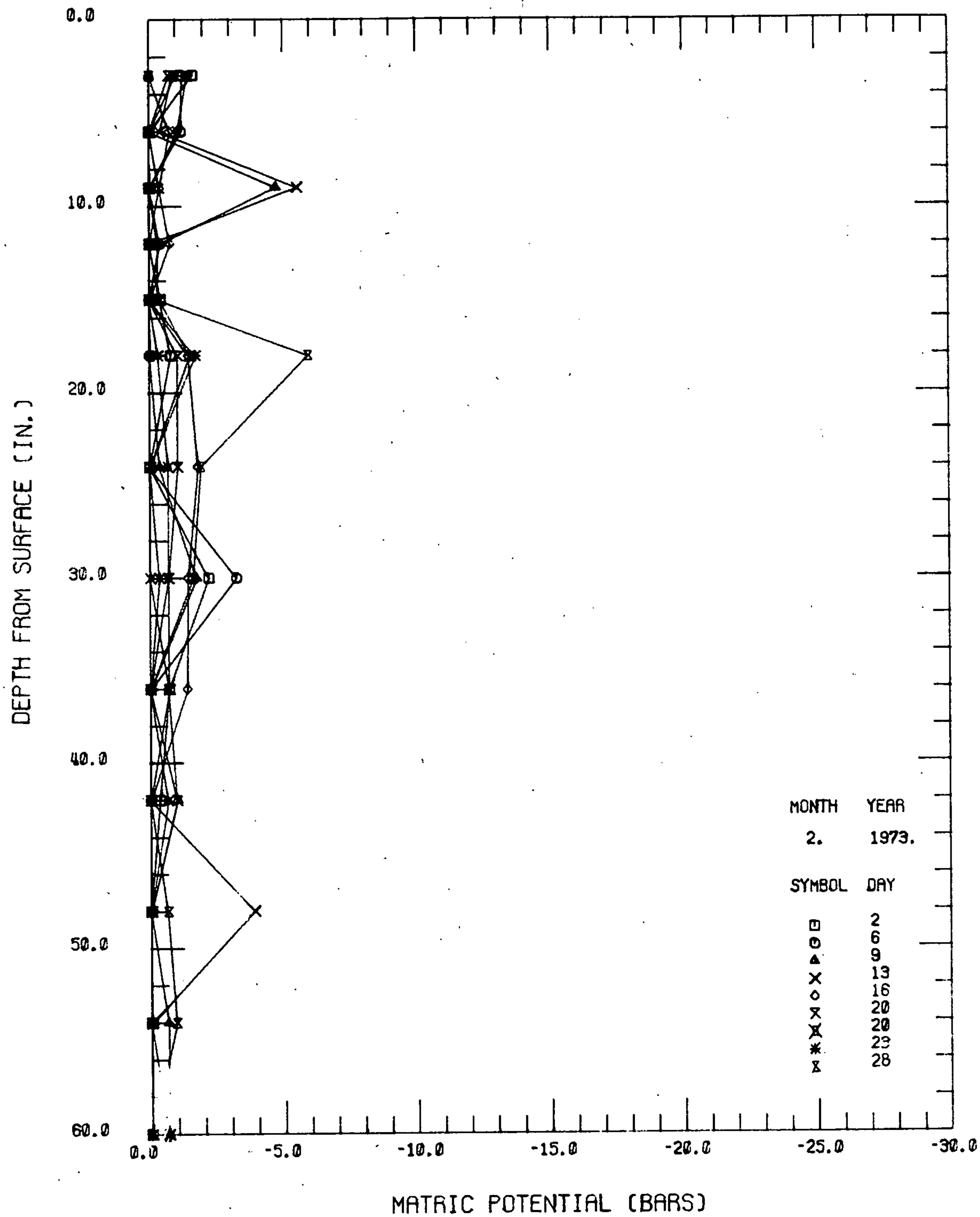


FIGURE 150

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR FEBRUARY 1973

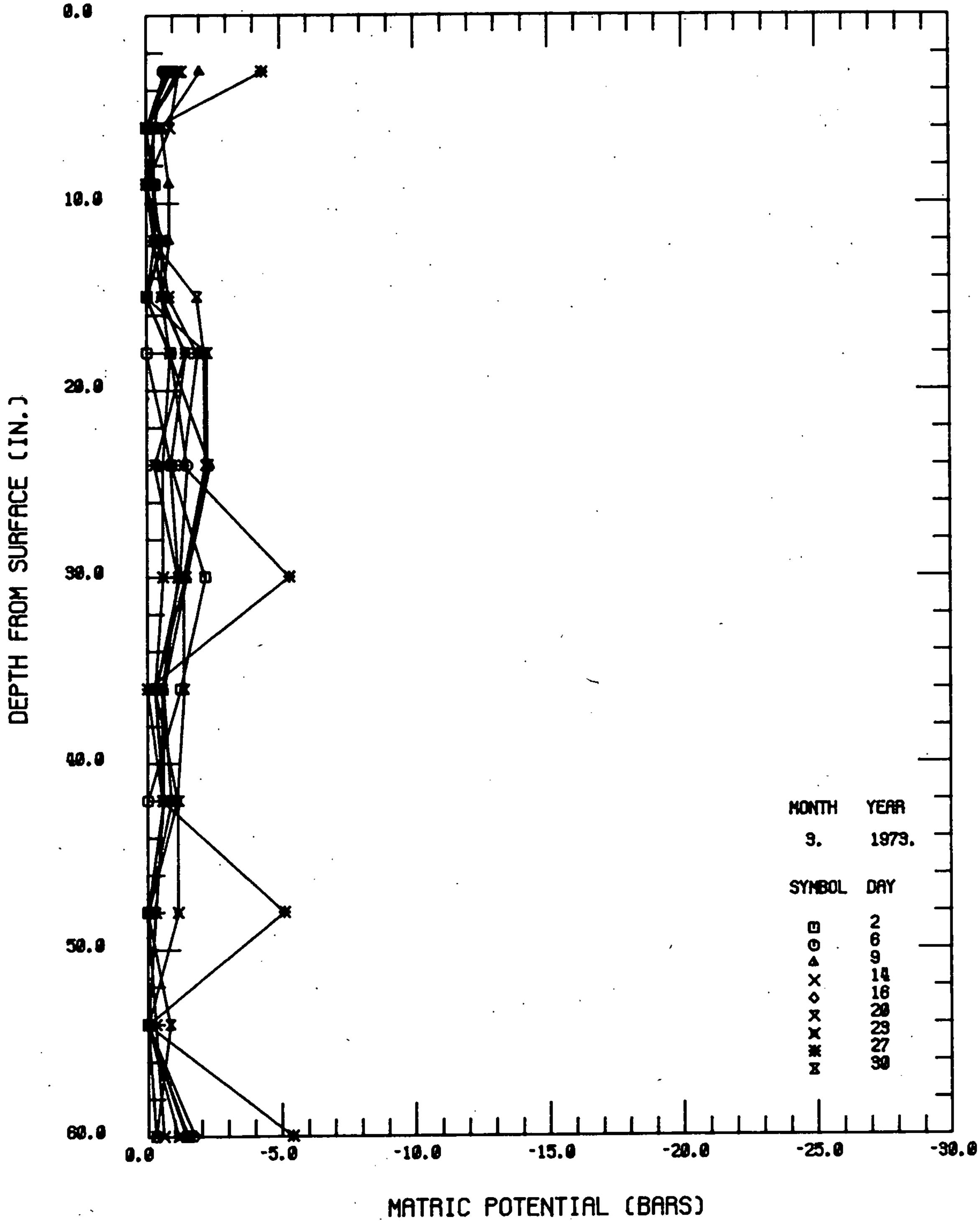


FIGURE 151

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MARCH 1973

