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# Preliminary analysis of salinity distribution in a solute transport process at field-scale

**A. Comegna** [1], **G. Severino** [2], **A. Sommella** [2]

[1] University of Basilicata, Hydraulics Division
[2] University of Naples, Italy – Division of Water Resources Management

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**Abstract.** Salt concentration and water content profiles were intensively measured within an area of 40x7 m$^2$ to a depth 1.0 m in a sandy (Ando) soil. A few models were considered to simulate salt movement in the soil. Comparison of simulation results with the field experimental data showed that the convective dispersive (CD) model with effective parameters well describes the mean concentration profiles. The failure of other models is probably due to the neglect of pore scale dispersion, which in the considered experiment seems to have a relevant impact.

**Keywords.** Solute transport – Heterogeneity – Stochastic modelling.

***Analyse préliminaire de la distribution de la salinité dans un processus de transport des solutés à l'échelle du champ***

***Résumé.*** *Les profils de concentration du sel et du contenu en eau ont été intensivement mesurés dans une aire de 40x7 m$^2$, à une profondeur de 1,0 m d'un terrain sablonneux (Ando). Quelques modèles ont été considérés pour simuler le mouvement des sels dans le sol. La comparaison des résultats des simulations avec les données expérimentales, a démontré que le modèle de convection/dispersion (CD), avec ses paramètres effectifs, décrit bien les concentrations moyennes des profiles. L'échec des autres modèles est probablement du au fait qu'ils négligent la dispersion à l'échelon du pore, ce qui semble par contre avoir un impact important dans ce cas d'étude.*

***Mots-clés.*** *Transport du soluté – Hétérogénéité – Modélisation stochastique.*

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## I – Introduction

Reliable and simple models for solute transport in unsaturated porous media are required for many application purposes like the optimal management of agricultural practices, designing proper strategies to preserve soils or assessing the potential pollution risks of groundwater. Numerous models have been proposed to account for the complicated physical/chemical processes occurring in soils (e.g. Brusseau *et al.*, 1989). Although the wide variety of mathematical models available in the literature (for a comprehensive review, see Sardin *et al.*, 1991), finding analytical solutions is not an easy task. Another complicating factor is represented by the unsteadiness of the water flow which especially in the case of soils is a quite common situation.

Due to its relevance, solute transport at field scale has been recently monitored in a typical soil of the Campania Region with the target to acquire a proper data-set to verify the capability of existing transport models to mimic salt transport in heterogeneous soils.

## II – Convection-Dispersion (CD) model

The convective-dispersive model for solute transport taking place in one dimensional homogeneous porous medium can be cast in terms of the following five non dimensional quantities (see e.g. Bear, 1972).

$$T = \frac{vt}{L}, \qquad X = \frac{z}{L}, \qquad Pe = \frac{vL}{D}, \qquad C = \frac{C_r - C_i}{C_r - C_i}, \qquad R = 1 + \frac{\rho\, k}{\theta} \tag{1}$$

where v=q/θ (L/T) is the effective velocity in the liquid phase (L/T), q (L/T) the flux, θ ($L^3$/ $L^3$) is the volumetric water content, L (L) is the characteristic flow domain length, z (L) is the depth, t (T) is the current time, *D* ($L^2$/T) is the pore-scale dispersion, $C_r$ and $C_i$ (M/$L^3$) represent the resident and initial concentrations, respectively, whereas $C_0$ is the concentration at the inlet, ρ (M/$L^3$) the bulk density, and k ($L^3$/M) the characteristic coefficient of the linear isotherm.

Thus, the convective-dispersive equation writes as

$$R\frac{\partial C}{\partial T} + \frac{\partial C}{\partial X} = Pe^{-1}\frac{\partial^2 C}{\partial X^2}. \tag{2}$$

In order to account for the spatial variability of the parameters *D* and *v* appearing into (1), in equation (2) one can introduce the “effective” parameters $D_{eff}$ and $v_{eff}$. Following Salzman and Richter (1995) the effective dispersion coefficient $D_{eff}$ and the effective velocity $v_{eff}$ are given by

$$D_{eff} = \langle D\rangle + \frac{45.45\sigma_v^{2/0.93}}{\left(1+\langle v\rangle\right)^{1.104}}\left(1+\frac{\sigma_v^2}{\langle v\rangle}\right) - 0.291\sigma_v^{2/0.64}\left(1-\frac{1}{1+\langle D\rangle}\right)^{-0.056}\left(1+\frac{\sigma_v^2}{\langle v\rangle}\right)^{-0.264} \tag{3}$$

$$v_{eff} = \langle v\rangle - 0.28\left(\frac{\sigma_v^2}{\langle v\rangle}\right)^{0.8} - 0.281\sigma_v^2 + 0.07\sigma_v^4 \tag{4}$$

where it is assumed that both the pore scale dispersion *D*, and the local effective velocity *v* are log-normally distributed.

## III – A brief description of the field experiment

Monitoring tracer transport was conducted in a 40 m x 7 m transect, located at Ponticelli, Naples (Italy). The soil is sandy (USDA) and pedologically classifiable as Andosoil. The soil texture in the upper 1.5 meters was studied in details and results are summarized in Comegna *et al.*, (2008). Field investigations showed that the soil is uniform with no layering within the first top meter. In particular, the soil bulk density had a mean value of 1.15 g/cm³ (σ=5.07·10-2 g/cm³) in the upper layer whereas, at higher depths, the soil showed its original andic features, with bulk density lesser than 1.0 g/cm³.

