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UNSATURATED ZONE MOISTURE AND VAPOR MOVEMENT INDUCED BY TEMPERATURE VARIATIONS IN ASPHALT BARRIER FIELD LYSIMETERS

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Protective barriers are being considered for use at the Hanford Site to enhance the isolation of radioactive wastes from water, plant, and animal intrusion. Lysimeters were constructed to evaluate the performance of asphalt barrier formulations under natural environmental conditions. These lysimeters (Figure 1) were constructed of 1.7-m lengths of PVC pipe that have a diameter of 30 cm. The lysimeters were filled with layers of gravel, coarse sand, and asphalt (Freeman and Gee 1989a). The sand and gravel placed under the asphalt barrier were wet when installed (Freeman and Gee 1989b). TOUGH was used to conduct simulations to assess the effect of temperature variations on moisture and vapor movement beneath the asphalt layer in field test lysimeters. All variables in TOUGH were converted to double precision so that simulations could be run on a Sun-4 UNIX workstation. A radially symmetric grid (Figure 2) was used to simulate the lysimeter.

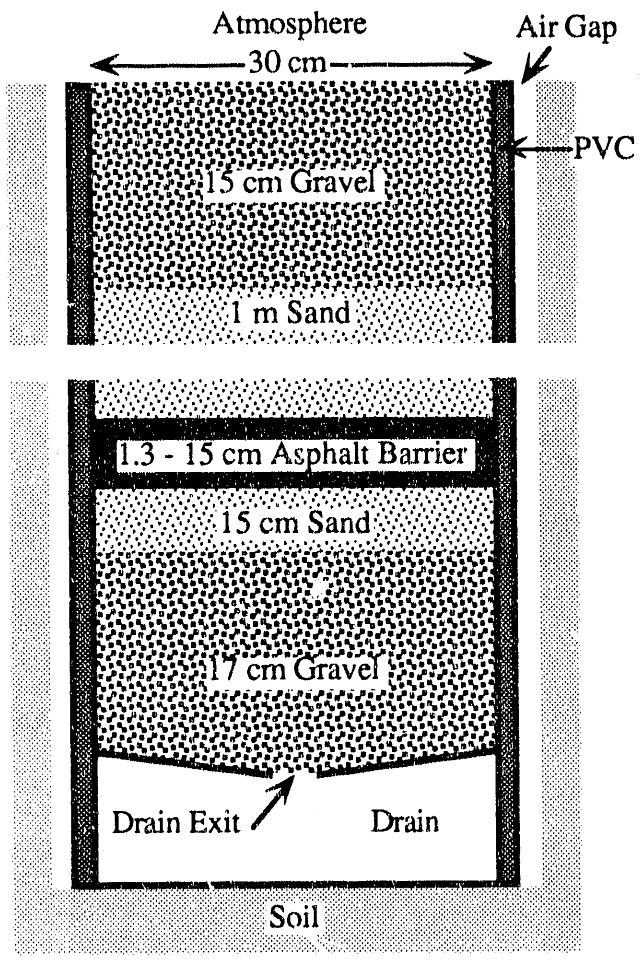

Figure 1: Cross Section of Lysimeter.

