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# EFFECT OF SOIL COLUMN CROSS-SECTION ON THE SOLUTE FLOW BEHAVIOUR IN UNDISTURBED AND DISTURBED SOIL

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A solute transport study was conducted to test the validity of two solute transport models in a series of experiments with varied soil column cross-section (10,15 and 20 cm inner diameter) in both undisturbed and disturbed soil columns. The column cross-section affected the shape of the breakthrough curve (BTC). The smaller width BTC had relatively greater peak height and less tailing than the BTCs from the wider columns, due to a decrease in the radial mixing distance. The dispersivity decreased significantly with a decrease in column cross-section in the undisturbed soil experiments. No real dependence of dispersivity values on column radius was observed for the disturbed soil experiments. The sigma parameter generally decraased significantly with decrease in column radius of the undisturbed soil but not in the case of repacked soil experiments.

## INTRODUCTION

Most water and solute transport models used in the unsaturated zone are an outgrowth of laboratory models developed to simulate flow in uniformly packed soil columns of identical widths (cross-section). As such they are one-dimensional models which assume vartical flow with no variability (Rose *et al.*, 1982). A thorough discussion of many of solute studies is given in a review of soil solute transport (Hassan, 1987). Field studies of solute movement have been less successful than laboratory studies because of the large variation in soil water flow properties in both the vertical and the the horizontal directions. However, basic principles deveeoped in the laboratory have been successfully generalized to the field. For example, Miller *et al.* (1965) showed that chloride could be leached more effectively if the field soil was kept unsatutated than if surface was ponded.

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Solute transport through soil columns may be roughly charactetized by two time scales: the lateral dispersive mixing time scale $td = R^2/D_T$, where R is the column width and $D_T$ is the transverse dispersion coefficient, and the convective residence time scale $t_c = L/V$, where L is the column length and V is the solute velocity. The transverse mixing time represents a specific time required to smooth out any lateral differences in solute concentration by radial mixing (Taylor, 1953).

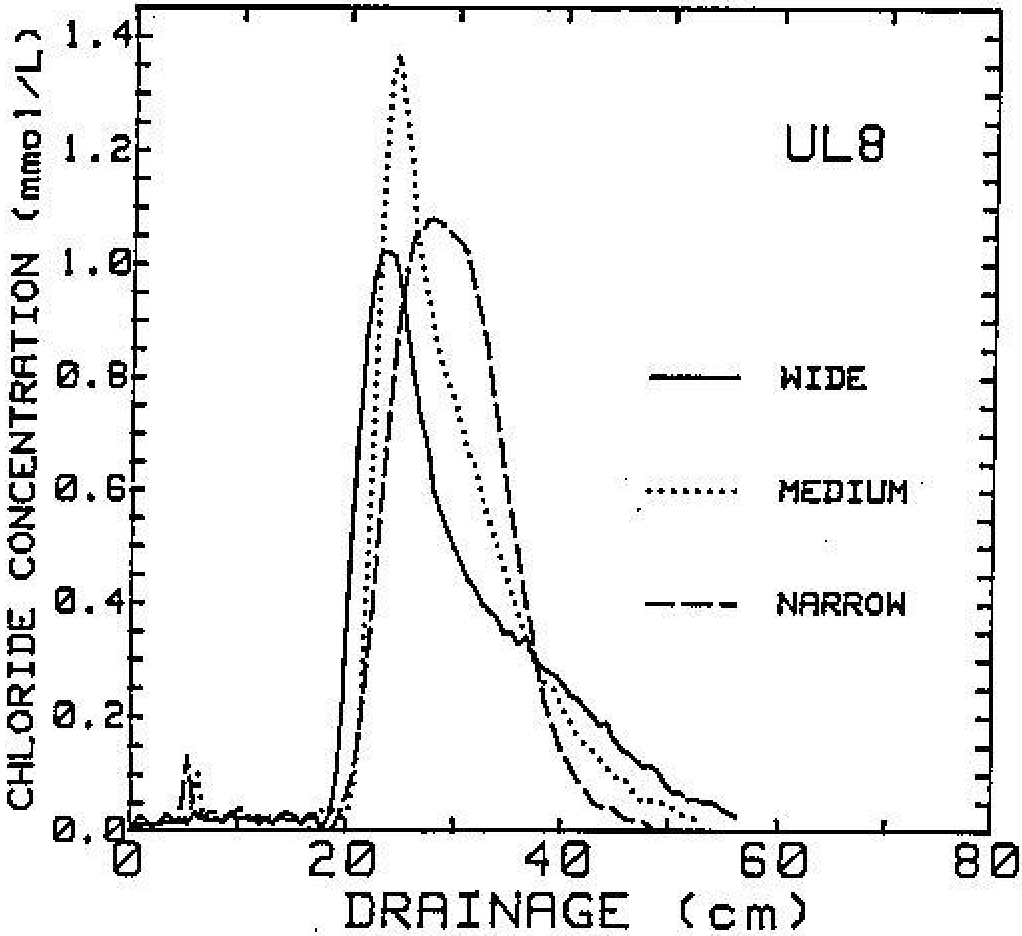
Variation of the dispersive mixing time with treatment is not known *a priori*. Since the experiments were designed to add water and solute over most of the entry surface, the mixing time is not necessarily proportional to the column radius R. If preferential vertical flow channels are present in the soil columns, they may have to mix with a larger lateral volume in the wider columns, particularly if there are few of them per unit area. By contrasting the behaviour of the undisturbed and disturbed columns, insight may be gained into the influence of these channels on outflow behaviour.

