Scaled forms of the infiltration equation: application to the estimation of the unsaturated soil hydraulic properties

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There is a clear need to assess the adequacy of scale matching of soil water dynamics to grid scales relevant for simulation of the vadose zone, aquifers, the land surface and atmospheric interactions. The difficulty of parameterization of soil water movement lies not only in the non-linearity of the saturated/unsaturated flow equations but also in the mismatch between the scale of (point) measurements and the scale of model predictions.
Traditionally, the scaling is performed through normalization analyses of static soil properties such as grain size diameter and/or hydraulic soil characteristics. However, the main importance for vadose zone hydrology is the knowledge of the unsaturated flow behavior of a soil, rather than the knowledge of hydraulic soil characteristics, which are just intermediate relationships used to calculate the flow behavior. For that reason we choose, in this paper, to study the problem of scaling directly through the dynamical analysis of the unsaturated flow equations for both *Dirichlet* concentration type and *Neumann* flux type boundary conditions. Applying inspectional analysis, a rigorous approach is made to scale Richards' equation for one-dimensional, isothermal flow in a homogeneous unsaturated soil resulting in a non-dimensional boundary value problem. The case of one-dimensional constant head infiltration in a semi-infinite uniform soil column using the *Green and Ampt* (1911) and *Talsma and Parlange* (1972) solutions, is applied to illustrate the principles of scaling theory. Full identification of scale factors of the unsaturated flow equation can be illustrated through the generalized constant head infiltration equation developed by *Parlange et al.* (1982) and *Haverkamp et al.* (1990). It had been shown (*Haverkamp et al.*, 1998) that the scale factors introduced for the constant head infiltration come naturally for the flux boundary condition as well.
The results demonstrate that there exists, so far, no unique dynamical similarity in the behavior of soil water movement in general field soils when governed by the *Richards* equation. Instead there is a multitude of dynamical similarity classes depending on the combination of soil type, initial and boundary conditions. In its most general form, the head and/or flux infiltration behavior is defined by three infiltration scaling factors embodying the effect of soil type, initial and boundary conditions. For two particular cases which correspond to the *Green and Ampt* soil and the *Gardner* soil, there is a unique similarity solution for which the physical system is macroscopically similar. These two solutions are the bounds of the envelope of all possible similarity classes; hence they become of great use for water watershed modeling at large scales as they fix the two extreme scenarios on which decision making can be based.
The results demonstrate that the purely soil related flux determined scale factors are identical for infiltration under head (negative or positive) and flux boundary conditions. These scale factors allow for the scaling of the classically used soil hydraulic characteristics in such a way that consistency with the invariant flux equations is maintained. Hence, once the flux defined scale factors have been determined, these factor can be de-convoluted into the classically used

soil hydraulic characteristic parameters. Consequently, the application of this scaling technique to in-situ measured infiltration experiments, is a promising tool to characterize the soil hydraulic soil properties at low costs and with affordable human resources. When performing the identification by means of the *Green and Ampt* and *Talsma and Parlange* infiltration solutions, which determine the invariant upper and lower bounds of the envelope of all possible infiltration classes, good estimations of the extreme soil characteristic parameters can be found which is of great use for watershed studies where stochastic modeling is needed.

In the last stage of this paper, the new method of characterization which was initially launched by *Haverkamp et al.* (1997) as the '*Beerkan*' method, is applied to a practical case of in-situ infiltration performed in the context of the '*Alpilles*' project. A detailed description of the step by step procedure is addressed. An algorithm for the identification procedure of the different soil characteristic parameters is given in an Annex.

References

Green, W.H, and G.A. Ampt, 1911. Studies in soil physics: I. The flow of air and water through soils. *J. Agric. Sci.*, 4:1-24.

Haverkamp, R., J.-Y. Parlange, J.L. Starr, G. Schmitz, and C. Fuentes, 1990. Infiltration under ponded conditions: 3. A predictive equation based on physical parameters. *Soil Sci.*, 149:292-300.

Haverkamp, R., J.L Arrue, and M. Soet, 1997. Soil physical properties within the root zone of the vine area of Tomolosso. Local and spatial standpoint. In *Final integrated report EFEDA II Spain*, Project CEE n° CT920090, chapter 3.

Haverkamp, R., J.-Y. Parlange, R. Cuenca, P.J. Ross, and T.S. Steenhuis, 1998. Scaling of the Richards equation and its application to watershed modeling. In *Scale Dependence and Scale Invariance in Hydrology*, Ed. G. Sposito, Cambridge University Press, chapter V: 190-223.

Parlange, J.-Y, R. Haverkamp, and J. Touma, 1985. Infiltration under ponded conditions: 1. Optimal analytical solution and comparison with experimental observations. *Soil Sci.*, 139:305-11.

Talsma, T, and J.-Y Parlange, 1972. One-dimensional vertical infiltration. *Austr. J. Soil Res.*, 10:143-150.