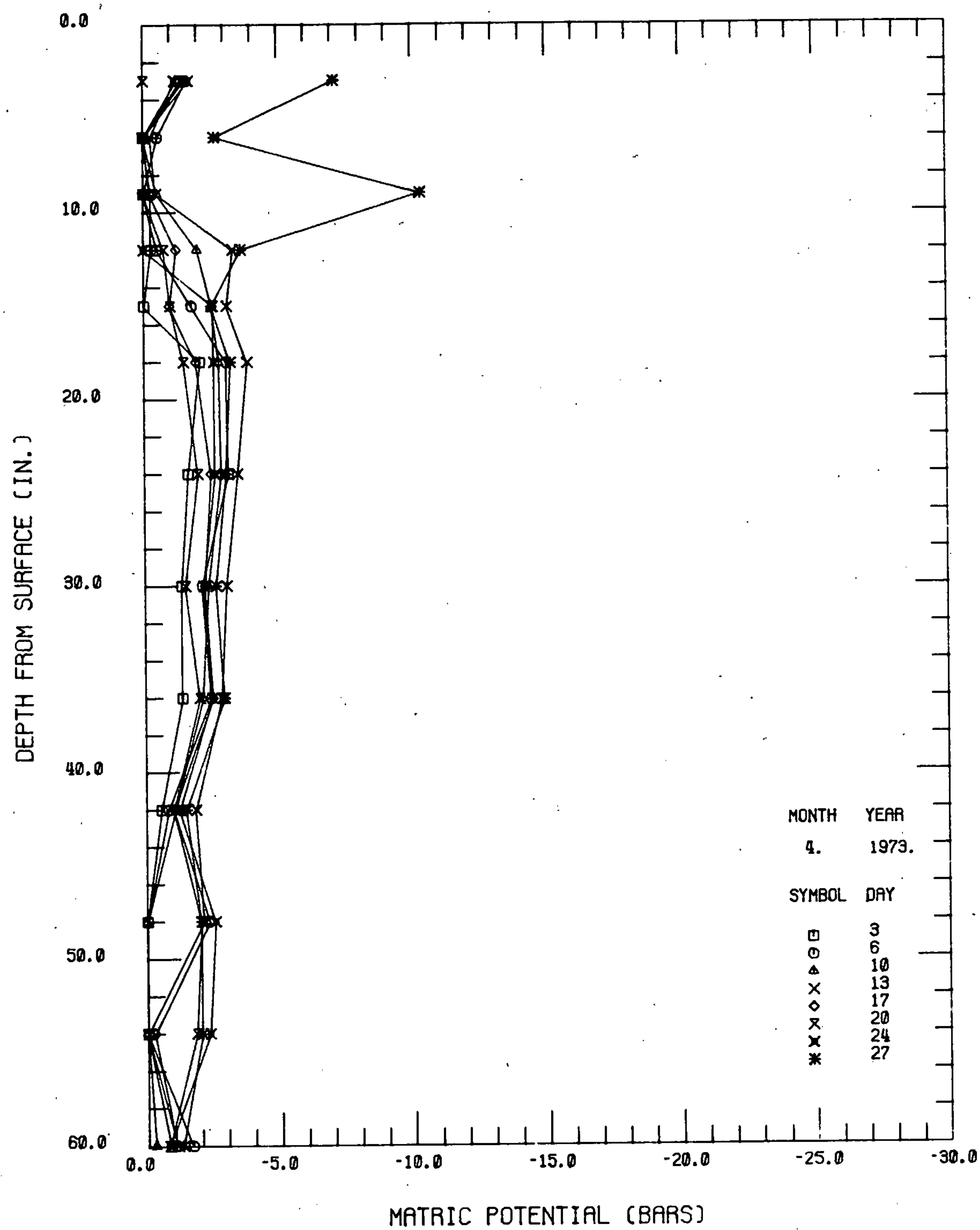


FIGURE 152

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR APRIL 1973

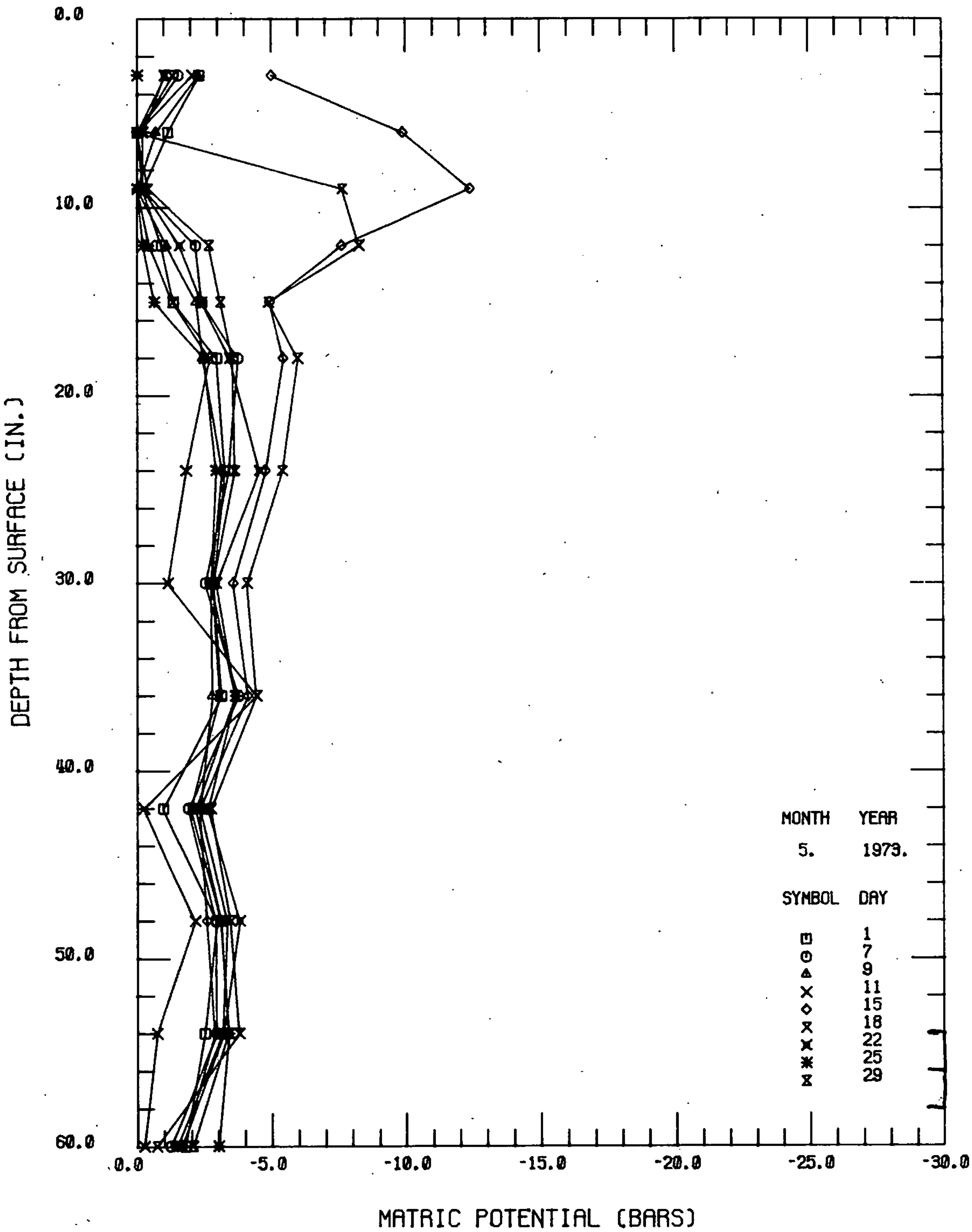


FIGURE 153

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MAY 1973

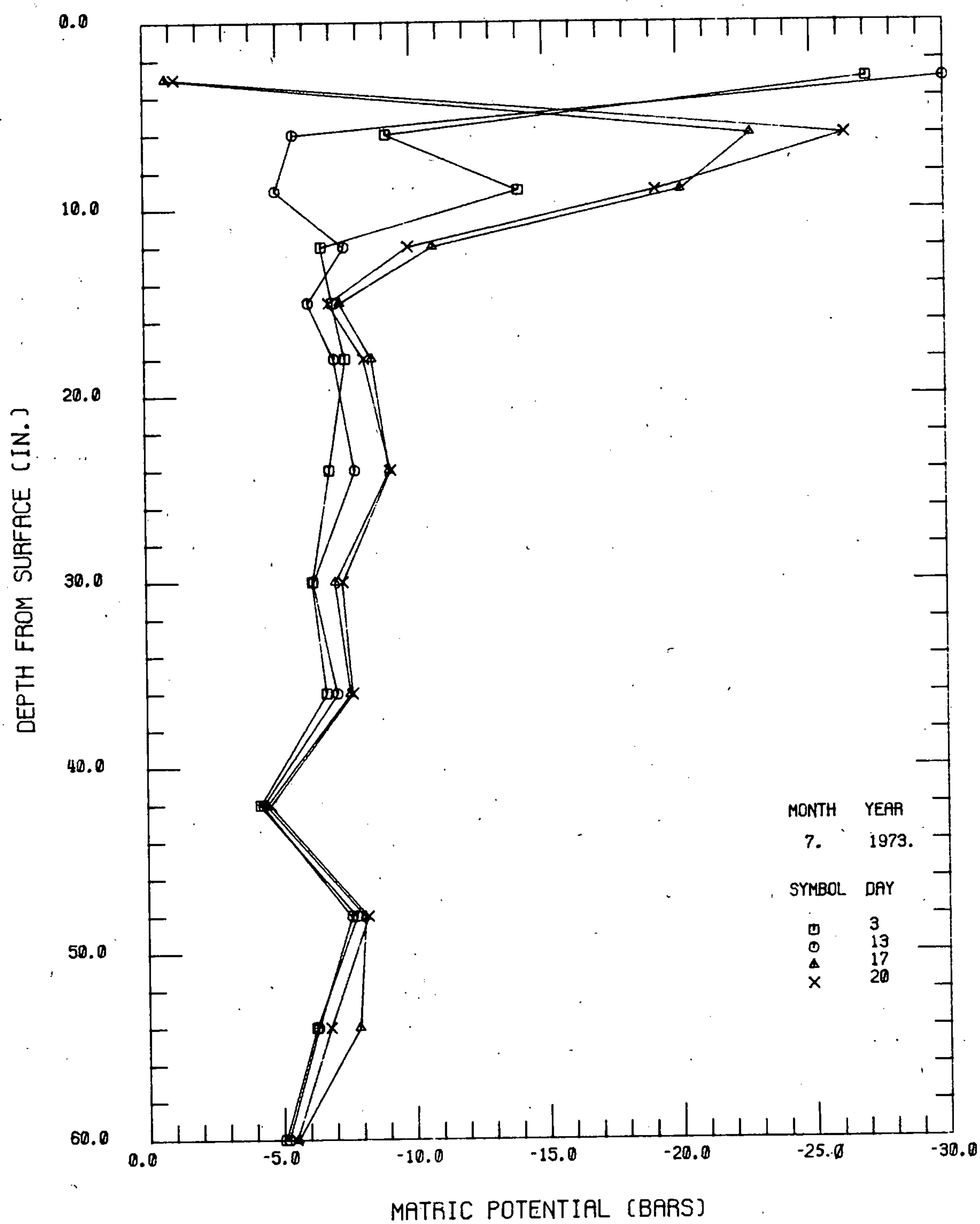