All experiments on a given column should yield the same value of dispersivity parameter. In principle, dispersivity could vary with column radius if the wider column contained a greater degree of heterogeneity than the smaller. The extent of change is not known *a priori*. Therefore, the best-fit parameters will be determined for each treatment and physical relationship between parameters and column width also will be determined experimentally.

## MATERIALS AND METHODS

A set of three soil cores was taken from a wetted site by slowly pounding 20-, 15- and 10 cm diameter cylinders into Tujunga loamy sand soil to a depth of 90 cm and then excavating the soil around the cylinders. A brass screen was attached to the bottom of each cylinder with the help of a wider inner tube band. The disturbed soil columns were uniformly packed from the excavated soil around the undisturbed columns. These columns were placed on top of large plastic funnels in two wooden racks and were irrigated by using pressure-driven calibrated fine hypodermic tubing. These columns were subjected to steady water flux rates of 8, 4 or 2 cm/d. After steady state water flow was achieved, a 1 cm pulse of 13 meq/L calcium chloride was applied. Drainage

Figure 1. Breakthrough curves from undisturbed long soil columns at 8 cm per day water flux rate and three widths.



waters collected after every three to four hours were analyzed for chloride concentration using an AMINCO analytical chloride titrator. The second phase of the experiments consisted of cutting the soil columns into halves and repeating the experiments on the top halves. The experimentally measured chloride concentration data were tabulated versus cumulative drainage or time and model parameters were evaluated by the *least squares methods* and the *method of moments* (Jury and Sposito, 1985) for both the convection-dispersion equation (CDE) and the transfer-function model (TFM).

## RESULTS AND DISCUSSION

1. *Breakthrough curve (BTC) Shapes* :

