LYSIMETER EXPERIMENT DESCRIPTION
AND PROGRESS REPORT
ON NEUTRON MEASUREMENTS

Battelle

Pacific Northwest Laboratories
Richland, Washington 99352

1973

Prepared for the U.S. Atomic Energy
Commission under Contract AT(45-1):1830

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by

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1973

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SUMMARY

Two large lysimeters were installed in the soil of the Hanford Reservation to gather data on the accumulation and penetration of meteoric water. This report describes the construction details of this experiment. The soil hydraulic characteristics and data collected for the first 6 months are included.

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LYSIMETER EXPERIMENT DESCRIPTION AND PROGRESS REPORT ON NEUTRON MEASUREMENTS

INTRODUCTION

The lysimeter experiment was designed to provide evidence to prove or disprove the hypothesis that meteoric water percolates down to the water table at the 200 Area plateau on the Hanford Reservation. It is currently believed that there is no net percolation; proof of this opinion is important to the long-term safety of radionuclides stored in the vadose zone of the 200 Area plateau. If the annual average precipitation is greater than the annual average evapotranspiration, there will be a net accumulation of water in the vadose zone which will eventually percolate down to the groundwater table.

This water conservation or water balance approach to the problem is simple in theory, but it is difficult to measure the values of the components (evapotranspiration, percolation, and water vapor flow) with sufficient accuracy to determine the direction of net moisture movement. If a representative sample of soil is isolated so the soil column can be weighed, the amount of evapotranspiration can be directly measured by the decrease in weight. Such an installation is often called a weighing lysimeter. If the soil column in the container has sufficient length and diameter, the error introduced by wall effects can be made small. Unfortunately, this requires the lysimeters to be huge in terms of soil mass (approximately 200 metric tons). This enormous weight poses a serious technical problem for a balance; i.e., to weigh the mass to the degree of accuracy required to detect a small change in weight resulting from the decrease or increase of soil water. The cost of such an installation would be prohibitive. To circumvent these difficulties, two modified lysimeters were constructed which use soil psychrometers and temperature transducers instead of an actual weighing balance to measure changes in moisture content in the lysimeter.

The lysimeters may be visualized as cylindrical cores of the vadose zone soil isolated by walls from the influences of horizontal moisture transport. One of the lysimeters was constructed with a closed bottom to prevent interchange of moisture with the vadose zone. Thus, if the average annual precipitation exceeds the average annual evapotranspiration, the moisture content near the bottom of this lysimeter should increase since the net moisture movement to the water table is prevented by the closed container. On the other hand, if the

average annual precipitation is less than the average annual evapotranspiration, the moisture content in the lysimeter should decrease since moisture movement into the lysimeter from the vadose zone would be prevented by the closed container.

An open bottom lysimeter was constructed to provide data to support the results obtained from the closed lysimeter. In this case, the natural water potential gradient and water content profile can be measured. Since the soil within the lysimeter is uniformly mixed, the water flux can be estimated using the hydraulic conductivity and the water content and potential profiles. The magnitude and direction of the soil moisture flux should provide corroborative information concerning the net water movement.

The modified lysimeters of 3 meters (10 feet) diameter and 18.3 meters (60 feet) depth were filled with well-mixed local soil. Each lysimeter was fitted with three aluminum tubes 63 feet long for neutron probe access for soil moisture content measurements and three instrumented cables consisting of soil psychrometers and thermocouples for water potential and soil temperature measurements. In addition, a number of small diameter stainless steel tubes were installed for measuring atmospheric pressure at various soil depths.

INSTALLATION OF THE LYSIMETERS

The installed lysimeters and measuring instrument room are located about 3 miles southeast of 200 East Area or 300 feet northwest of Well 699-32-49D (see Figure 1) where a 310 foot instrumented cable with soil psychrometer and temperature diode transducer was installed in 1970. The site is a habitat for sagebrush (Artemisia tridentata) and cheatgrass (Bromus tectorum). Figure 2 shows the elevation view of the lysimeters and instrument room, while Figure 3 shows a plan view.