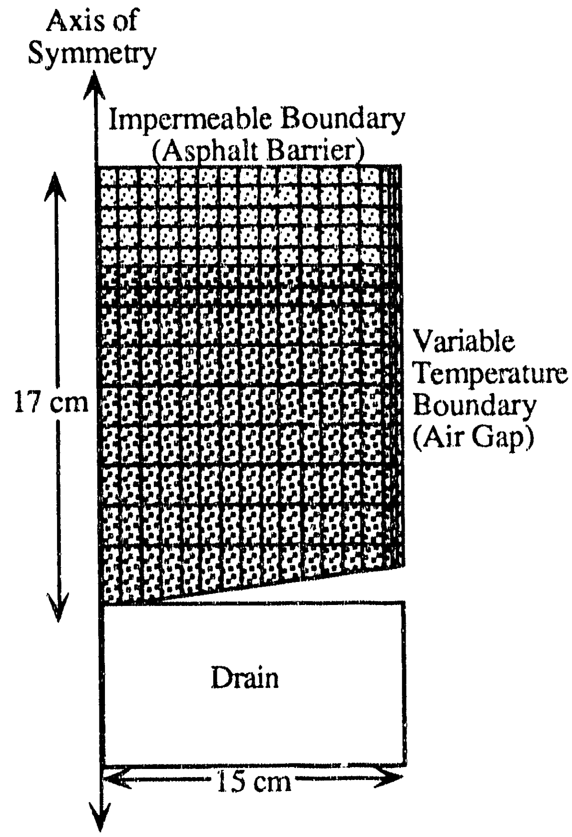

Figure 2: Cross Section of radial grid (Scale 2x that of Figure 1).

Figure 3 shows measured monthly water drainage from a control lysimeter (with no asphalt layer) for the 2-year period since the lysimeter was installed in July 1988. Also shown is the average monthly rainfall and soil temperature measured at a nearby site (Stone et al. 1983). Because there is no barrier to impede infiltration, drainage correlates to rainfall with a lag time of one month.

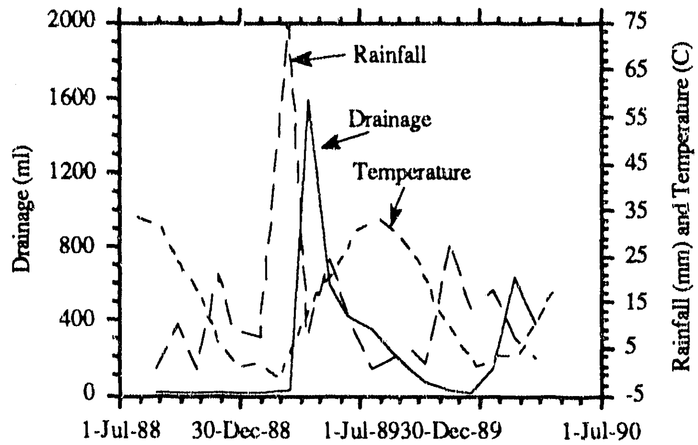

Figure 3: Drainage from lysimeter #9 (control) compared with average monthly rainfall and soil temperature at 1.3 cm depth.

Figure 4 shows drainage from a lysimeter with a rubberized asphalt layer compared with the same rainfall and temperature data shown in Figure 3. Unlike the control lysimeter, drainage correlates to temperature. Also, the amount of drainage is small compared with the control lysimeter and shows no correlation with rainfall. For these reasons, we hypothesize that the drainage water is not from leakage through the barrier, but is residual water from the installation of the barriers. This hypothesis is further borne out by the fact that salt placed above the asphalt barrier has not been found in the drainage water.

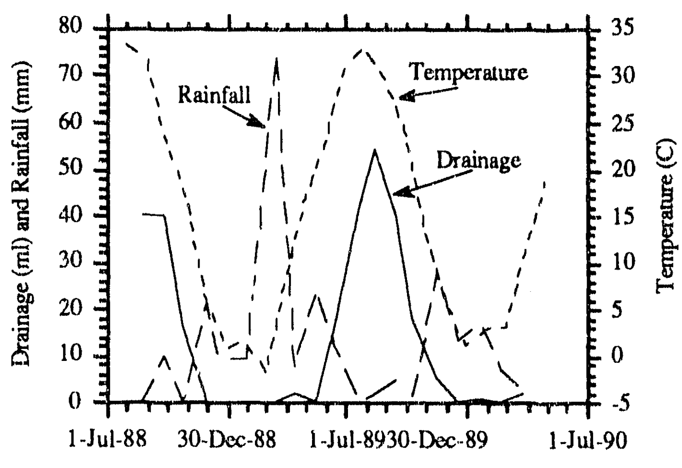

Figure 4: Drainage from lysimeter #2 (rubberized asphalt barrier) compared with average monthly rainfall and soil temperature at 1.3 cm depth.

