MILESTONE REPORT

EVALUATION OF PREFERENTIAL FLOW IN PLAYA SETTINGS NEAR THE PANTEX PLANT

(Activity No. 17 of Appendix C, Supplement to Scope of Work, 1992–1993)

INTRODUCTION

Problem

Analysis of water movement through the unsaturated zone is critical for understanding recharge and contaminant transport at DOE's Pantex Plant. Although preferential flow pathways such as root tubules, cracks, and fissures (Beven, 1991) may not be important volumetrically from a ground-water recharge standpoint, such flow may play a critical role in rapidly transporting contaminants to the ground water and bypassing much of the soil matrix. Previous studies found that flow along preferential pathways may be up to two orders of magnitude higher than that predicted by homogeneous flow models (Richard and Steenhuis, 1988). In order to accurately evaluate pathways for contaminant transport, it is necessary to understand the spatial distribution of preferential flow pathways. The objective of this study was to delineate the spatial distribution of preferential pathways and evaluate the controls on such pathways.

METHODS

Locations of test plots

All ponding tests are located in the TDCJ playa basin. This typical playa basin is located approximately 35 km (21.75 mi) northeast of Amarillo, Texas, or about 8 km (4.97 mi) northeast of the Pantex Plant. Plots 1 and 2 were sited in grasslands on the eastern slope of the playa basin, about 300 m (984.3 ft) east of the eastern shoreline of the playa lake, approximately 5 m (16.4 ft) south of the TDCJ 5 borehole (fig. 1). The soils are classified as Estacado clay loam (F. Pringle, personal communication, 1993), and the area does not appear to have been modified by cultivation. Plot 1 was constructed on the natural surface. Plot 2 was adjacent to plot 1, but the site was excavated using a bulldozer to 1 m below the ground surface before construction of the pond. Plot 2 was designed to evaluate preferential flow in the calcareous soil (Bk) horizon of the Estacado surface soil. Plots 3 and 4 were sited in the playa lake near its eastern edge (fig. 1). Plot 3 is 3 m (9.8 ft) and plot 4 is 23 m (75.5 ft) from the 1992 high-water line of the playa lake. Both of these tests were conducted in Randall clay soils. Plot 3 was located on the nearly flat floor of the playa lake. Plot 4 was located in the annulus of the lake, the gently sloping transitional shoreline. The annulus is marked by conspicuous zonation in the vegetation and is above a break in slope with the nearly flat playa lake floor and below a break in slope at the high-water line. These tests were conducted on June 1, 1993, several months after desiccation of the playa lake, and as summer rain began to pond in the center of the playa. In the months since the marginal part of the playa was flooded, a variety of plants colonized the originally bare clay floor of the lake. The soils at the surface in the area of plot 3 were moist to a depth of a few centimeters but contained large surface cracks that defined large polygons. Annulus soils near plot 4 were somewhat drier and cracks in the surface smaller, more irregularly distributed, and closer spaced.

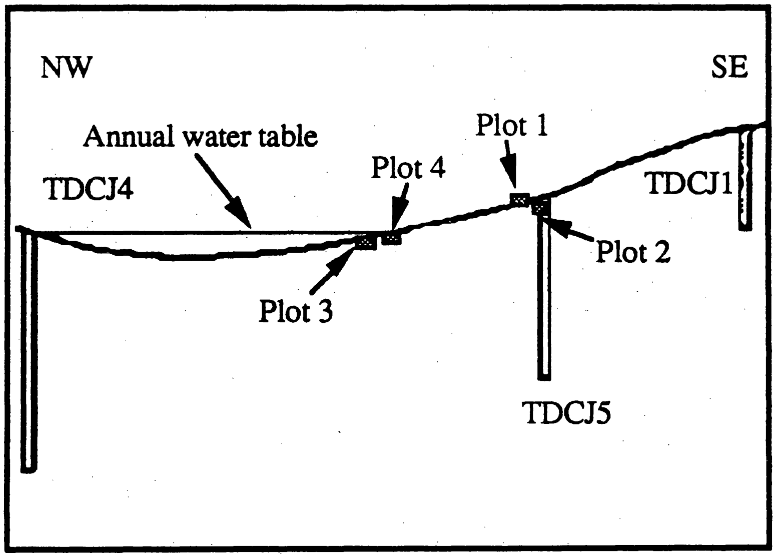

Figure 1. Schematic of ponding test locations at TDCJ playa.