FIGURE 154

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JUNE 1973

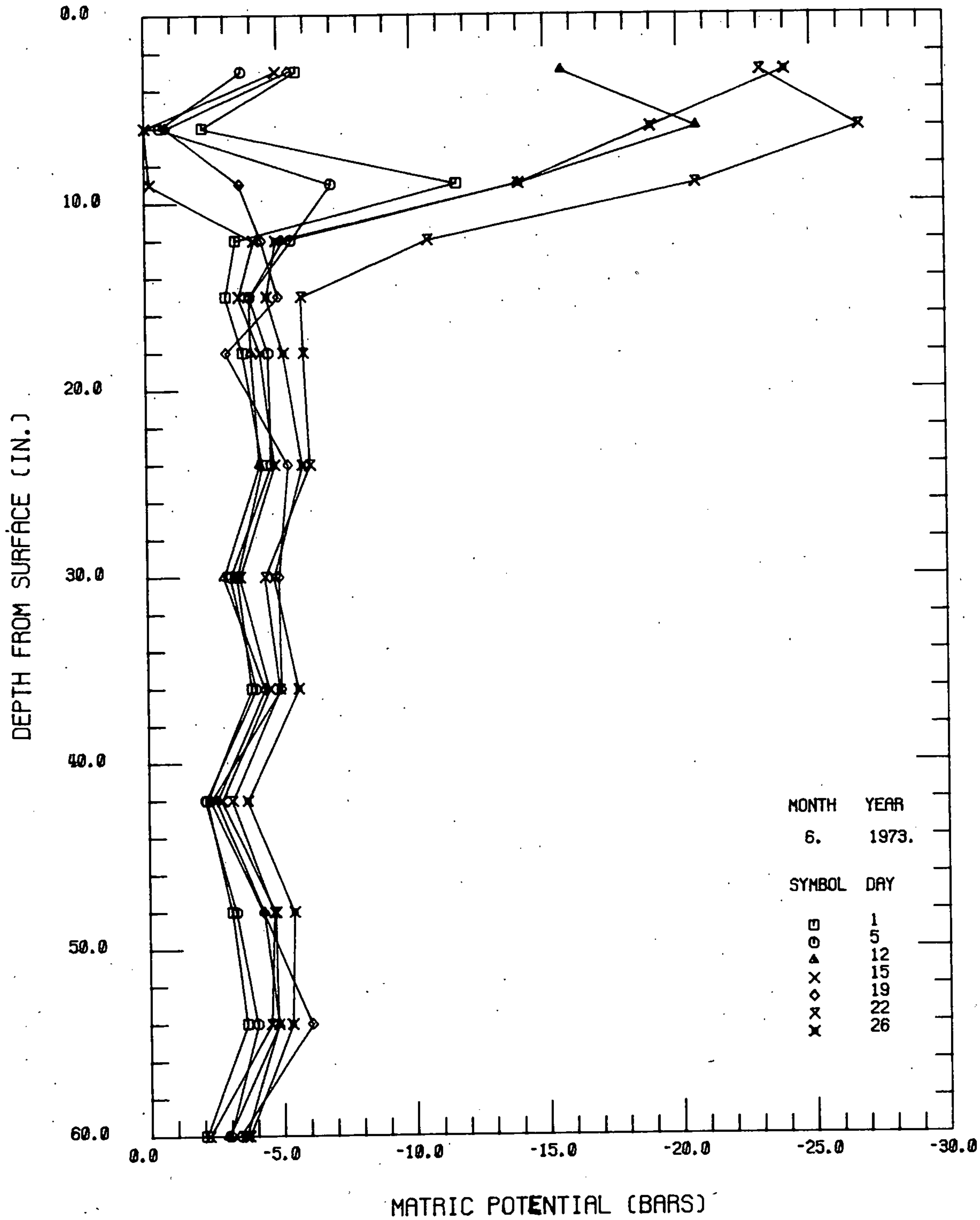


FIGURE 155

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JULY 1973

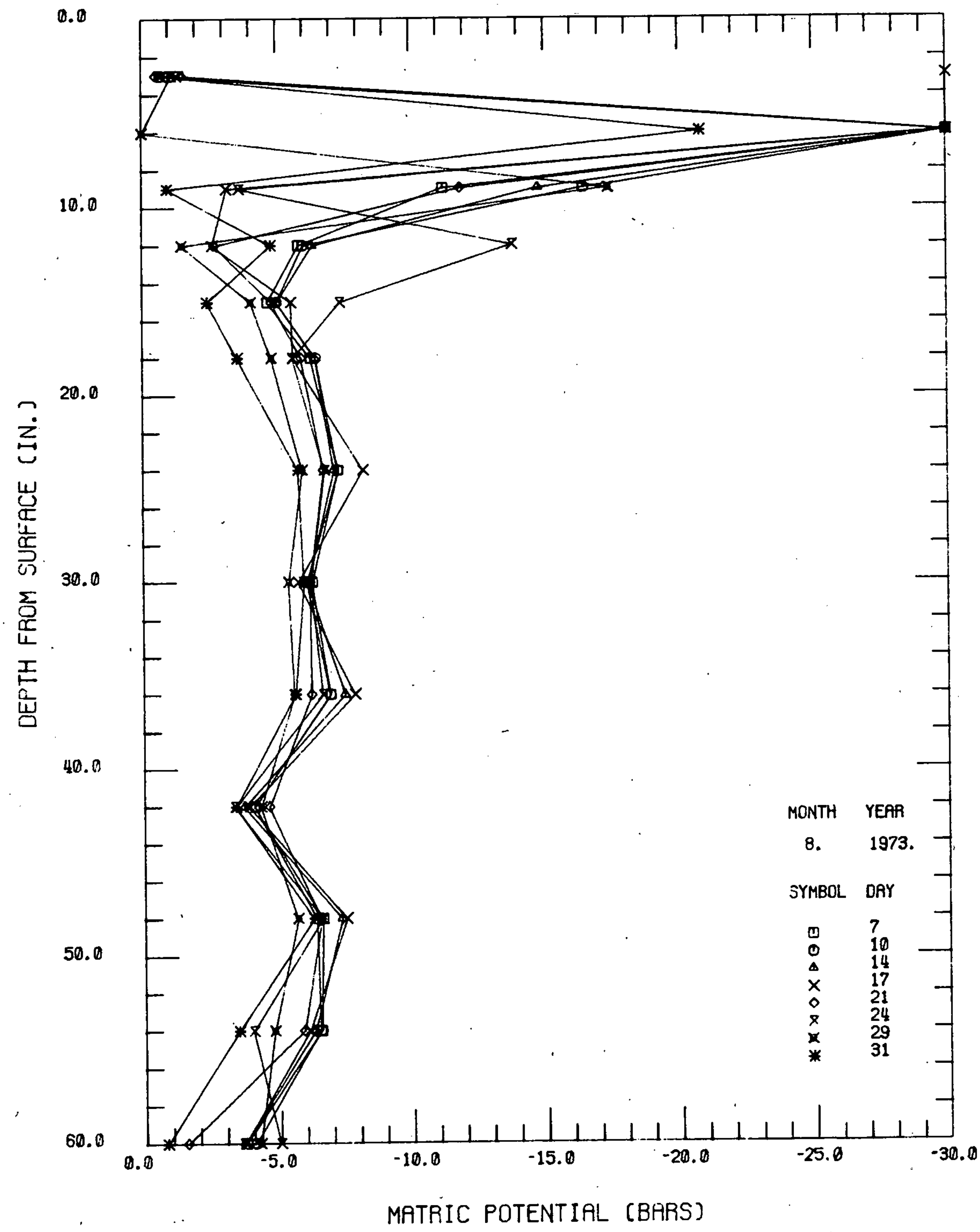


FIGURE 156