TOUGH was used to conduct two axi-symmetric simulations of the lysimeter to assess the effect of temperature variations on water movement in the liquid and vapor phase beneath the asphalt layer. In the first simulation, the lysimeter temperature was maintained at a constant temperature of 15.3 °C (the yearly average soil temperature). For the variable temperature simulation, the average monthly temperature at 1.3 cm depth (Figure 5) was applied along the side boundary of the model (Figure 1). The drain was held at a constant temperature of 15.3 °C. The initial temperature throughout the entire system was 32.9 °C (the average July soil temperature). The initial water saturation for the sand layer was 90% and the gravel layer was 10%.

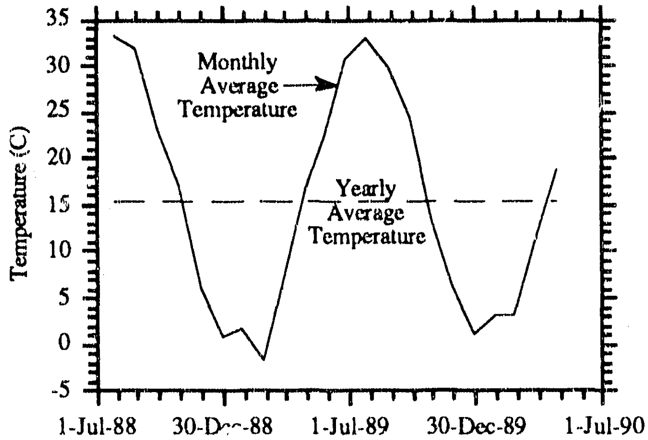

Figure 5: Monthly and yearly average temperatures at 1.3 cm depth in soil at the Hanford Meteorological Station.

Thermal conductivities at saturated and dry conditions (0.29 and 2.2 W/m°C) were estimated from properties for average soils (Hillel 1980). Specific heat of quartz (Hillel 1980) was used for the sand, and specific heat of granite (Weast 1982) was used for gravel. Nodes next to the variable temperature boundary were given a large (10^8) specific heat so that they would remain at the specified temperature.

The parameters used for the hydraulic properties of the soils (Table 1) are for van Genuchten moisture retention and Burdine hydraulic conductivity functions (van Genuchten 1980). The coarse sand parameters were fit to data for coarse sand from the literature (Mualem 1976), and the gravel parameters were fit to estimated gravel properties from (Fayer et al. 1985).

Table 1. Parameters for Describing Hydraulic Properties with the van Genuchten Functions

Material	S_{lr}	S_{ls}	α (1/Pa)	λ	K_s (m/yr)
Coarse Sand	0.02247	1.00	0.000741	0.64331	1.09×10^{-10}
Pea Gravel	0.01193	1.00	0.050365	0.54260	3.57×10^{-10}

Figure 6 shows a comparison of drainage predicted by constant temperature and variable temperature simulations.

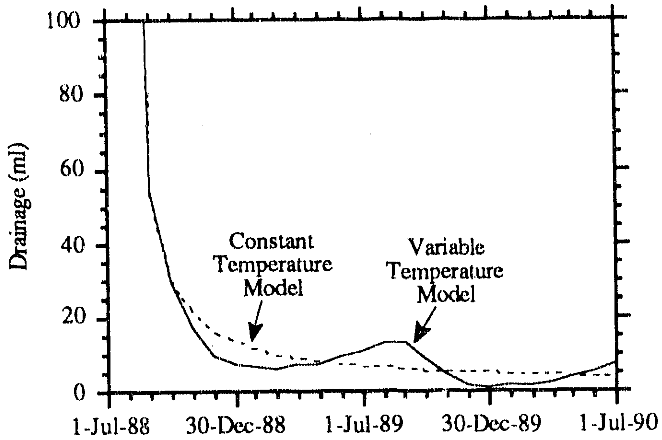

Figure 6: Comparison of drainage predicted by constant temperature and variable temperature simulations.

The variable temperature shows a decrease in drainage relative to the constant temperature simulation when temperatures are below the yearly average and an increase in drainage when temperatures are above the yearly average. However, the increase in drainage in summer is not as great as actually observed in many of the lysimeters (Figure 7). Drainage from an asphalt barrier lysimeter reached a maximum of 54 ml in August 1989, whereas the simulated drainage for that month was 13 ml.