Two ponding procedures were used. One is a constant hydraulic head, and the other is falling hydraulic head. To monitor water movement in the vadose zone, FD&C blue organic dye and $CaBr_2$ tracers were used.

PONDING TESTS

Test for Plot 1

Surface vegetation was removed from the test site prior to ponding. A wood frame (1 × 2 × 0.2 m [3.28 × 6.56 × 0.656 ft]) was constructed and lined with plastic to prevent leakage. The gap between the ground surface and the wood frame was backfilled with soil. A water tank (500 gal; 2.27 m^3) was used for the primary water supply. Two 50 L (13.21 gal) containers were used to mix the tracer. These containers were placed 1.2 m (3.94 ft) above the ground surface to provide a constant flow. A Dwyer flowmeter with a calibration range of 0.2272×10^{-4} to 1.1513×10^{-4} m^3/s (0.3 to 2 gal/min) was used to measure the flow rate while a constant head of 10 cm (0.328 ft) was maintained.

The water with blue dye in the container was supplied to the ponding plot with a garden hose. It took about 1.5 hr to reach a hydraulic head of 10 cm (0.328 ft). The initial flow rate was 0.378×10^{-4} m^3/s (0.5 gal/min). The constant head of 10 cm was maintained until a constant flow rate of 1.1513×10^{-5} m^3/s (0.2 gal/min) was attained, which took approximately 2 hr. Based on the results of laboratory experiments we intended to use a blue dye tracer concentration of 1% by volume; however, because heavy rainfall for 2 days prior to the ponding test almost saturated the soil and water stored in the soil would dilute the dye, we increased the blue dye concentration from 1.0% to 1.5%. For a hydraulic head of 10 cm (0.328 ft), the measured initial infiltration rate was as high as 1.893×10^{-5} m/s (6.21×10^{-3} ft/s). Then the rate gradually decreased, and the final measured infiltration rate was 7.57×10^{-6} m/s (2.484×10^{-3} ft/s).

Test for Plots 2, 3, and 4

The same preparation for the ponding test at plot 1 was followed for ponding tests at plots 2, 3, and 4. An initial hydraulic head of 0.18, 0.18, and 0.15 m (0.591, 0.591, and 0.492 ft) was used at plots 2, 3, and 4, respectively. Because tests at plots 2, 3, and 4 were conducted several weeks after the testing at plot 1, soil conditions were drier and a 1% concentration of blue dye was used for these tests.

The exact amount of time over which complete infiltration occurred at plot 2 was not measured; however, we know that infiltration was completed in less than 15 hr. This suggests that the average infiltration rate was more than 3.33×10^{-6} m/s (1.093×10^{-3} ft/s).

In plot 3, 0.12 m (0.394 ft) of water infiltrated into the subsurface soil in 18 hr. The average infiltration rate was 1.85×10^{-6} m/s (6.07×10^{-4} ft/s). In plot 4, only 0.10 m (0.328 ft) of water infiltrated into the soil after ponding for 16 hr. This resulted in an average infiltration rate of 1.74×10^{-6} m/s (5.71×10^{-4} ft/s).

RESULTS

Because of rain prior to ponding test 1, the soil in this test plot was initially quite wet. The initial water content is illustrated in figure 2a (the saturated water content was 0.43). The soil samples for water-content analyses were taken from a trench wall near the ponding area at every 0.2 m (0.656 ft) along a vertical transect. Figure 2a shows that the soil in the upper 0.1 m (0.328 ft) was close to saturation, but the soil below 0. 6 m (1.967 ft) was very dry. To show the water movement after ponding, 30 soil samples for water-content analyses were taken from the trench wall under plot 1 on a 0.2 m (0.656 ft) grid (the top soil was assumed to be saturated). Figure 2b illustrates the distribution of water content after ponding. These figures indicate that after infiltration for 6 hr, the water content in the upper 0.7 m (2.3 ft) increased significantly. The dye tracer distribution showed that matrix flow of the tracer occurred in the top 0.07 m (0.23 ft). Tracer distributions in the profiles of plots 3 and 4 showed that matrix flow was restricted to the top 0.01 or 0.02 m (0.0328 or 0.0656 ft) of the clayey Randall soils.