FIGURE 1. Map of Hanford Reservation Showing Approximate Location of the Lysimeters

FIGURE 2. Elevation View of the Lysimeter and Instrument Room

FIGURE 3. Plan of Lysimeter Complex Showing Relative Positions of Various Components

Construction of the Caissons

The sides of the caissons were constructed by screwing together sections of corrugated steel plate which were approximately 10 feet in diameter and 18 inches high (Figure 4). As excavation proceeded, sections of a corrugated steel plate were added so that the hole was always cased. When consolidated soil layers were encountered the soil directly under the caisson wall had to be removed manually (Figure 5). During construction, the excavated soil was piled in a mound to reduce the exposed surface and thus minimize the evaporation of soil water. After the caisson was constructed, the inside wall was sprayed with 1 inch of polyurethane to provide temperature and water insulation.

For the closed lysimeter a 20 cm thick concrete slab was poured to form the bottom and a 0.6 cm thick aluminum plate was placed on top of it. Six holes were bored through both the plate and slab so that instrumented cables and neutron access tubes could be extended through the caisson bottom and into the soil below.

Instrumentation

Soil Thermocouple Psychrometers

The soil thermocouple psychrometers were individually calibrated and only those within specified limits were used. They were assembled into six identical instrumented cables, with a steel cable inside as the axis. Three cables were installed in each lysimeter in a radial pattern, as shown in Figure 3. The temperature sensors were installed at depths of 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, 17.0, 18.0, 18.1, and 18.3 meters.

In addition to the above six cables, two additional cables were assembled, each with four pairs of lead wires extending 0.6 meter above the ground surface. These wires were used to measure soil temperature and air humidity at or just above the soil surface (Appendix A), data which are needed to conduct a water balance.

In the open lysimeter, soil psychrometer and temperature sensors extended through the lysimeter walls. These sensors were packed with mixed lysimeter soil and installed about 10 cm from the wall into virgin unmixed soil according to the following procedure: 4 inch ID plastic tube was forced through the opening in the lysimeter wall and into the soil outside the lysimeter to a depth of about 0.7 meter. The soil was then excavated from the plastic tube using a 3 inch soil auger. Lysimeter

FIGURE 4. Sections of Corrugated Steel Plate Were Used for the Caisson Cylinder Walls

FIGURE 5. Consolidated Soil Beneath the Caisson Wall was Manually Removed

soil was pushed to the front end of the plastic tube and the soil sensors put in place as more lysimeter soil was pushed in and packed around the sensors. A flat-end tool was pushed against the lysimeter soil inside the plastic tube while the tube was slowly withdrawn a small distance. The soil that had been excavated from the hole was pushed into the plastic tube as it was withdrawn. The process was repeated until the plastic tube was completely withdrawn. These installations were made at depths of 4.6, 9.2, 12.2, and 16.8 meters (Figure 2).

Soil Temperature Thermocouples

A copper-constantan thermocouple was attached to every soil thermocouple psychrometer in the instrumented cable described above, enabling soil temperature to be measured simultaneously with water potential.

Neutron Probe Tubes

Three 1.6 inch ID aluminum pipes (1-1/2 inch nominal size) were installed to a depth of 18.3 meters in each lysimeter to accommodate the Nuclear Chicago Neutron Moisture Probe. The bottom ends of the pipes were closed and they were placed radially at 0.5 meter. The axis of the neutron probe tubes was offset 60° from the axis of the psychrometer and temperature sensor cable (Figure 3).

Pressure Sensors

Fifteen pressure sensor tubes with openings at 0, 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 above the soil surface were bundled and installed radially 1 meter from the center of each lysimeter (Figure 3). The tube used in conjunction with the atmospheric pressure measurement was stainless steel and had a 0.125 inch OD. The remaining tubes had a 0.25 inch OD. The pressure sensor tubes exit the lysimeter at a depth of 3 meters through a 4 inch steel conduit which leads into the instrument room. Although 15 pressure sensor tubes were installed in each lysimeter (a total of 30 tubes), the pneumatic scanner considered is capable of recording only 24 readings. The final decision as to 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 is examined.

Instrument Room

The room for housing the recording and measurement instrumentation is to be buried approximately 1 foot below ground

level. This will eliminate possible climatological influences, such as interfering wind patterns, shading, etc., which may be associated with an above-ground structure. The room temperature will be controlled at 25°C, with a maximum deviation of $\pm 2^\circ\text{C}$. The humidity will also be controlled for the benefit of the equipment and a telephone will be installed for safety purposes.