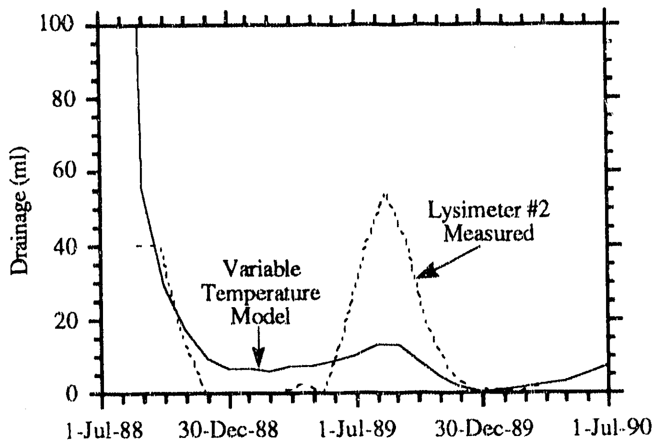

Figure 7: Comparison of drainage predicted by variable temperature model and measured from an asphalt barrier lysimeter.

The difference between the drainage rates in winter and summer is illustrated by the simulated flow fields for February and August 1989 in Figures 8 and 9. Overall, flow velocities are much higher in August than in February, delivering more liquid mass to the drain in the lower left-hand corner. The absolute temperature is much higher in August, with the highest temperature (32.8 °C) along the right-hand side and the lowest (29.4 °C) at the lower left-hand corner. The saturated vapor pressures are much higher in August, and the vapor pressure gradient is an order

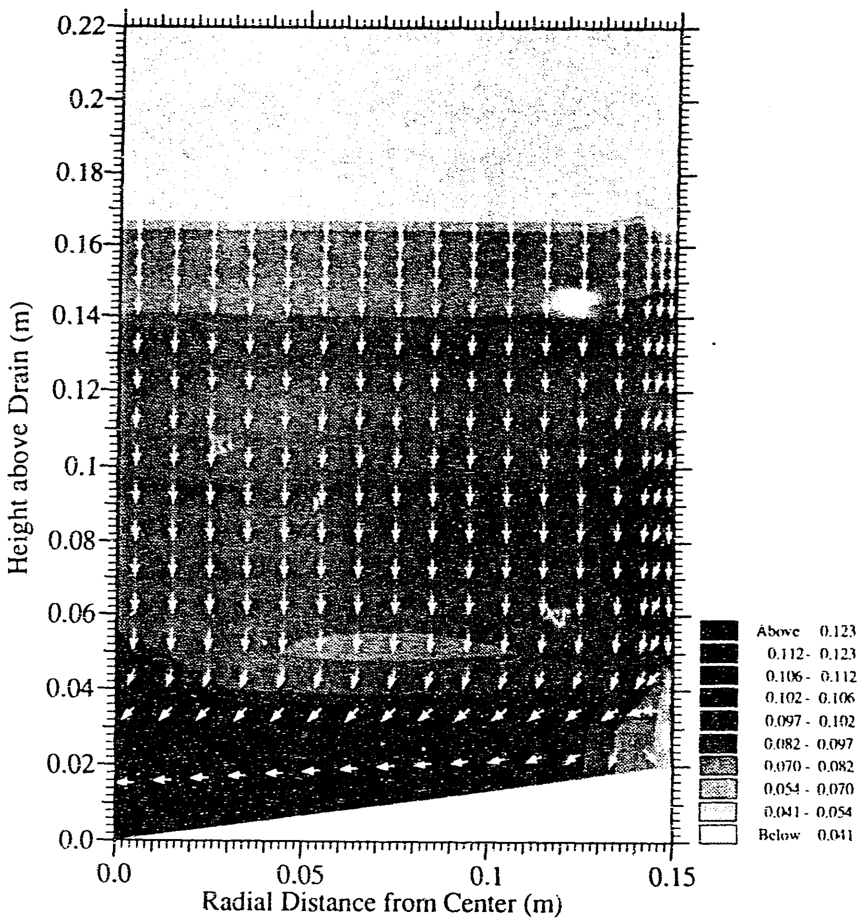

Figure 8: Simulated liquid velocities for February 1989 (minimum = 6.0x10-4, maximum = 2.8 m/yr)