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR AUGUST 1973

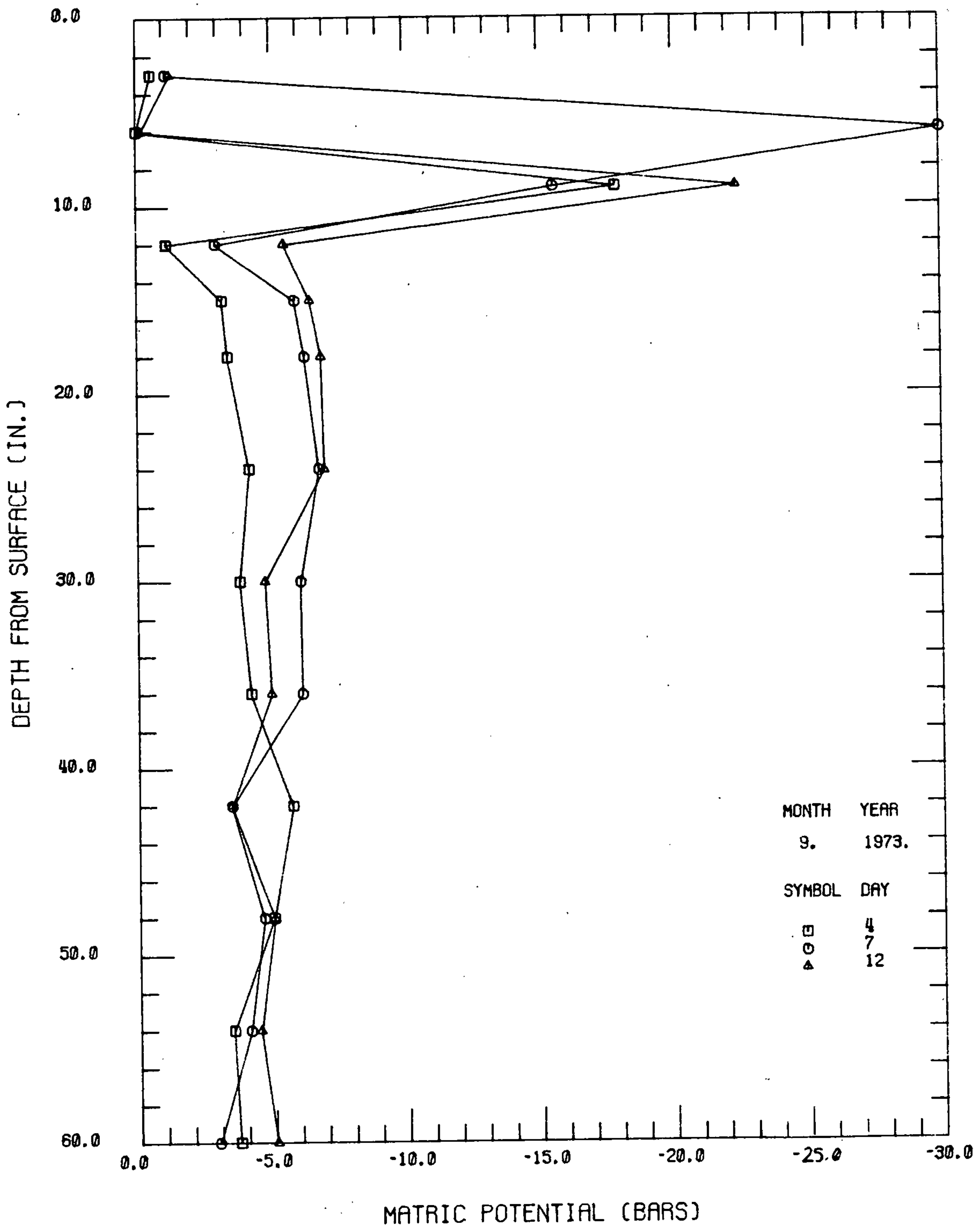


FIGURE 157

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR SEPTEMBER 1973

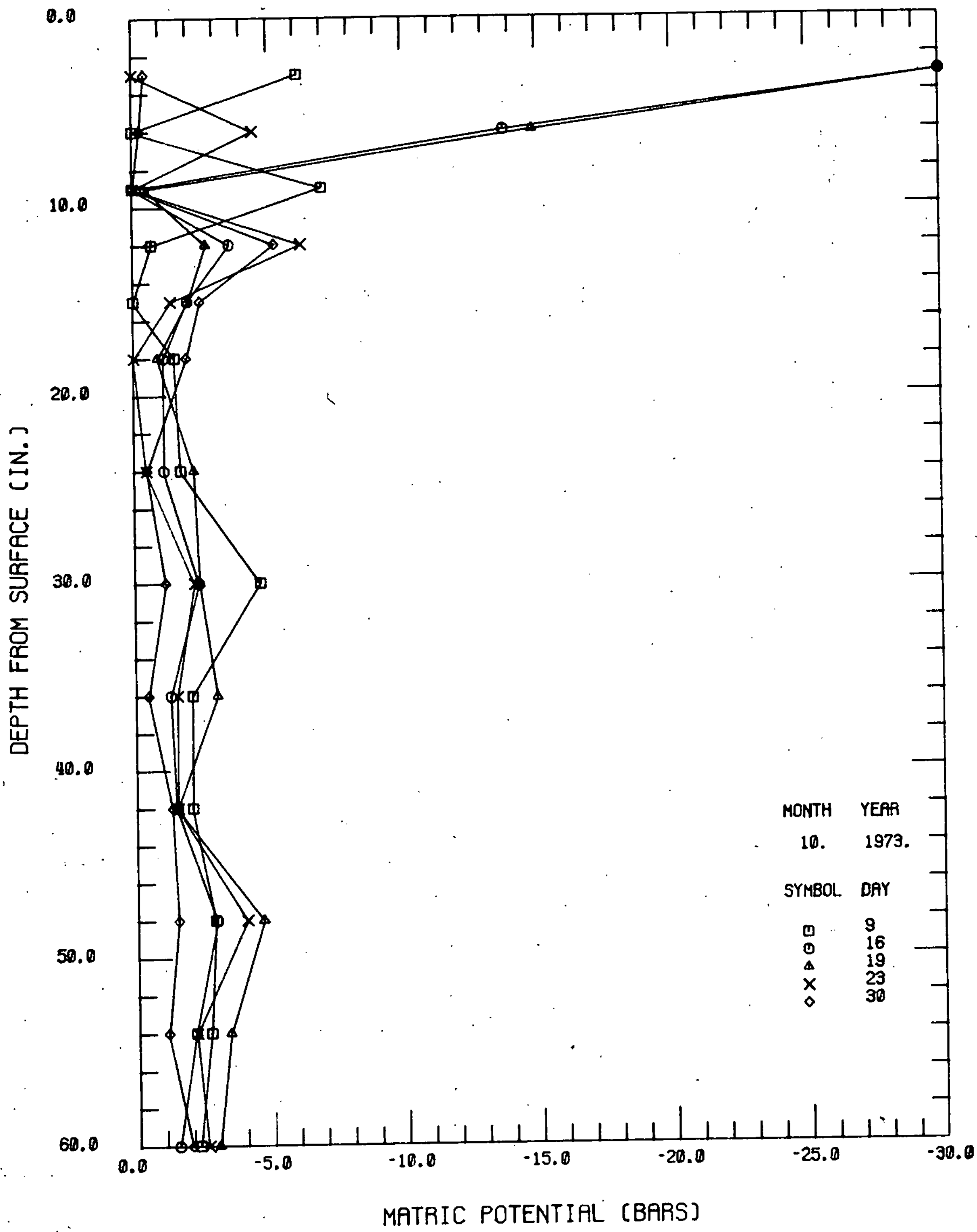


FIGURE 158