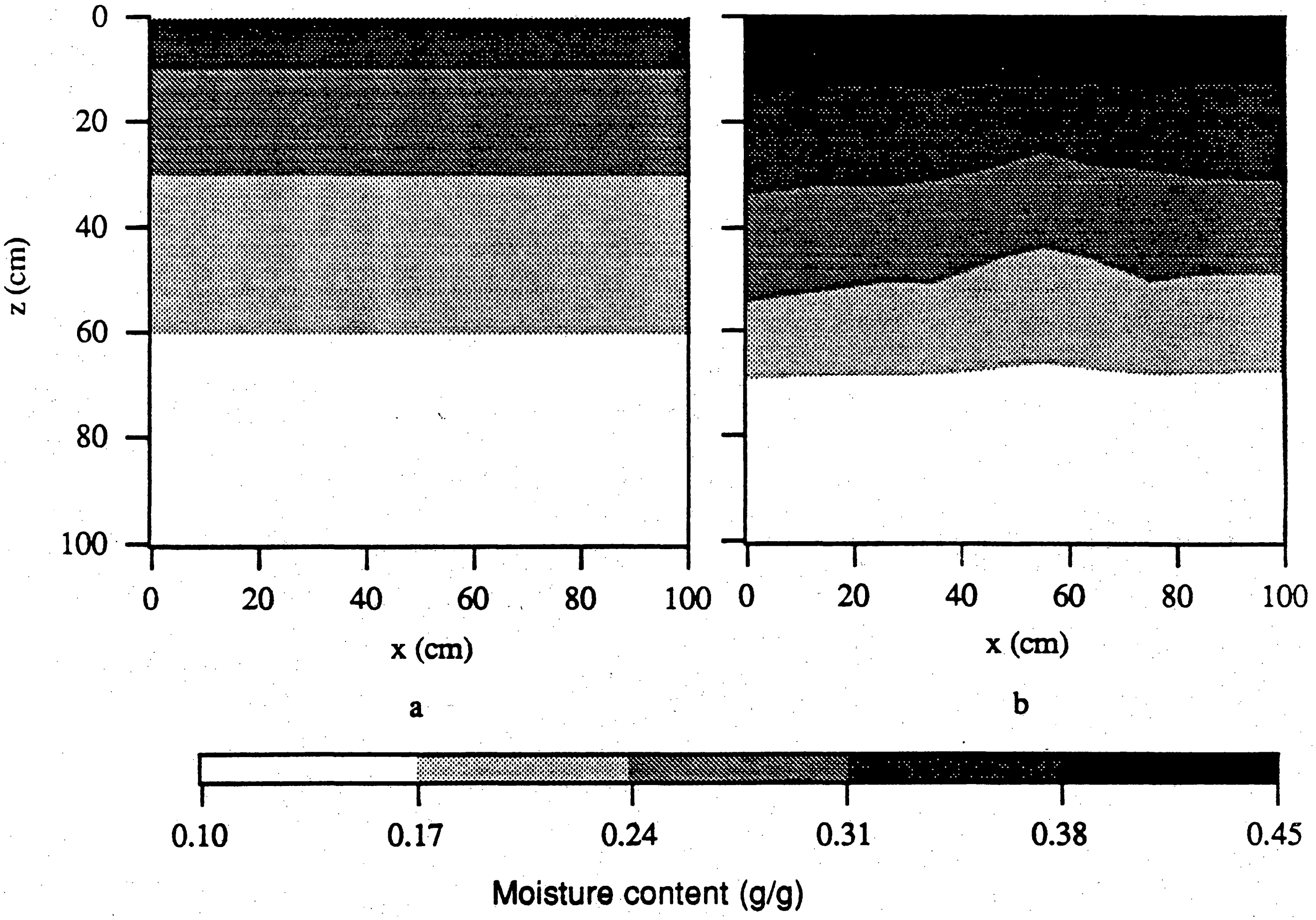

Figure 2. The spatial distribution of water content, a) the initial water content, and b) the water content after ponding 5 hours. The water content between measurements are interpolated bilinearly using Spyglass and shown as gray levels.