The measurements of the collected drainage water and corresponding chloride ion concentration (mmol per liter) for the set of three different soil column diameters for the two represntative experiments are presented in Figs. 1 and 2. These curves should be identical if the dispersion coefficient D is independent of width. Figure 1 shows that the wide (20-cm width) undisturbed column pulse arrived after a somewhet smaller quantity of cumulative drainage than the others and had the longest tailing. The pulse for the 16-cm diameter column arrived somewhat after that in the wide column and has a greater peak height and less tailing than the pulse in the wide column. The shape of the narrow column BTC is an artifact resulting from the rock present in the lower part of the column. The solute pulse had to move around this obstacle, resulting in an almost symmetric shape of BTC. The considerable tailing in the BTC of the wide column indicates that a large amount of preferential flow and lateral diffusion into a stagnant matrix is occurring, and that it is more pronounced than in the medium column. Figure 2 shows the coresponding BTCs from the three disturbed or packed soil columns. In contrast to the undisturbed column BTCs, the curves for three diameters were very similar to each other. The three pulses appeared at approximately the same quantity of cumulative drainage, have the same amount of spread and are nearly symmetrical. Natural drainage in the undisturbed soil column tends to set up vertical channels and pathways producing skewed BTCs, whereas in the disturbed soil the solute moves through the entire wetted soil matrix, producing more symmetric BTCs (Elrick and French, 1966).

Figure 2. Breakthrough curves from packed long soil columns at 8 cm per day water flux rate and three widths.

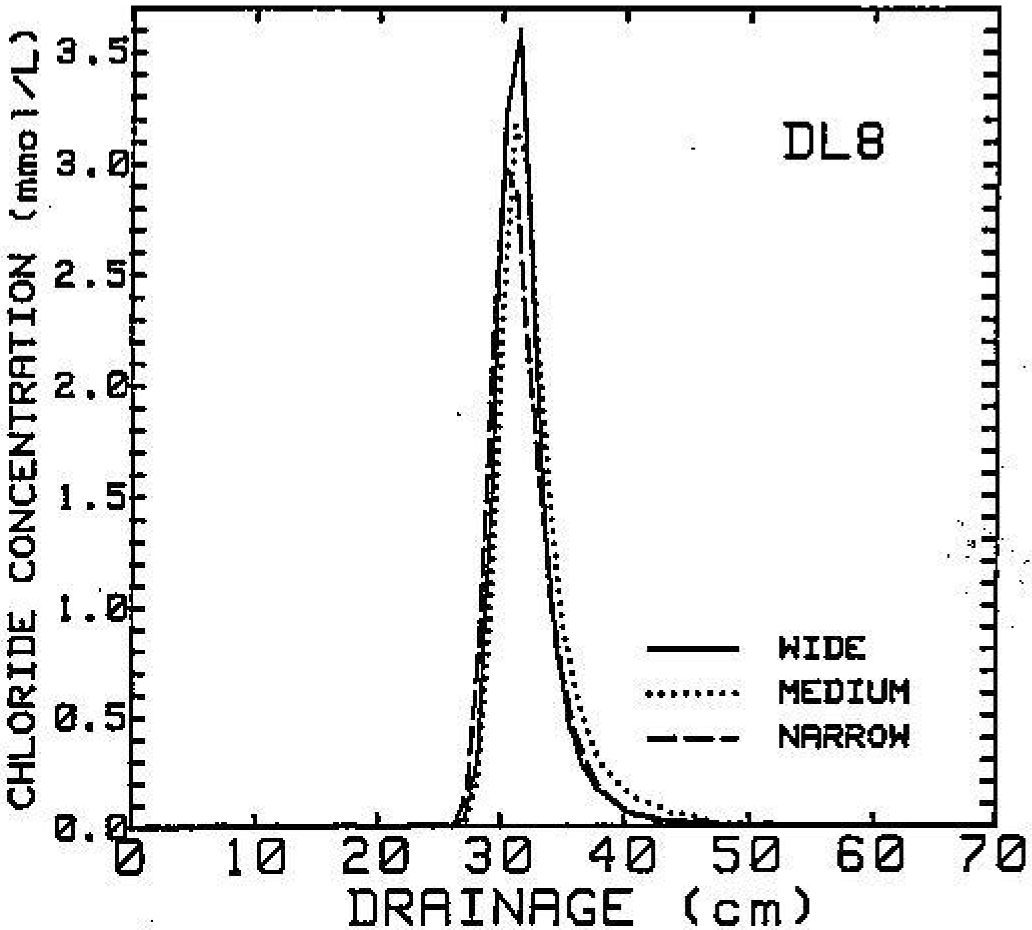


Table 1. *Curve-fitted parameter values using CDE and TFM models with respect to column width*