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR OCTOBER 1973

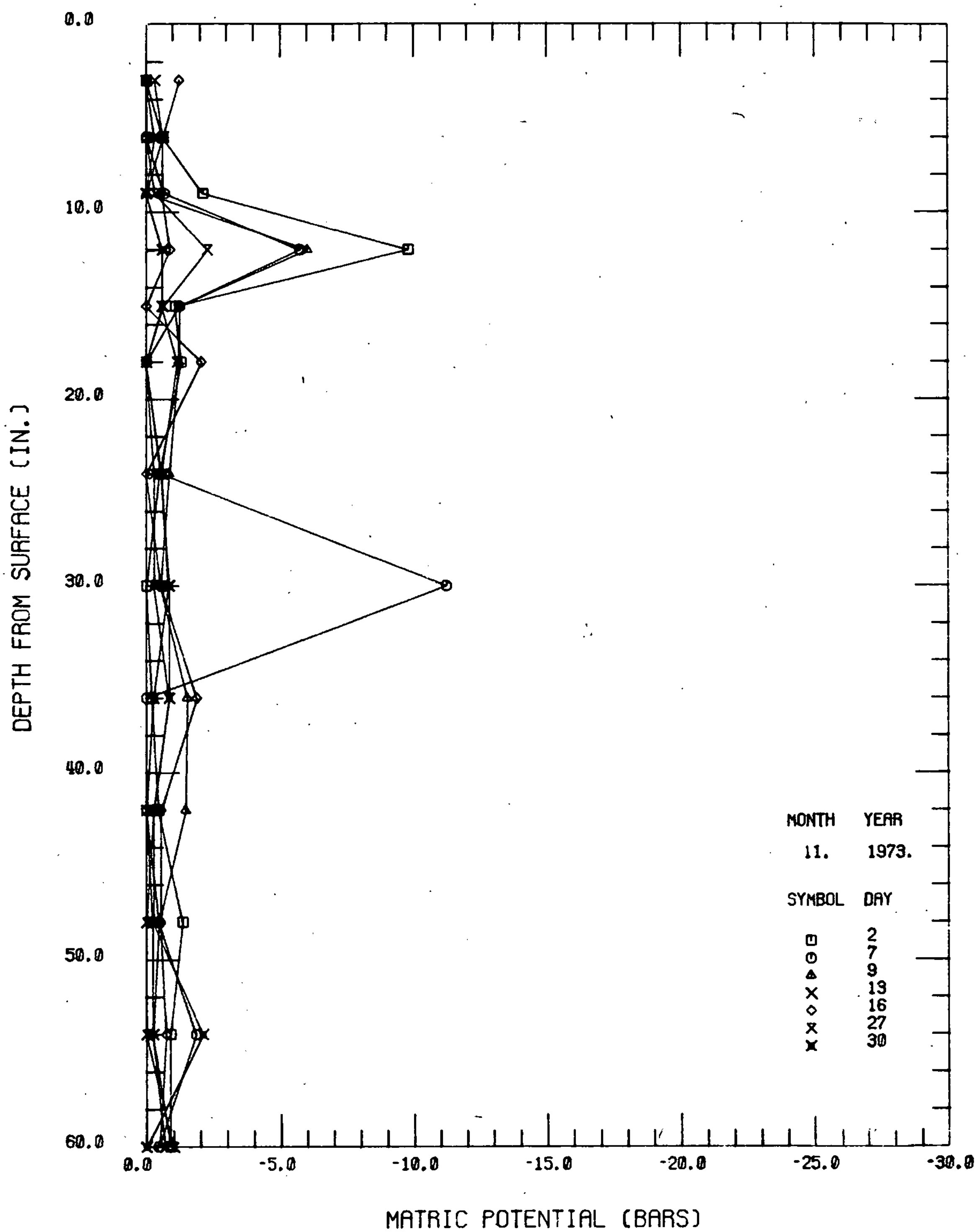


FIGURE 159

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR NOVEMBER 1973

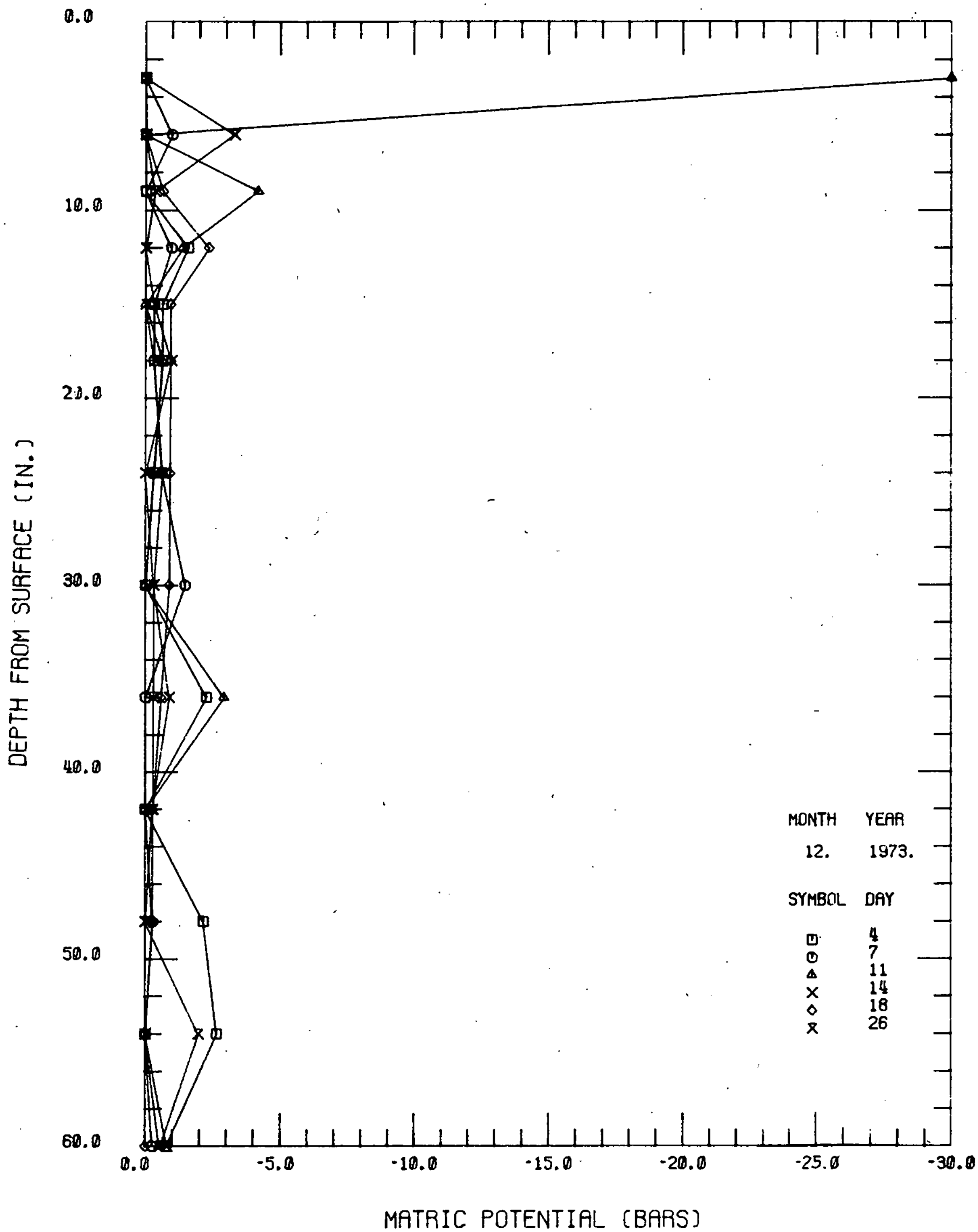


FIGURE 160

