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INFILTRATION INTO THICK UNSATURATED ALLUVIAL DEPOSITS: A PRELIMINARY STUDY

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ABSTRACT

An infiltration and dye transport study in an unsaturated alluvial deposit was conducted using a square flooding type infiltrometer over a 50 hour period. Red and blue dyes were added to the applied water and photographs taken of the exposed face to determine the rate of advancement of the dye and wetting fronts. After infiltration was stopped, vertical "slices" were excavated at regular intervals up to the midpoint of the infiltrometer so the shape of the fronts could be described in a quasi three-dimensional manner. Dye fronts exhibited significantly more complication than did the wetting front suggesting highly variable solute transport in these alluvial deposits. Lateral spreading was twice that of the vertical movement indicating anisotropy due to pronounced horizontal layering. Infiltration measurements were compared with established infiltration equations.

INTRODUCTION

The characterization of water and contaminant movement within thick unsaturated alluvial deposits is a major unresolved issue in vadose zone hydrology. These deposits often contain many discrete layers of highly variable thickness and extent that span from fine sands through gravel and cobble layers and vary from well to poorly sorted. In addition, many small

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scale structures are visible within layers including microlayering and cross bedding. It is impossible to obtain information about the lateral connection of these sediment layers required for modelling water and contaminant transport from cores alone. Therefore, an approach to characterization that also relies on geologic and hydrologic data collected from local outcrops analogous to the site-specific geologic units encountered in the sub-surface is under development (Glass et al. 1993).

To aid in this characterization approach development, preliminary studies were performed in complicated ancestral Rio Grande sediments. The studies include: 1) geologic mapping at a variety of scales; 2) measurement and prediction of pressure/saturation curves; 3) use of tension infiltrometer to characterize undisturbed sediment volumes of 1000 cm^3; 4) measurement of dye tracer dispersion and retardation in laboratory columns; and 5) an intermediate-scale field infiltration and dye transport experiment within a porous media volume of 25 m^3.

Briefly described herein is the intermediate-scale field infiltration and dye transport experiment. Several recent field experiments conducted in less complicated sub-soils, have been reported (Stephens, et. al., 1988; Wierenga, 1988; McCord, et. al. 1988). This experiment concentrates on examining the development of wetting and transport fronts as delineated with a sequence of dyes. The information is required to design subsequent experiments which will incorporate a number of standard and non-standard techniques for measuring moisture content and solute concentration.

EXPERIMENTAL DESIGN

A field site was selected in Albuquerque, New Mexico, at the southwestern corner of the intersection of I-25 and Rio Bravo. Fluvial sediments from the ancestral Rio Grande are present and provide an ideal field laboratory for studying geologic controls on fluid flow in the unsaturated zone. A vertical face was cut into a steep hillside and a 46 cm square infiltrometer was installed in a flattened area above the face approximately 15 cm below the natural ground surface. Figure 1 contains a front view sketch of the infiltrometer and water supply system. The flooding type infiltrometer was kept at a constant head and measurements were made to determine the infiltration rate and saturated hydraulic conductivity of the site. A sequence of dyes (United States Department of Agriculture (USDA) red no. 3 followed by USDA blue no. 1) were mixed with the infiltrating water to allow visualization of transport along the vertical face. Photographs of the exposed face were taken to visually record the advancing wetting and dye fronts. The experiment ran for approximately 50 hours. At the end of infiltration, the face of the escarpment was excavated vertically at regular intervals and photographed.

A total of six "slices" were excavated with the last one directly under the center of the infiltrometer.

RESULTS AND DISCUSSION

The blue and red dye and wetting front locations were digitized from the photographs. The advancing wetting front on the open face is shown in Figure 1. Figure 2 shows each front along the center-line "slice" after infiltration. The wetting front may have resulted from a combination of either the forcing of insitu moisture ahead of the advancing dye fronts, and/or the adsorption of red dye to the sands.

Overall, there is significant horizontal movement of the wetting front as shown in Figures 1 and 2. The wetted region is nearly symmetrical with a slight skew towards the right side, and has an approximately elliptical shape below the infiltrometer. The lateral spreading is nearly double the vertical flow indicating significant anisotropy most likely due to pronounced horizontal layering. This influence of lateral flow is more pronounced than was found during the wetting phase of the experiment of Wierenga (1988) in less strongly stratified subsoils.