Soil Preparation

Criteria established for the lysimeter soil required that it: 1) have homogeneous particle size distribution; 2) have uniform moisture content, preferably close to the original average soil water content; and 3) be representative of the soil of the site and general Reservation area. To meet these criteria, the soil excavated from the caisson was mixed thoroughly to achieve both uniform particle size distribution and soil water content. In addition, soil from the first 60 feet of nearby wells 2B(699-32-49B) and 2D(699-32-49D) was obtained and mixed with the excavated lysimeter soil to insure that enough soil was available to fill the lysimeter and provide an adequate sample for determining the soil hydraulic characteristics. This was accomplished in the following manner: the soil from the coring of the two wells was stored in a can at the site and added equally to the two piles of soil beside the caisson sites. Then equal amounts of soil were removed from the two soil piles by a loader, put into dump trucks, and transferred to the batch mixing plant at J. A. Jones Construction Company.

The batch plant has five hoppers, each with a capacity of 30 cubic yards. One is a loading hopper and feeds into four storage hoppers. The soil in the storage hoppers can be fed in measured quantities into the mixer, which has a capacity of 4 cubic yards.

The soil from the two lysimeter piles was transferred to two storage hoppers through the loading hopper. Two cubic yards of soil from each storage hopper were then fed into the mixer and mixed for 3 minutes. This mixed soil was then fed into the remaining two empty hoppers. This process was repeated until the two hoppers that were initially full were empty. Then 2 cubic yards of previously mixed soil from each storage hopper were returned to the mixer and mixed again for 1-1/2 minutes to achieve better uniformity. The completely mixed soil was transported back to the lysimeter site where it was mounded to minimize the surface area. The procedure was repeated until all of the soil for the lysimeter had been mixed.

Fifteen 30-gallon cans were filled with soil taken directly from the mixer. This soil was used for soil moisture calibration with the neutron moisture probe and for derivation of soil desorption curves by a pressure membrane and plate.

Filling of the Lysimeters

The instrumented cables, aluminum neutron tubes, and pressure sensor tube bundles were hung in the lysimeters in the pattern shown in Figure 5. To straighten and anchor the cables, a 500 gm lead brick was tied to the bottom of each cable and buried in the soil. The relative positions of the aluminum neutron tubes were maintained by two pieces of triangle-shaped plywood with holes at each corner to accommodate the tubes. These two plywood triangles held the tubes at the top and bottom of the caisson. The bottom plywood triangle was moved up as the lysimeter was filled.

At the bottom of the closed lysimeter were six openings in the aluminum plate and cement slab through which the aluminum tubes and instrument cable passed into the soil beneath the caisson. After the tubes and cables were in place, 5 cm of sealing compound and 3 cm of epoxy were applied to the openings to insure complete waterproofing.

The closed lysimeter was the first filled. A dozer with a bucket mixed the soil to equalize the soil moisture and then transferred the soil into a hopper. The soil was transferred from the hopper into the lysimeter through an 18-inch diameter plastic tube which extended to the bottom of the lysimeter. The bottom end of the plastic tube was manually placed to direct the placement of the soil and the end of the tube was cut off as the caisson was filled.

A metal stairway with a guard rail was welded to the wall of the caisson for access to the bottom of the lysimeter during filling. The stairway was also cut off as the lysimeter was filled and was eventually eliminated to prevent potential thermal conduction.

The sensors were hand-packed during the filling operation to minimize breakage as well as to ensure good contact between the sensors and the soil.

After every 2 feet of filling, tamping tools were used to compact the soil. Three holes were bored to a depth of 4 feet with a long auger after every 4 feet of filling; soil from these holes was mixed and samples were stored in two 1/2-gallon glass bottles. Soil water contents of these samples were subsequently determined.

After filling and packing of the closed lysimeter, the surrounding soil was graded and leveled. The open lysimeter was filled in the same manner.

During construction of the lysimeters the natural vegetation in the area was destroyed. Therefore, it is anticipated that the behavior of soil water in this area will be similar to that which has been observed to occur in summer fallow in dry-land farming regions. Under such conditions, winter precipitation can penetrate into the soil to appreciable depths. However, since the surface is devoid of deep-rooted plants, evaporation during the summer can only remove the fraction of the soil water which is near the land surface. Where deep-rooted plants are present, their root systems can draw out soil water from as deep as 40 to 50 feet.