| D ± S D | $\lambda \pm S\lambda$ | $\mu \pm S\mu$ | $\sigma \pm S\sigma$ | C.W.* |
|---|---|---|---|---|
| | | *Undisturbed soil experiments* | | |
| | | *8cm/day flux, 87 cm (Long)* | | |
| 2.64±0.39 | 2.64±0.40 | 3.37±0.02 | 0.25±0.02 | W |
| 1.45±0.20 | 1.55±0.21 | 3.46±0.02 | 0.19±0.01 | M |
| 1.23±0.05 | 1.35±0.05 | 3.48±0.01 | 0.18±0.01 | N |
| | | *43.5 cm (Medium)* | | |
| 1.18±0.22 | 1.21±0.22 | 3.40±0.03 | 0.24±0.02 | W |
| 1.13±0.13 | 1.26±0.14 | 3.47±0.02 | 0.24±0.02 | M |
| 1.87±0.18 | 2.06±0.20 | 3.45±0.02 | 0.30±0.02 | N |
| | | *21.8 cm (Short)* | | |
| 0.58±0.08 | 0.67±0.09 | 3.61±0.02 | 0.25±0.02 | W |
| 0.60±0.06 | 0.75±0.08 | 3.59±0.02 | 0.26±0.02 | M |
| 0.99±0.14 | 1.11±0.15 | 3.47±0.03 | 0.31±0.02 | N |
| | | *Disturbed soil experiments* | | |
| | | *Long* | | |
| 0.38±0.04 | 0.41±0.04 | 3.48±0.01 | 0.10±0.01 | W |
| 0.34±0.04 | 0.40±0.05 | 3.57±0.01 | 0.10±0.01 | M |
| 0.28±0.02 | 0.29±0.02 | 3.44±0.00 | 0.08±0.00 | N |
| | | *Medium* | | |
| 0.41±0.03 | 0.46±0.03 | 3.52±0.01 | 0.14±0.01 | W |
| 0.17±0.01 | 0.20±0.01 | 3.67±0.00 | 0.09±0.00 | M |
| 0.31±0.04 | 0.37±0.04 | 3.57±0.01 | 0.12±0.01 | N |
| | | *Short* | | |
| 0.17±0.02 | 0.22±0.02 | 3.65±0.01 | 0.12±0.01 | W |
| 0.18±0.01 | 0.24±0.01 | 3.68±0.01 | 0.13±0.01 | M |
| 0.20±0.01 | 0.28±0.01 | 3.72±0.00 | 0.14±0.00 | N |

*Column Width, W = Wide, M = Medium, N = Narrow

II. *Effect of Soil Column Radius on Model Parameters* :

Table I shows the effect of soil column width on the CDE and TFM parameters at a given length and water flux rate of the representative solute experiments. In the case of the undisturbed soil experiments, the dispersion coefficient D (and the dispersivity $\lambda$ = D/V) decreased significantly (P = 0.05) with a decrease in column radius for the long column. However, the narrow column behaviour is not representative of our experimental design owing to the presence of a stone. At the shorter lengths, the dispersion coefficient and the dispersivity stayed nearly uniform in the case of the wide and the medium columns but increased significantly in the narrow column. One possible explanation for this behaviour may be that the assumption that the cross-section was large enough to make boundary or wall effects negligible might not be valid in the narrow undisturbed soil column. In the case of the repacked soil experiments no real dependence of dispersivity values on column radius was observed because it significantly increased from narrow to medium-width at the longer length, decreased significantly between these two widths at the short length and was independent of width at the medium length.

The TFM parameter mu stayed statistically uniform with changing column width for a given length in most of the structured and repacked soils. For the undisturbed soil the sigma parameter generally decreased significant with a decrease in column width for the long columns. However, at the medium and short lengths it remained statistically uniform for the wide and medium cross-sections and increased significantly most of the time for the narrow one.

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