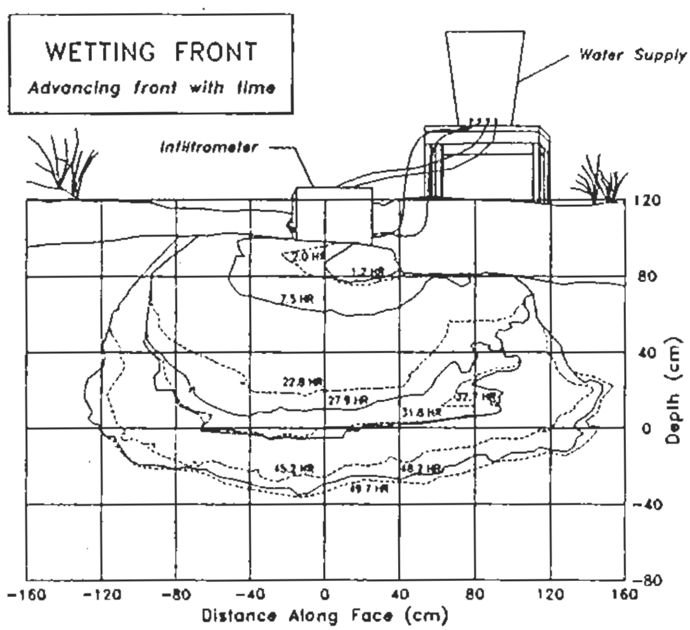

Figure 1. Position of wetting front in time. Note significant lateral spreading indicating anisotropy and pronounced horizontal layering.

Non-homogeneous and preferential flow was more significant in the dye fronts than the wetting front. A visible fracture on the vertical face extended into the hillside under the right corner of the infiltrometer. Preferential flow down the fracture was clearly visible in photographs of the face and "slices". The fracture may have contributed to higher horizontal flow on the right side. In addition, the blue and red dye fronts show significant preferential flow away from the visible fracture as shown in Figure 2. Preferential flow paths have been observed in the field by Glass et al. (1988), Kung (1988) and others. They can be due to a variety of mechanisms including macropore flow, gravity driven-fingering and property variability.

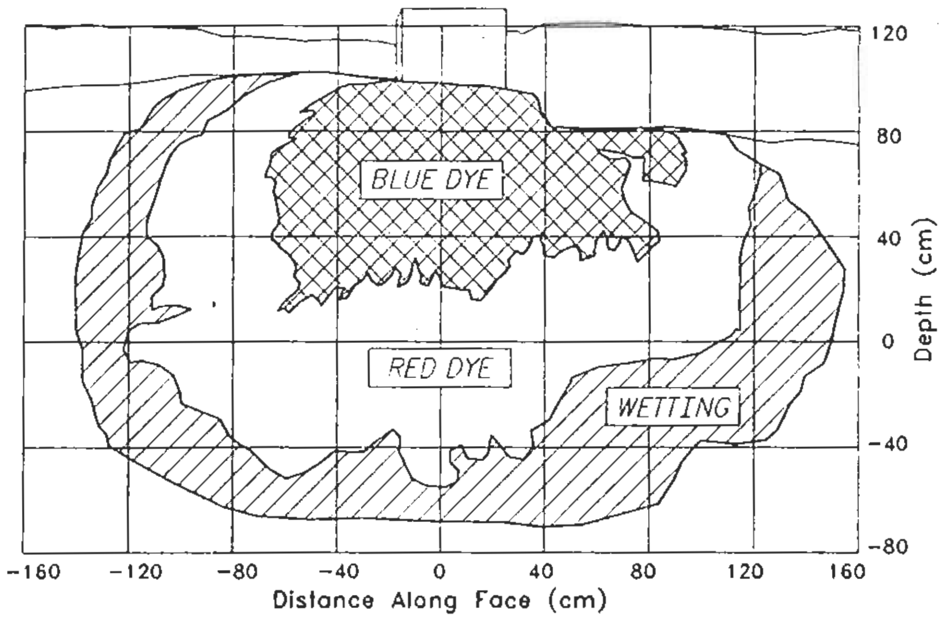

Figure 2. Front position under infiltrometer along "Slice No. 6". Notice dye front complication suggesting highly variable solute transport properties in these alluvial deposits.