With the exception of the ponding test conducted at 1 m (3.28 ft) depth (plot 2), all the other ponding tests showed that preferential flow is a potentially important mechanism for transporting contaminants to the water table. Figure 3 illustrates the spatial distribution of pathways, which was observed from the exposed soil profile after the trench was excavated at plot 1. Blue-dyed preferential pathways were most abundant in the top 0.2 m (0.656 ft) and were less abundant at depths of 0.2 to 0.4 m (0.656 to 1.31 ft). No blue-dyed pathways were observed below 0.8 m (2.625 ft). At least three different types of pathways were observed in this plot (fig. 4a, b, and c): (1) root tubules, (2) cracks filled with dark, organic-rich clays, and (3) interconnected ped faces. Because the grass roots were most concentrated near the surface as a mat, these pathways are most important in this zone. The cracks filled with dark clays may serve as pathways for preferential flow. Dark organic material from the A horizon of the soil has been transported and deposited along the fractures. Ped surfaces are the natural blocky planes of weakness in the B horizon of the soil. Many of these surfaces have slickensided clay coats, indicating that they accommodate shrink-swell in the soil. They do not, however, contain organic material. The transmission of blue dye along these surfaces may be related to creation of 0.1 m (0.328 ft) of head in the pond. Normally, water does not pond in this slope environment and therefore organics are not illuviated along these interconnected ped surfaces. Travel velocity for the preferential flow is about 4 times that of matrix flow.

In plot 2, after 15 hr of ponding, the blue dye was widely distributed. Because the soil was initially very dry and the tension (the negative of the capillary pressure) was large, the capillarity of soil water resulted in strong downward movement under an initial hydraulic head of 0.2 m (0.656 ft). In this case, the travel velocity of the soil matrix flow is the same order of magnitude as that of the preferential flow. As the water saturation increases and soil tension decreases, water may flow primarily along preferential pathways similar to those shown in figure 4; however, because of the initial matrix flow, the dye was widely distributed, making it difficult to define any specific preferential pathway. Figure 5 also indicates that the water movement was nonuniform. This figure also illustrates that lateral flow was insignificant in this area.

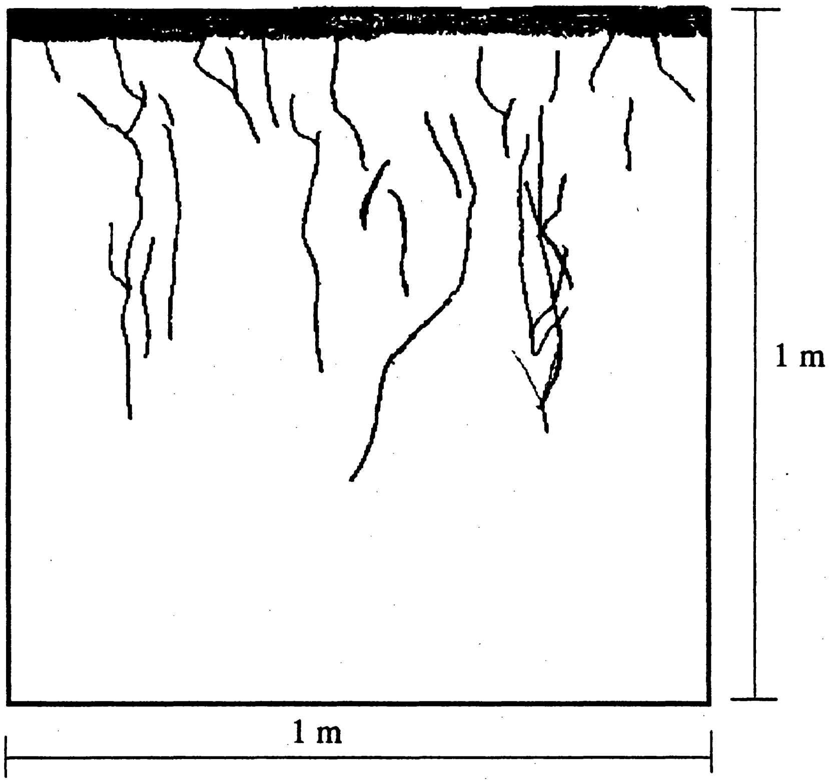

Figure 3. The spatial distribution of blue dyed preferential flow pathways, observed from the trench well of ponding Plot 1, at TDCJ playa.