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR DECEMBER 1973

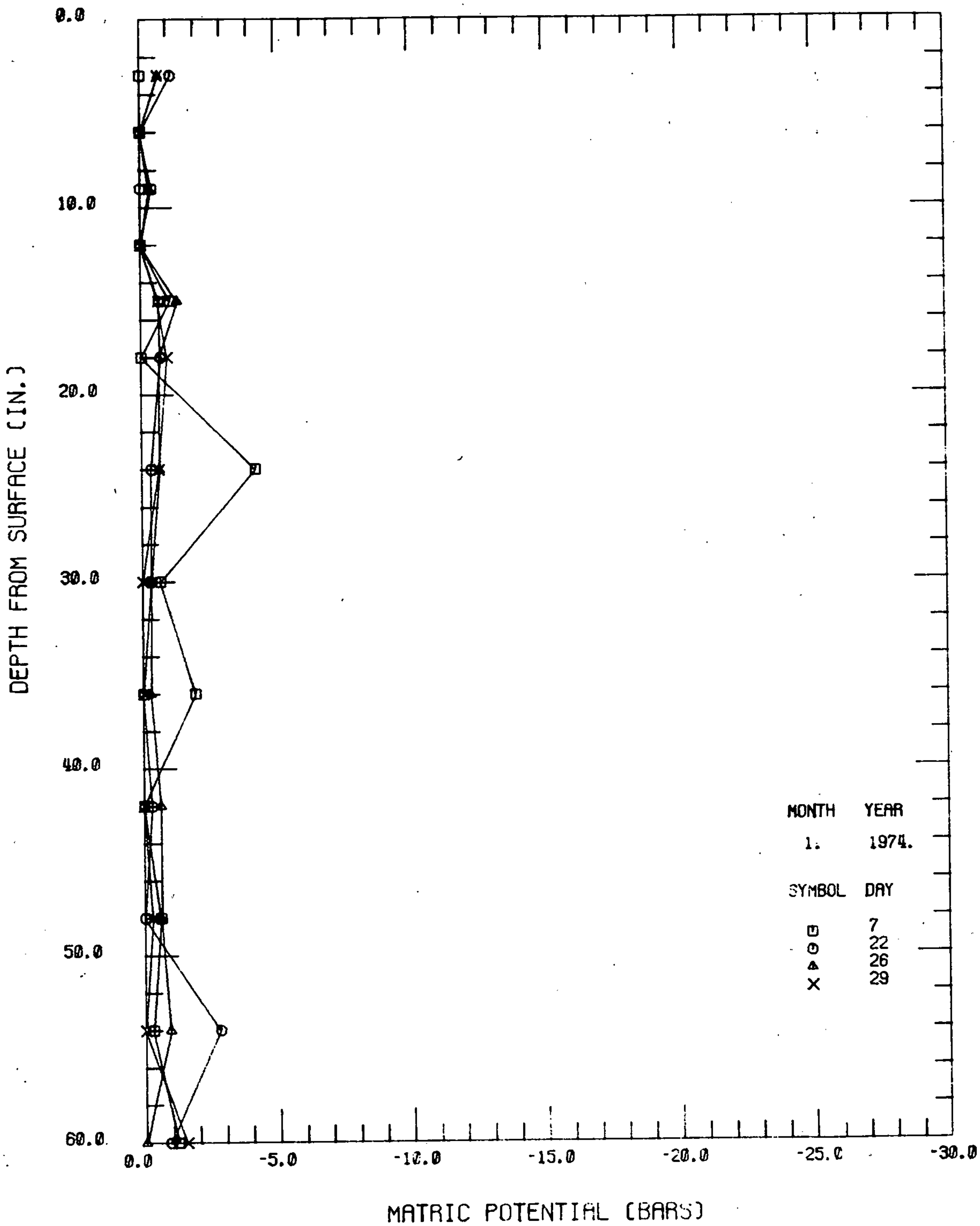


FIGURE 161

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JANUARY 1974

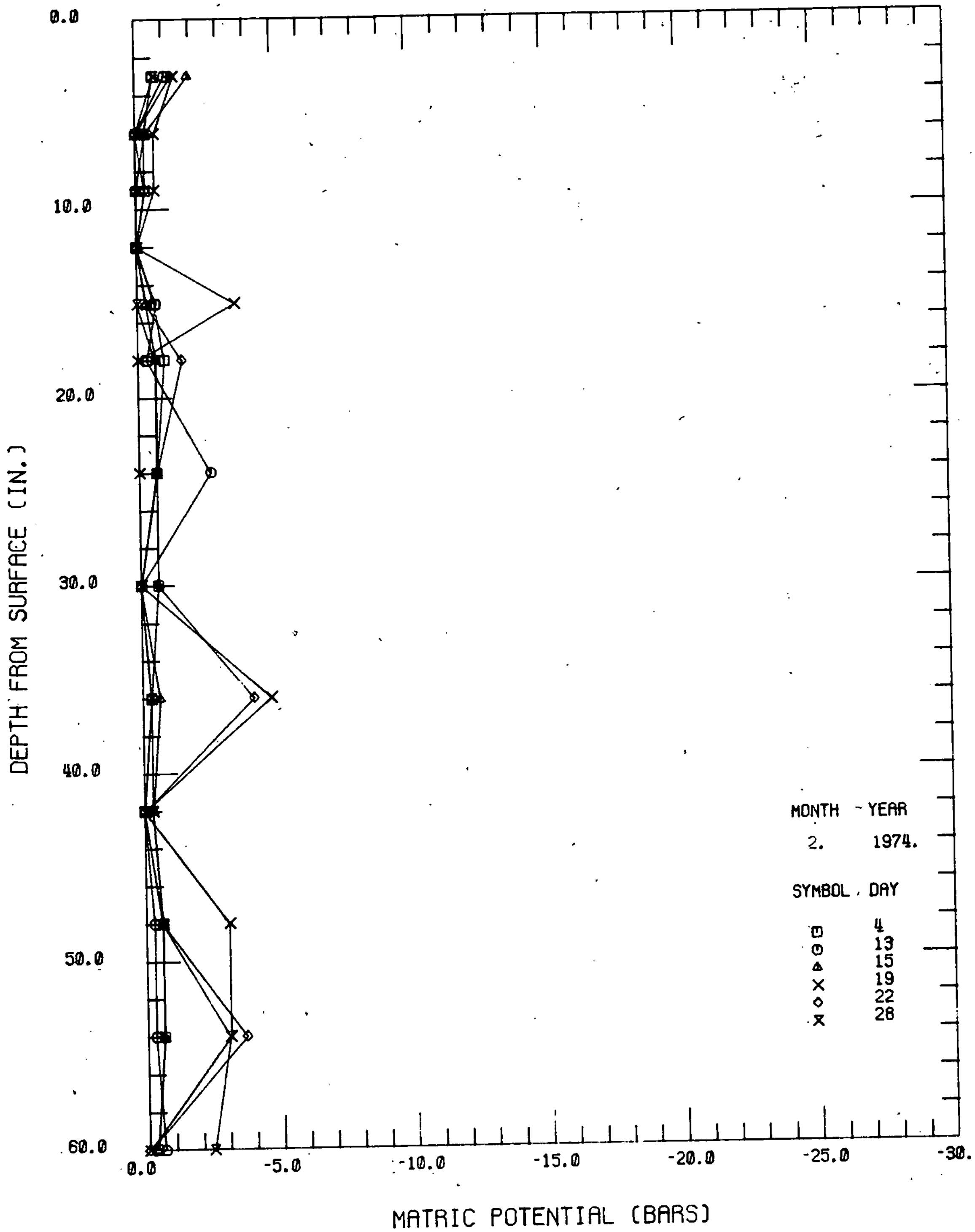
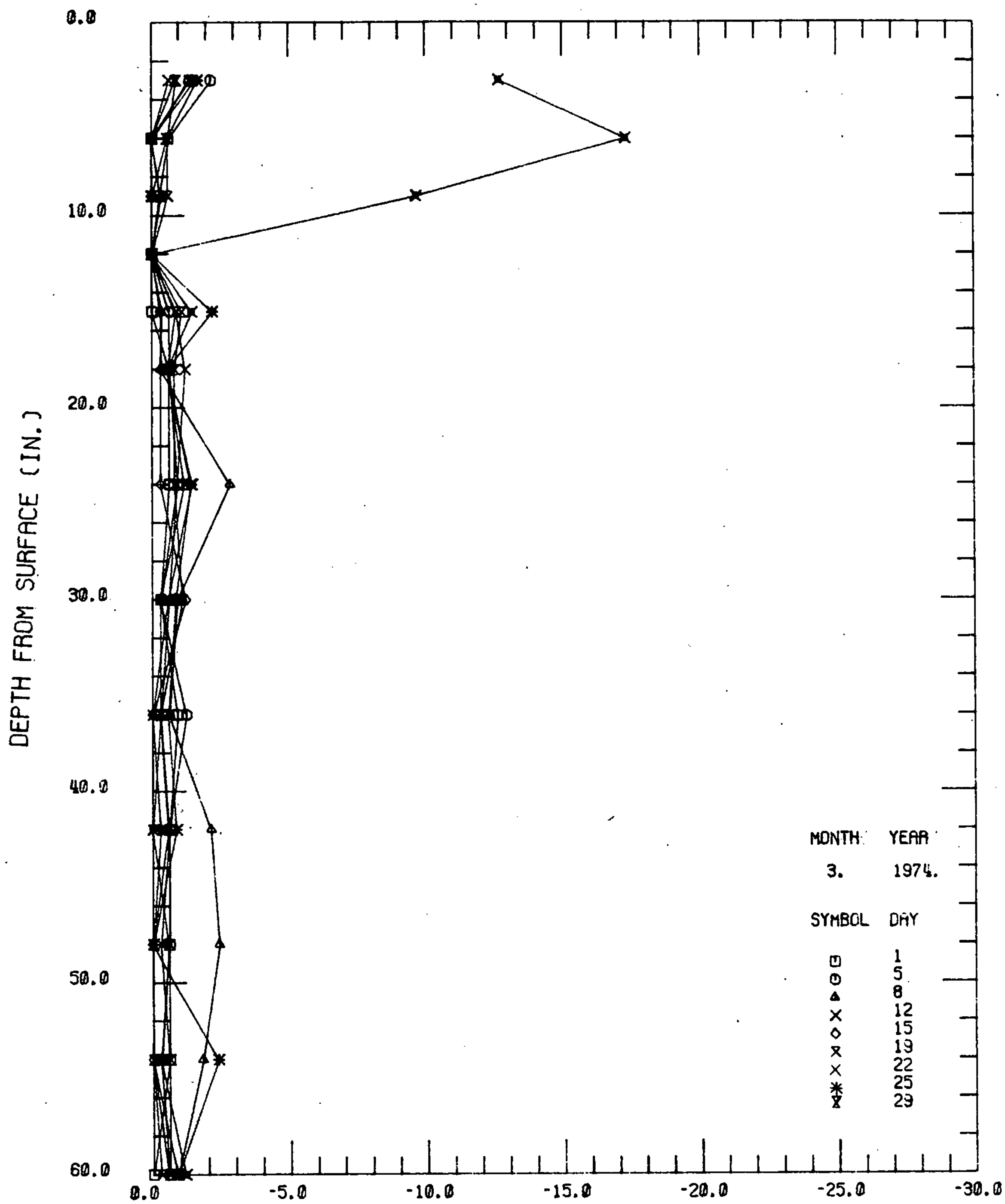