The well established response of measured infiltration rate versus time is shown in Figure 3. The apparent, long time, asymptotic rate increases slightly after 24 hours from 7.3 cm/hr to 7.9 cm/hr at 49 hours. This change in apparent asymptotic rates may be partly due to changes in ambient temperature and its effect on the viscosity of water. During the experiment, the ambient maximum temperature on the first day was 23°C. By the second day the temperature dropped to 21°C at a point when the infiltration rate reached a low of 7.3 cm/hr. On the last day of the experiment, the temperature increased to 26°C when the infiltration was 7.9 cm/hr and rising.

While the experiment was not designed to exhibit one-dimensional behavior, one-dimensional infiltration equations were fit to measured data to demonstrate their ability to model infiltration rate. The equations used were a) Kostiakov, b) Horton, c) Early Green and Ampt, and d) Philip (see Jury et al. 1991). Figure 3 shows how well these equations fit despite three-dimensional flow properties.

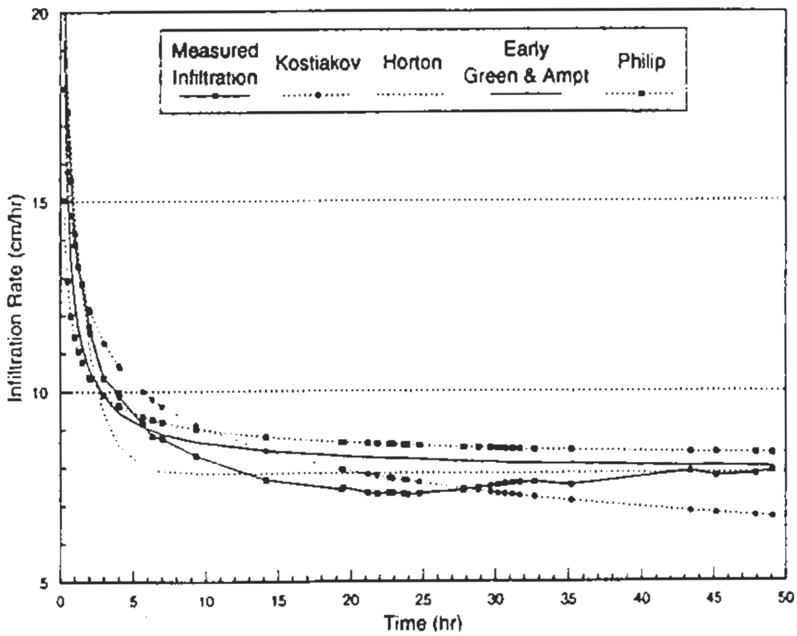

Figure 3. Comparison of measured data to infiltration equations.

Wooding (1968) derived an approximate expression for the steady infiltration rate from a circular pond. Using this equation and a simplification of the three-dimensional flow equation, Wooding derived an equation for steady infiltration that includes the fundamental difference between one-dimensional and three-dimensional flow in the parameter alpha (α). Using a final infiltration rate of 7.8 cm/hr, and an α of 0.03, the Wooding equation yields a saturated conductivity, K_o, of 7.4 cm/hr. The Wooding equation final infiltration rate exceeds K_o due to lateral spreading. Changing α in Wooding's equation from 0.01 to 0.03 does not change K_o appreciably. In addition, the one-dimensional saturated conductivity K_s for the Green and Ampt equation was nearly equal to the Wooding equation K_o.

CONCLUSIONS AND FUTURE RESEARCH

Dye fronts exhibited greater irregularity than did the wetting front which suggests variable solute transport properties in these alluvial deposits. Lateral spreading exceeded vertical movement by nearly two to one which indicates a three-dimensional non-homogenous system influenced by horizontal stratification. Established one-dimensional infiltration equations fit measured data reasonably well despite three-dimensional property variability suggesting the equations can reliably model infiltration rates. Ambient temperature variations may influence long time saturated conductivities resulting in changing infiltration rates. Future studies will be carried out for more than 50 hours to better determine long-term steady infiltration rates and their variation.

Preliminary modelling of the geology and flow/transport during the experiment is currently underway and will be used to evaluate effective flow/transport properties in these alluvial sediments. In future studies, a continuously recording network of tensiometers and time domain reflectometry (TDR) probes will be used to record the flow conditions in terms of matric suction and moisture content. This will enable better use of sophisticated mathematical solutions for flow/transport. Geophysical techniques will also be incorporated to monitor wetting and solute fronts during experiments.

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