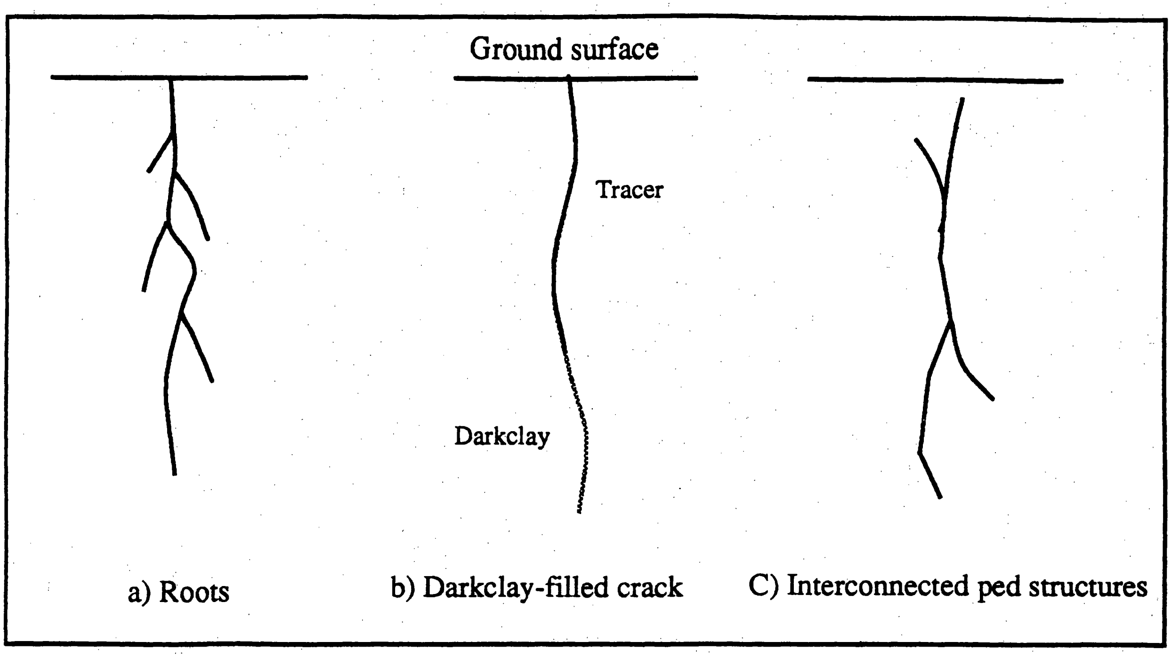

Figure 4. Three kinds of pathways observed at ponding test plot 1, at TDCJ playa.