In 1971 wild rye seeds were sown, but all of the seeds and seedlings were apparently eaten by mice and rabbits even when protected by a cheesecloth cover. Cheatgrass seed was sown over the area in May of 1972.

SOIL CHARACTERISTICS AND CALIBRATION

The water contents of the soil in the fifteen 30-gallon cans taken during the soil mixing operation are reported in Table 1. These water contents are assumed to be relatively uniform after mixing.

The soil water contents measured from the soil samples taken at 4-foot intervals during the lysimeter filling operation are reported in Table 2.

The soil was sampled in sequence from the bottom (50-60 foot depth) to the top of each lysimeter. The first few samples from the 35-60 foot depth show the same level of water content as the sample taken directly from the mixer of the batch mixing plant. However, soil samples taken at higher levels show the effect of winter rain and snow on the soil water content, particularly near the top of the open lysimeter. In the future such installations should be made at least 2 months earlier to avoid the effects of winter rain and snow.

DESORPTION CURVE AND HYDRAULIC CONDUCTIVITY

The desorption curve of the lysimeter soil (Figure 6) was determined from pressure plate measurements. Each data point is the average of 12 subsample measurements. The hydraulic conductivity as a function of water potential which was calculated using the desorption curve and the saturated permeability is reported in Figure 7. The methodology for calculating the hydraulic conductivity function is described in another report.¹

TABLE 1. WATER CONTENTS FROM SOIL DURING MIXING OPERATION*

<u>Can Number</u>	<u>Average Water Percent by Weight</u>
1	2.3
2	2.9
3	2.7
4	2.6
5	2.3
6	2.3
7	2.5
8	2.8
9	2.5
10	2.4
11	2.3
12	2.4
13	2.9
14	2.5
15	<u>2.1</u>
Total Average	2.5

*Each reported value is the average of four samples.

TABLE 2. SOIL WATER CONTENTS OF LYSIMETERS AT TIME OF FILLING*

<u>Soil Depth (in feet)</u>	<u>Percent Soil Water by Weight Closed Lysimeter</u>	<u>Open Lysimeter</u>
0-5	3.4	7.4
5-10	3.5	5.8
10-15	3.2	4.6
15-20	3.3	4.3
20-25	3.1	3.7
25-30	2.8	3.6
30-35	3.1	3.5
35-40	2.8	2.9
40-45	2.4	3.2
45-50	2.4	3.2
50-55	2.5	3.1
55-60	2.6	3.2

*Each value is the average of four or eight subsamples.

FIGURE 6. Desorption Curve for Lysimeter Soil (each data point is the average of twelve subsamples)

FIGURE 7. Hydraulic Conductivity Versus Suction Head for Lysimeter Soil

CALIBRATION OF THE NEUTRON PROBE

Four 55-gallon oil drums were used as soil containers for calibration of the neutron probe since such probes have an influence sphere of approximately 8 to 12 inches radius in soils. A section of the same kind of aluminum pipe used in the lysimeters was centered in the oil drums and the drums were filled with the lysimeter soil from the fifteen 30-gallon cans. The soil water contents were adjusted for the calibration procedure by adding a known volume of water to some samples and drying others by spreading the soil on the ground. The soil was well mixed before it was packed into the 55-gallon drums. The drums were then covered, sealed, and allowed to come to equilibrium for approximately 4 days. Then the thermo-neutron activity was measured 4 times at 2 inch intervals from the surface to the bottom of each drum. A soil auger was used to obtain samples from these drums for water content determination. Three cores were augered from each drum.

The calibration curve for the neutron probe determined in these tests is shown in Figure 8. Water content is expressed on a volume basis; i.e., weight of the water content multiplied by 1.6 (the soil bulk density).

The count ratio, or the actual count divided by the "standard count" of the instrument, is used instead of the actual count rate. Since any factor which affects the actual count rate will also affect the "standard count" rate, use of the count-ratio method can minimize the error introduced by the ambient or internal factors on the scaler.