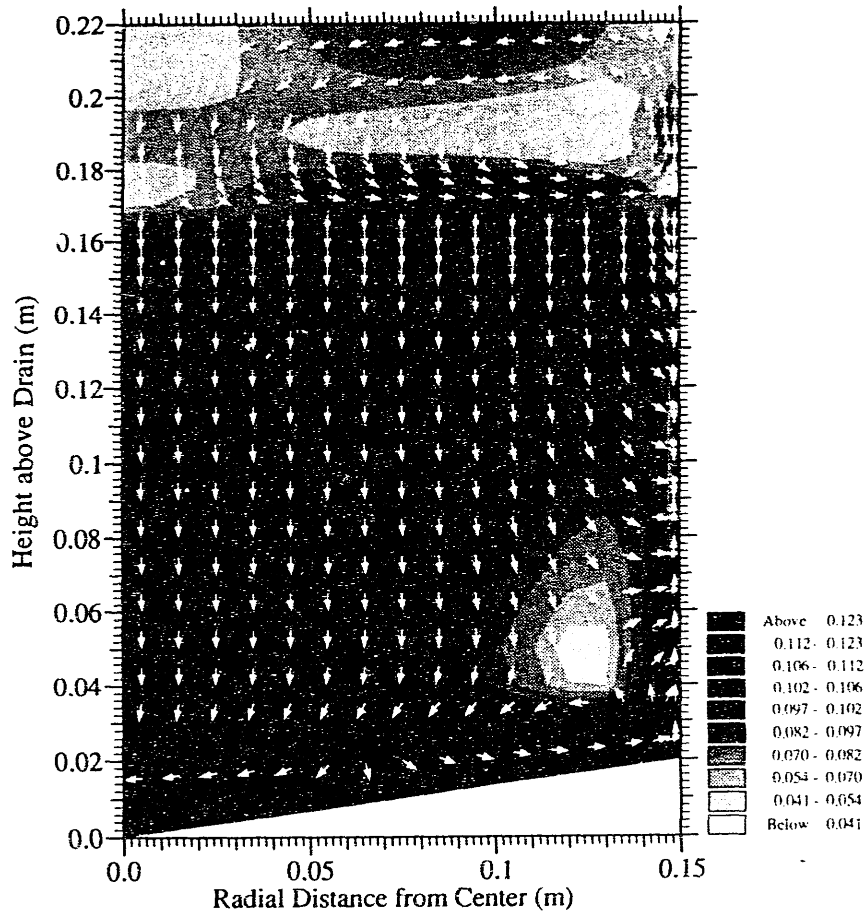

Figure 9: Simulated liquid velocities for August 1989 (minimum = 9.2x10-3, maximum = 6.6 m/yr)

of magnitude higher. The vapor pressure gradient in August follows the temperature gradient from the right-hand side to the lower left-hand corner, driving water in the vapor phase to the drain, where it condenses at the cooler drain temperatures. In August, the higher temperature along the right-hand side caused the column to dry out slightly, causing some upward flow along that side. This effect may have impeded the simulated drainage slightly.

The most interesting feature of the flow fields is the convection cell that formed in the wet, sandy layer. Because the dry, gravel layer acts as a barrier to downward flow of water, the water in the wet layer circulates because of liquid density differences caused by the temperature gradient across the system. The convection cell flows counterclockwise in the summer and clockwise in the winter; however, the convection cell flows counterclockwise during January and February because temperatures in the column are between 1.5 and 4 °C, and the density of water is highest at 4 °C.

The effect of temperature on the hydraulic conductivity of the soils was not included in this simulation, and this would enhance the differences in drainage simulated in winter and summer. Also, diurnal temperature variations could cause greater drainage to occur in the summer months, while freezing of soil moisture during the winter months would stop drainage from the column. Future simulations could include the effect of a temperature gradient in the air gap around the lysimeters, rather than imposing a uniform temperature. Also, simulations for individual months could be rerun using diurnal temperature variations rather than just the monthly average temperature.

Although the simulated drainage does not match the observed drainage in magnitude, the seasonal trends are the same. This provides supporting evidence that temperature variations can affect drainage of residual water from beneath the asphalt barrier in the lysimeters.

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