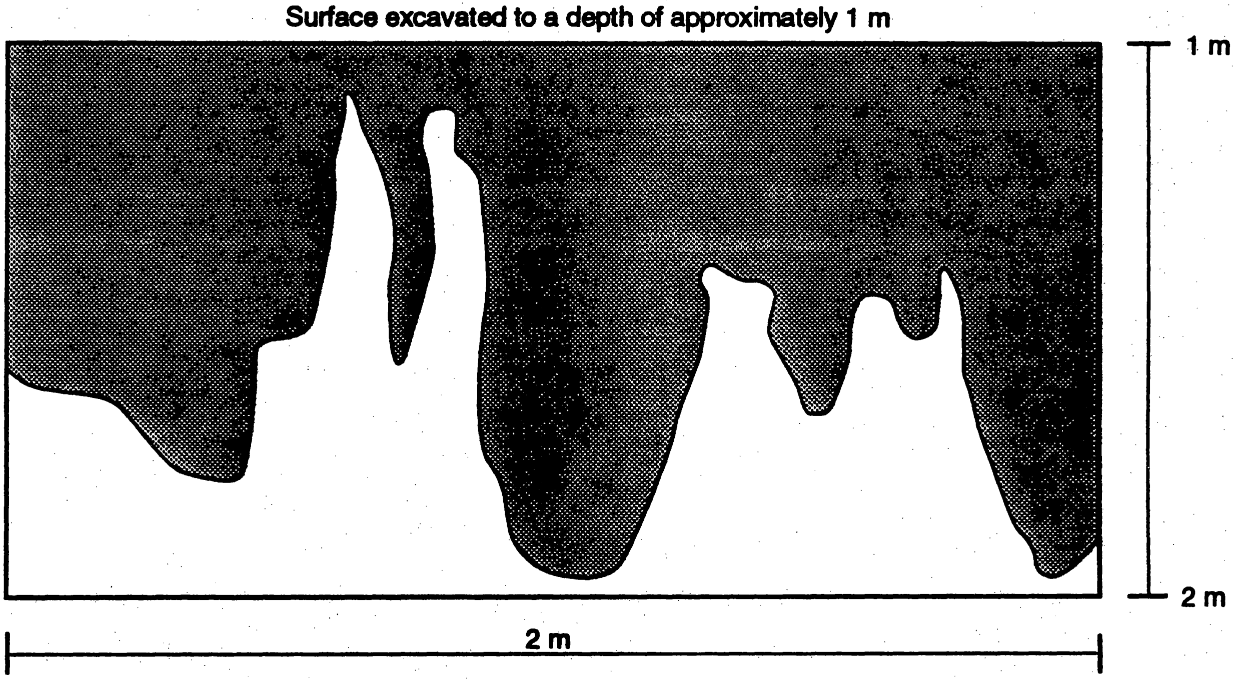

Figure 5. The spatial distribution of dyed area, mapped in the trench wall under ponding plot 2. The top of the profile is 1 m below the natural land surface, and is in the calcareous (B_k) horizon of the Estacado clay loam surface soil.

The spatial distribution of pathways in plots 3 and 4 is different from that in plot 1. First, there are many more blue-dyed pathways in plot 3 (fig. 6). These pathways occur mostly along roots and near-vertical planar soil structures. Second, there is a series of near-horizontal pathways. From field observation, most horizontal pathways consist of roots with a diameter of about 0.2 to 0.5 mm (0.0656 to 0.164 ft). The uppermost soil saturated by the tracer has a thickness of only 0.01 m (0.0328 ft), and the longest pathway observed in the profile in this plot is about 1.0 m (3.28 ft), which shows that the flow through the pathways may be two orders of magnitude faster than that through the soil matrix. The red-brown sediments beneath the dark Randall clay soils contain abundant dark, organic-rich, clay-filled cracks, indicating that the downward translocation of organics described in plot 1 has been active at greater than 1 m (3.28 ft) depth in the area of plot 3. These red-brown sediments were damp, in contrast to the lower parts of the soil profile at plots 1 and 2. Plot 4 (fig. 7) exhibits many large preferentially dyed areas and near-horizontal pathways. During preparation of the profile, we noted that most large dyed areas have a nearly two-dimensional sheet geometry. Some of these features were observed during excavation of plot 3 but were not well represented on the mapped trench surface. These near-vertical sheet-geometry soil structures were not visible as cracks prior to movement of the dye; however, there is sufficient permeability contrast along the structure to allow preferential flow. Vertical planar structures colored by blue dye have nearly the same strength under tension as the uncracked matrix. Presumably these cracks originated as desiccation cracks formed as a result of shrink and swell of the Randall clay soils, and the permeability enhanced by films or microstructures that are retained when the cracks are closed by hydrated swelling clays. Additional examination of the soil structure is needed. Open cracks containing mold were locally observed in the playa annulus where water had not been artificially