Based on the neutron count-moisture calibration curve, the following equation converts neutron counts per minute into percent by volume of soil water content:

$$\text{soil water percent by volume} = \frac{\text{field neutron counts/min.} \times 22.0}{\text{scaler's standard counts/min.}}$$

FIELD DATA AND ANALYSIS

At the present time the atmospheric pressure sensor measuring system is awaiting completion of an instrument room. The measurements of the soil thermocouples (which are inherently very sensitive to ambient temperature changes) and psychrometers were discontinued due to erratic readings. The construction of the instrument room is essential for collection of meaningful data.

FIGURE 8. Calibration Curves for Neutron Probe

Neutron moisture measurements have been made regularly. The neutron probe readings of the lysimeters were translated into percent water content by volume by the neutron calibration curve equation. The results of the neutron measurements of soil moisture content in the lysimeter soil profiles are reported in two sets of figures. Figures A-1 through A-14 are for the open lysimeter during the period of March 13 to the middle of August, and Figures B-1 through B-14 are for the closed lysimeter for the same period. The open lysimeter had a higher initial water content than the closed lysimeter; however, the difference has been diminishing since the first measurements on March 13, 1972.

A record-breaking rain (1.39 inches in a 24-hour period) occurred on May 20-21, 1972, which affected the water content in the upper portion of the soil profiles. By comparing May 15th and May 26th moisture profiles one can observe that on May 26th the wetted front of the rain water passed through the 3'11" depth but not the 5'11" soil depth in the open lysimeter, while it just passed through the 5'7" soil depth of the closed lysimeter.

In order to observe the general trend of water content changes of a given soil depth (i.e., whether the soil is becoming drier or wetter), one can replot the data as curves of the mean water content against time for a given soil depth.

Despite the record-breaking precipitation in May of 1972, a definite general drying trend is evident for both the open and closed lysimeters during the period of March 13 to August 15, 1972. Figures C-1 through C-8 (Appendix C) show plots of the water content change as a function of time for each soil depth in each lysimeter. This drying trend should continue through summer until the advent of the fall and winter moisture cycle. The data from the closed lysimeter are of particular interest since there is no water exchange between the soil inside and the soil outside. The decrease of water (as indicated by neutron measurement) in the soil profile should be equal to the loss of water to the atmosphere.

The neutron readings imply that the amount of water decrease is about equal for soil at lower levels in the lysimeters and the soil beneath the bottom of the closed lysimeter. The cause of this anomaly is unknown at present; soil water under the bottom plate of the closed lysimeter was expected to act differently from the soil water inside. The neutron scaler was temperature compensated and all field readings expressed as ratios to the standard reading before being converted into water content. This procedure should correct for any variation in electronics or ambient temperature effects on the neutron scaler.

Despite the unexplained phenomena, the trend of decreasing water content over the whole soil profile is reasonable, particularly for the open lysimeter soil. This result is encouraging.

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1. Reisenauer, A. E. "Calculation of Hydraulic Conductivity From Soil-Water Retention Relationships," BNWL-1710, 1973.