FIGURE 162

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR FEBRUARY 1974



MATRIC POTENTIAL (BARS)

FIGURE 163

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MARCH 1974

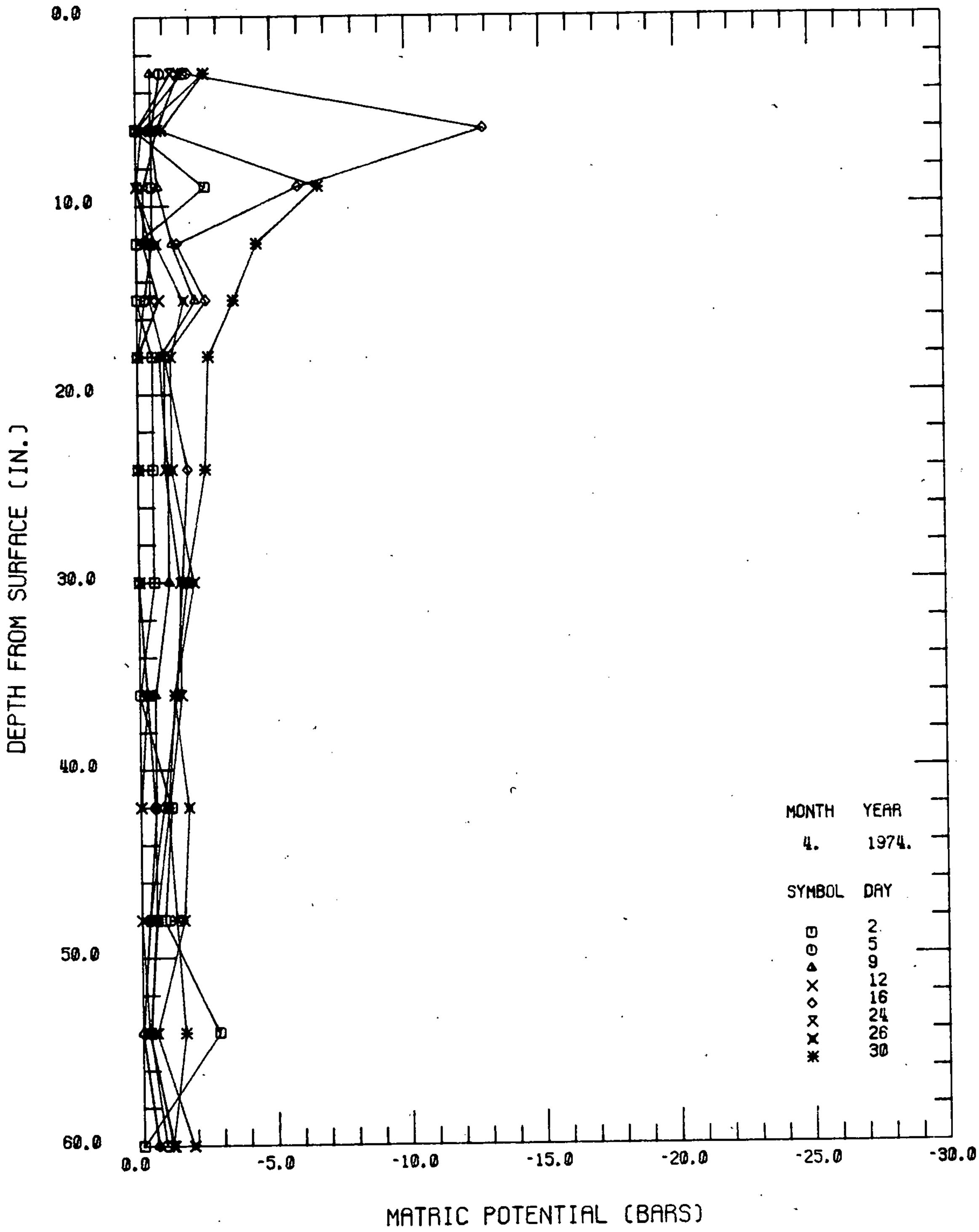


FIGURE 164

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR APRIL 1974

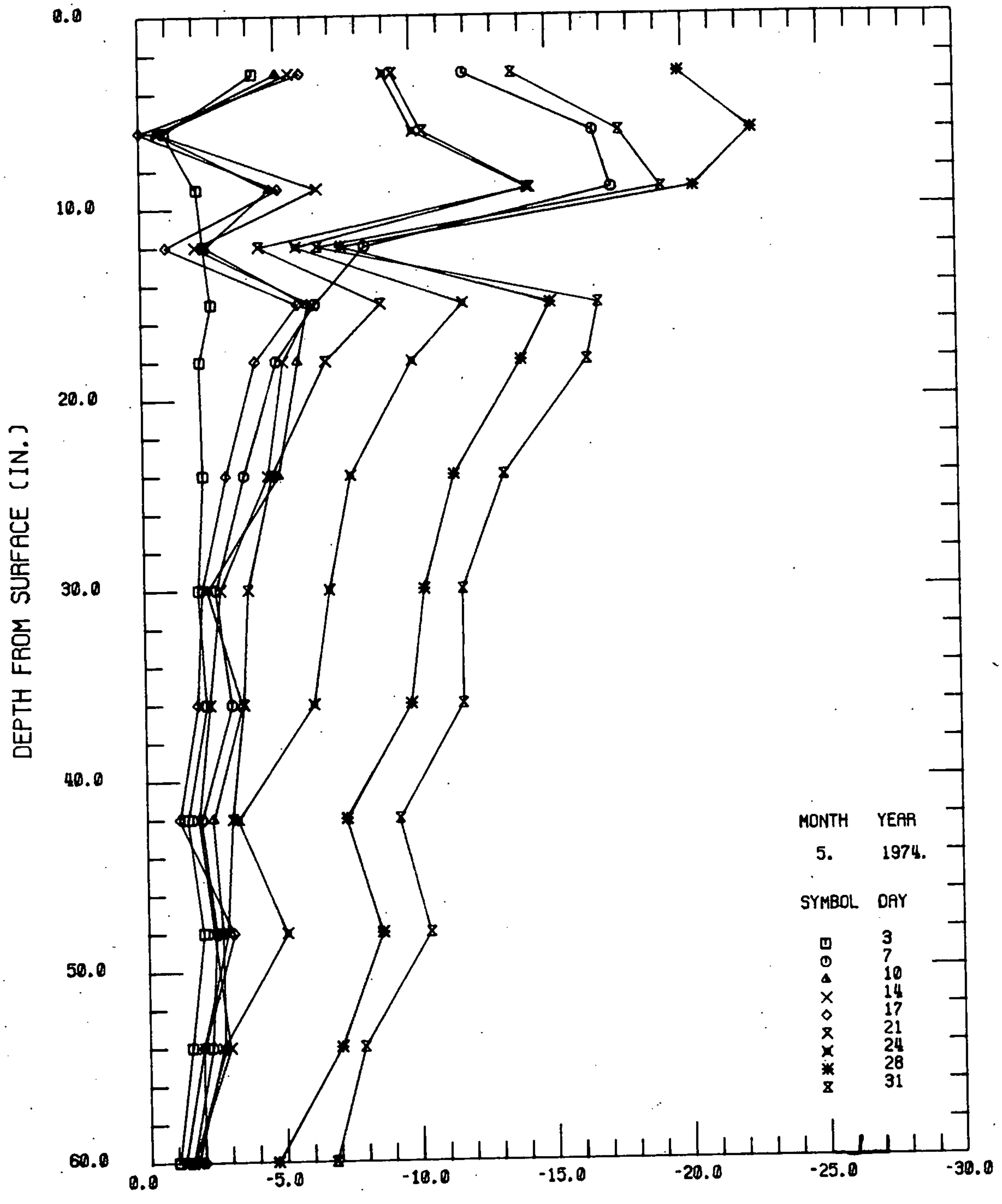


FIGURE 165