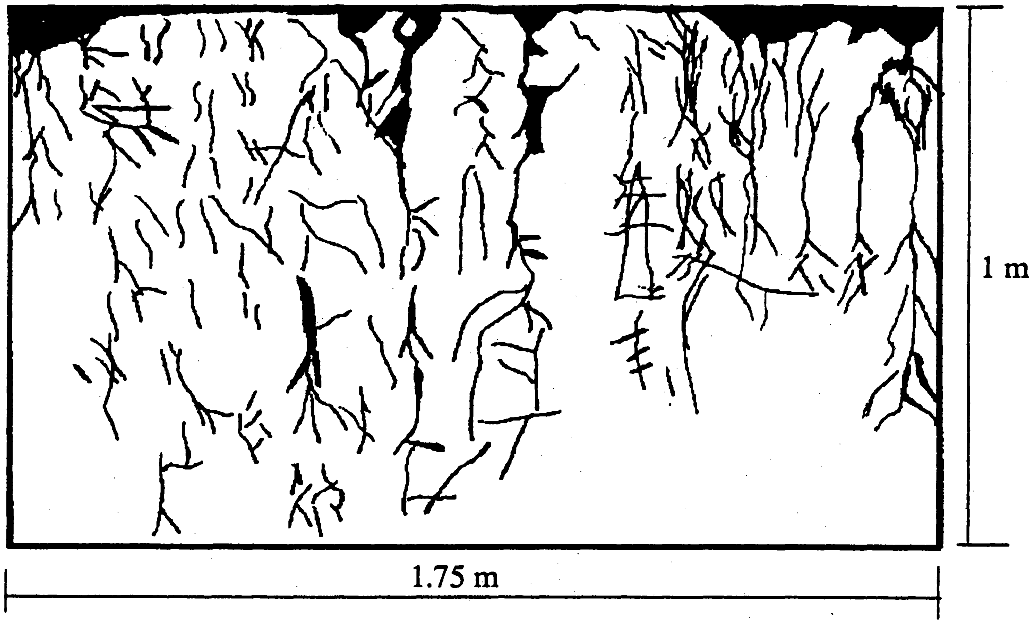

Figure 6. The spatial distribution of preferential flow pathways, mapped from the trench wall under ponding plot 3.

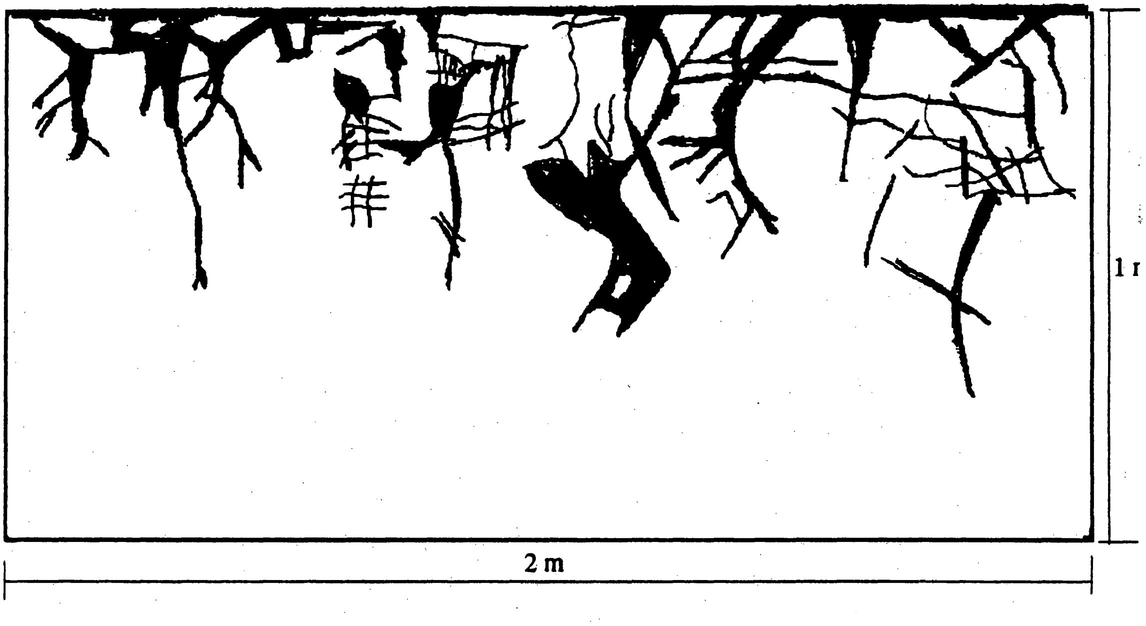

Figure 7. The spatial distribution of preferential flow pathways, mapped from the trench well under ponding plot 4.

ponded. Because the ponding period was shorter in plot 4 than that in plot 3 (2 hr less), the longest pathway is less than 0.65 m (2.133 ft) (1 m [3.28 ft] in plot 3).

SUMMARY

Four ponding tests were conducted in the TDCJ playas, northeast of Amarillo, Texas, to evaluate preferential flow. Organic blue dye was used to identify the preferential pathways. After ponding ceased, trenches were dug to expose the preferential pathways. At least four different types of pathways could be identified, including (1) root tubules, (2) ped faces, (3) cracks filled with dark, organic-rich clays, and (4) planar soil structures. Flow moves much more rapidly along these pathways than in the soil matrix. The infiltration rate was about 7.0×10^{-6} m/s (2.3×10^{-5} ft/s) in the interplaya and was 1.7 to 1.9×10^{-6} m/s (5.576 to 6.232×10^{-6} ft/s) in the playa.

REFERENCES

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