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APPENDIX A

WATER PROFILES IN OPEN LYSIMETERS

FIGURE A-1. Water Profile in Open Lysimeter on 3/13/72

FIGURE A-2. Water Profile in Open Lysimeter on 3/21/72

FIGURE A-3. Water Profile in Open Lysimeter on 4/4/72

FIGURE A-4. Water Profile in Open Lysimeter on 4/12/72

FIGURE A-5. Water Profile in Open Lysimeter on 4/18/72

FIGURE A-6. Water Profile in Open Lysimeter on 4/25/72

FIGURE A-7. Water Profile in Open Lysimeter on 5/1/72

FIGURE A-8. Water Profile in Open Lysimeter on 5/15/72

FIGURE A-9. Water Profile in Open Lysimeter on 5/26/72

FIGURE A-10. Water Profile in Open Lysimeter on 6/13/72

FIGURE A-11. Water Profile in Open Lysimeter on 6/26/72

FIGURE A-12. Water Profile in Open Lysimeter on 7/17/72

FIGURE A-13. Water Profile in Open Lysimeter on 8/1/72

FIGURE A-14. Water Profile in Open Lysimeter on 8/15/72

APPENDIX B

WATER PROFILES IN CLOSED LYSIMETERS

FIGURE B-1. Water Profile in Closed Lysimeter on 3/14/72

FIGURE B-2. Water Profile in Closed Lysimeter on 3/21/72 and 3/22/72

FIGURE B-3. Water Profile in Closed Lysimeter on 4/4/72

FIGURE B-4. Water Profile in Closed Lysimeter on 4/12/72

FIGURE B-5. Water Profile in Closed Lysimeter on 4/18/72

FIGURE B-6. Water Profile in Closed Lysimeter on 4/25/72

FIGURE B-7. Water Profile in Closed Lysimeter on 5/1/72 and 5/3/72

FIGURE B-8. Water Profile in Closed Lysimeter on 5/15/72

FIGURE B-9. Water Profile in Closed Lysimeter on 5/26/72

FIGURE B-10. Water Profile in Closed Lysimeter on 6/14/72

FIGURE B-11. Water Profile in Closed Lysimeter on 6/27/72

FIGURE B-12. Water Profile in Closed Lysimeter on 7/17/72

FIGURE B-13. Water Profile in Closed Lysimeter on 8/1/72

FIGURE B-14. Water Profile in Closed Lysimeter on 8/15/72

APPENDIX C

OPEN LYSIMETER - WATER CONTENT CHANGE VERSUS TIME

FIGURE C-1. Open Lysimeter - Water Content Change Versus Time for 2'7", 8'11", 35', and 58' Soil Depth

FIGURE C-2. Open Lysimeter - Water Content Change Versus Time for 2'11", 15'4", 41'8", and 61'3" Soil Depth

FIGURE C-3. Open Lysimeter - Water Content Change Versus Time for 3'11", 22', 48'2", and 62'3" Soil Depth

FIGURE C-4. Open Lysimeter - Water Content Change Versus Time for 5'7", 28'6", 54'9", and 63' Soil Depth

FIGURE C-5. Closed Lysimeter - Water Content Change Versus Time for 2'7", 8'11", 35', and 58' Soil Depth

FIGURE C-6. Closed Lysimeter - Water Content Change Versus Time for 2'11", 15'4", 41'8", and 61'8" Soil Depth

FIGURE C-7. Closed Lysimeter - Water Content Change Versus Time for 3'11", 48'2", 22', and 62'3" Soil Depth

FIGURE C-8. Closed Lysimeter - Water Content Change Versus Time for 5'7", 28'6", 54', and 63' Soil Depth

APPENDIX D

TEMPERATURE MEASUREMENTS OF
NEAR-SURFACE SOILS

FIGURE D-2. The Effect Artificial Shading of the Temperature Sensors has on the Temperature Profile

APPENDIX D

TEMPERATURE MEASUREMENTS OF NEAR-SURFACE SOILS

In the calculation of evaporation, the temperature at the soil surface as well as the air temperature just above the soil surface must be known. Standard temperature sensors are unsuitable since they have too large a heat capacity and their heat absorption and reflection characteristics are different from those of the soil to be measured. Therefore, a new kind of temperature sensor was developed. Small transistors of 2 mm diameter were dipped into transparent epoxy, then completely coated with surface soil from the test site from which the larger soil particles were removed. Care was taken to avoid any coating of epoxy on the exposed particle surface to prevent change in the optical characteristics of the surface.

Ten of these soil-coated transistors were installed at the site 30 cm away from Well 2D. Six of the ten transistors were supported by a small stick above ground at <.5 cm, 1 cm, 2.5 cm, 5 cm, 10 cm, and 30 cm levels. The remaining four transistors were buried at <.5 cm, 1 cm, 2.5 cm, and 5 cm depths.

In a series of temperature measurements made on May 2, 1972, a pronounced difference occurred in temperature profiles between measurement times, as shown in Figure D-1. The maximum temperature difference just above and just below the soil surface was 8°C. The air temperature variation at 1 cm above ground was greater than 8°C. The soil just beneath the surface was 20°C warmer than the soil 5 cm beneath the surface. Data points below 30 cm were taken from the instrumented well.

Figure D-2 shows the effect of artificial shading on the temperature sensors (by a notebook) starting at 11:10 a.m. The temperature near the soil surface decreased by 11°C in five minutes, while the temperature just beneath the surface decreased by only 2°C. This reversed the thermal gradient at the soil surface.

In summary, temperature at the soil surface and away from the surface varies significantly. It is the surface temperature that controls the evaporation rate.

FIGURE D-1. Air and Soil Temperature Profiles at 9:30 a.m. and 3:20 p.m. During a Sunny Day

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