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR MAY 1974

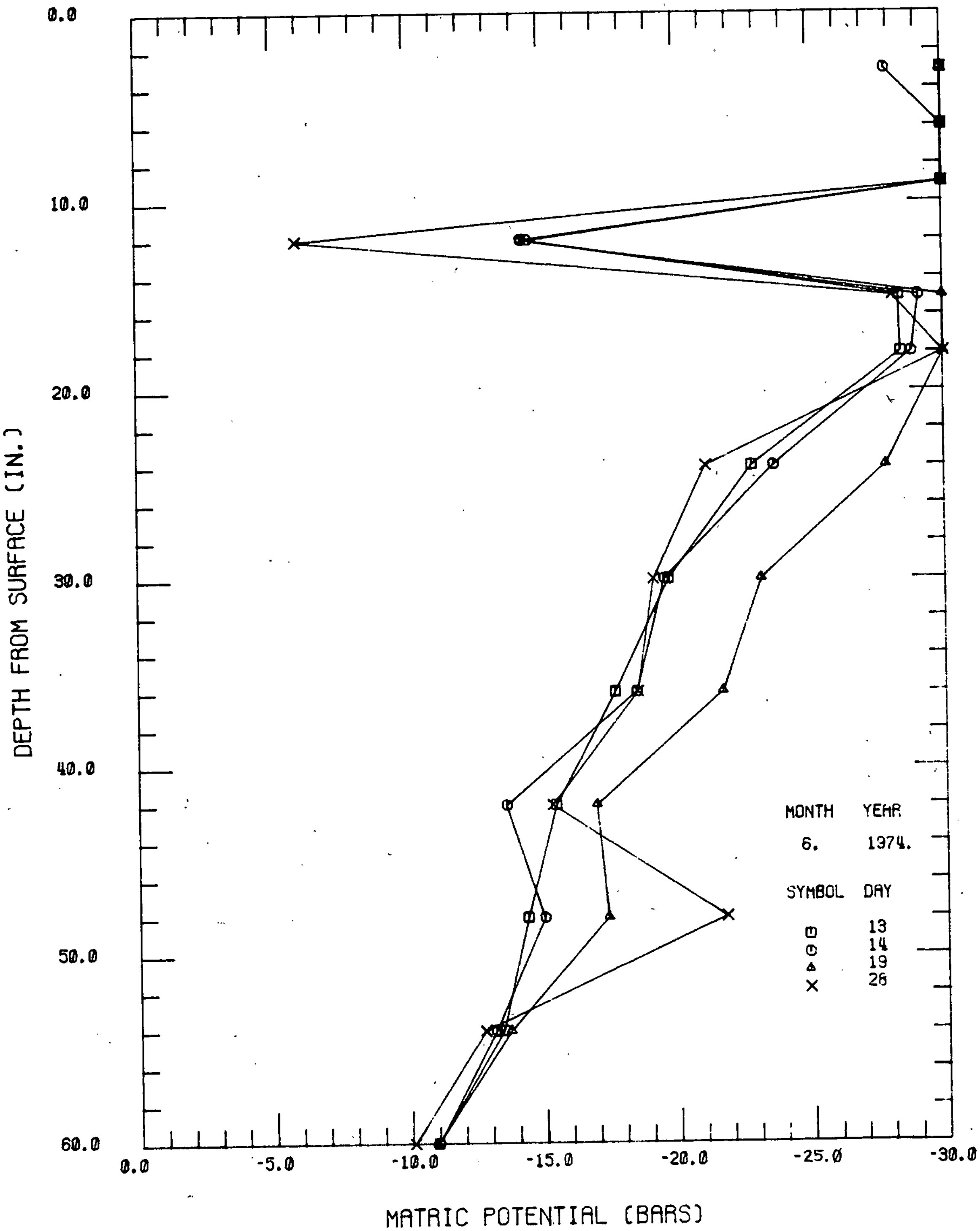


FIGURE 166

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JUNE 1974

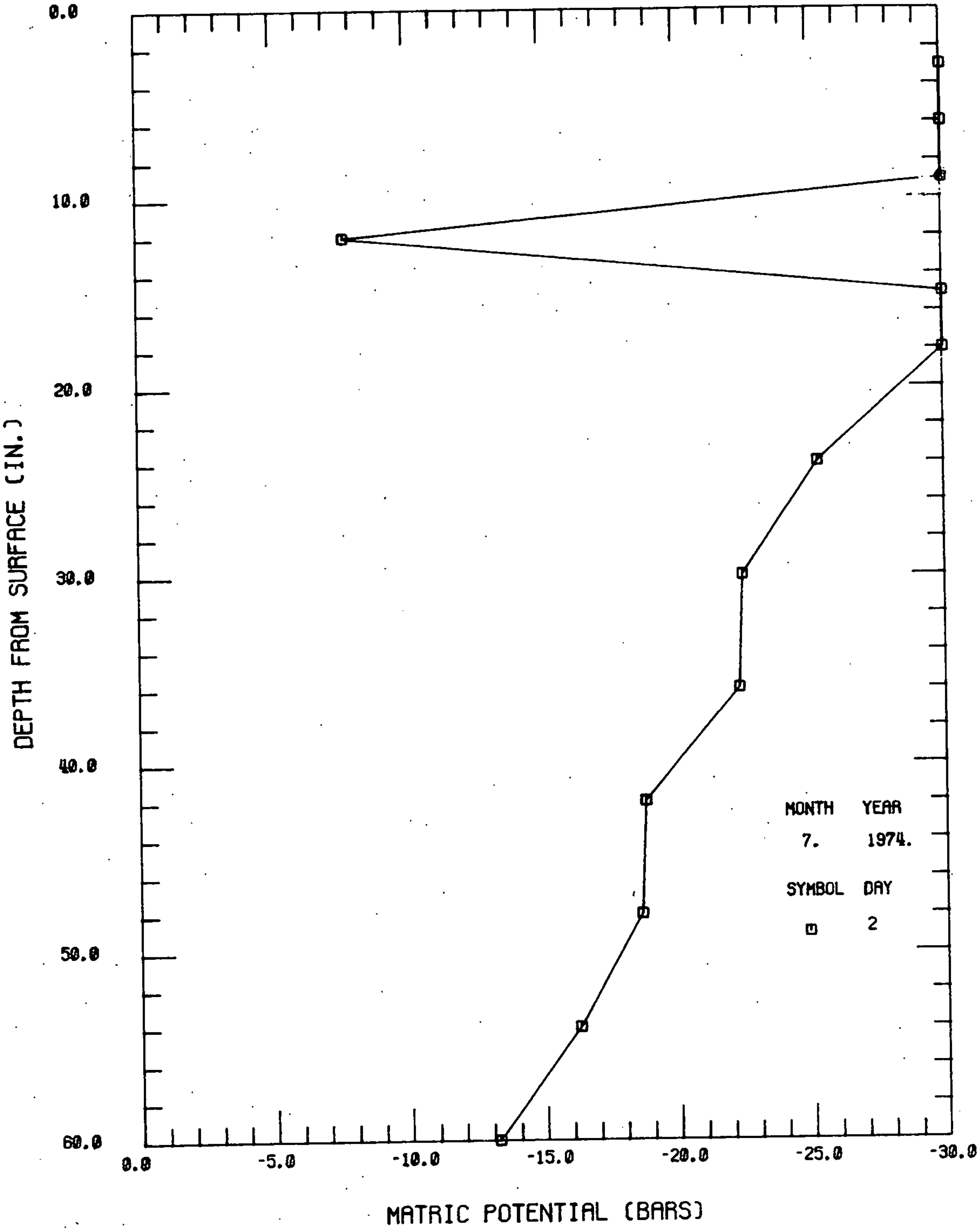


FIGURE 167

PROFILE OF MATRIC POTENTIAL TO 1.52-METER (60-Inch) DEPTH AT 32-49 HANFORD COORDINATES FOR JULY 1974

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