The plot selected was covered with a greenhouse to control the influence of the rainfall. The irrigation system consisted of 96 (40 $lh^{-1}$) static sprinklers arranged with a spacing of 1.5 m in the longitudinal and 2.5 m in the transversal direction. The water application rate was controlled by a peristaltic pump, connected to 5 m³ water storage tank. Sprinkler system uniformity was checked with the Christiansen Uniformity Coefficient (UCC) (Christiansen, 1942). The observed UCC over the entire field was estimated to be 80 %. To minimize a possible risk of changes in application rates and water flux, an on-off system was introduced.

Prior the solute application, the transect was irrigated for several days in order to guarantee steady-state flow conditions. Then, a solution of 67.5 Kg of KCl was dissolved in 1500 liter of water, and subsequently applied (105 g/m²) in a pulse-like form to the soil surface. Transport was forced by the same constant flux q=0.042 cm/h which were established before the salt application. Soil cores were collected at 7 time intervals (t=97, 167, 263, 335, 407, 573, 742 hours after solute application). At each site, 40 different points were sampled. The soil samples were taken from the surface to a maximum depth of 90 cm in 20 cm increments. At the end of the tracer experiment ≈4000 soil cores were collected, sealed in plastic bags and returned to the laboratory for $Cl^-$ analysis. Soil solution was extracted using a 1:2 soil-water mixture; after mixing and equilibrating, solution extracts were obtained using suction funnels lined with filter paper.

Chloride ion concentration in the extracts was determined using a Methrom ion analyzer, model 781. All samples were oven dried for 48 hours to determine water contents.

## IV – Discussion

The mean water content $\langle\theta\rangle$ and the corresponding error (with confidence of 68%) at t=97 h is depicted in figure 1 as function of the depth z. It is seen that $\langle\theta\rangle$ is uniformly distributed up to z=0.55 m, whereas the increase which is observed at higher depths is due to the different (pedological) structure of the soil at such depths. As first step to characterize the mechanisms affecting chloride migration, we have computed the so called "mobile water content" $\theta_m$=qt/z where q=0.0417 cm/h is the flux density at the soil surface, t the sampling time, and z the depth at which the maximum concentration value is detected. It resulted $\theta_m$=0.23 to be compared with $\langle\theta\rangle$=0.34, suggesting that the chloride in mean is transported at higher depths as compared with the mean concentration value.

Subsequently, convective-dispersive parameters have been determined by matching analytical solution pertinent to our case (van Genuchten and Wierenga, 1986) with real data. Results of such a procedure suggest that the most stringent feature is the high variability of v and D along the transect, thus suggesting a deep impact of the soil heterogeneity.

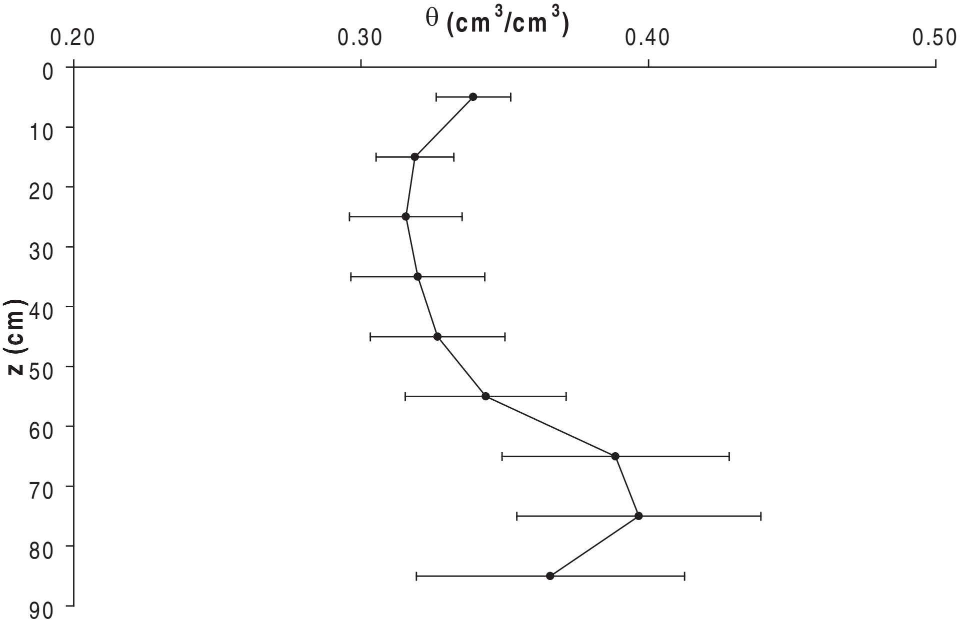

**Figure 1. Mean water content distribution at t=97 h.**

In particular, it is seen that both the dispersion coefficient *D*, and the local velocity v can be approximately considered as log-normally distributed. In order to model solute transport at field scale we have compared the CD with other models (for details, see Comegna *et al.*, 2005). In addition, we have also considered the convective dispersive model as obtained from effective parameters. The result is that the CD model with effective parameters is the best performing model for predicting purposes.

## V – Concluding remarks

Even if the water content is apparently scarcely affected by the soil heterogeneity, a huge spatial variability in the salt spatial distribution (especially in the surroundings of the peak of concentration values) has been observed.

The absence of preferential flows as well as fractures suggests that a possible transport model is the classical convection-dispersion equation with effective parameters. Indeed, good matching between real data and simulation have been obtained.

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