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Validity time domain estimation for the transient two terms and steady state infiltration equations

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Modeling of water fluxes in the vadose zone that links surface water with groundwater is important with regards to understanding hydrological cycle and transfer of water-transported contaminants. Such modeling is usually based on the description of water flow using models such as Richards' equation, unless preferential flow is involved. Several analytical solutions have been proposed to provide either approximate or exact solutions for 1D water infiltration. Based on the analytical model for 1D ponded cumulative infiltration and its extension to 3D for a surface disc source, Haverkamp et al. (1994) proposed a set of analytical equations that were adapted for a constant water pressure head at surface (hsurf) and an initial uniform water pressure head profile, ho(z). This equation system includes a quasi-exact implicit formulation and the related direct approximations. Even if the quasi-exact formulation may be much more precise than the related approximations, it is much more difficult to employ, which has lead to a more common use of the direct approximations. Yet, it can be demonstrated that in certain cases, the error can be no longer acceptable, suggesting that the use of related approximations should be restricted to the domain in which these are consistent approximations of the quasi-exact formulation. This study focuses then on the definition for such validity domains for the two-term and steady state approximations. A specific analytical procedure is developed. First, we will scale the equations proposed by Haverkamp et al. (1994) to derive the scaled (dimensionless) one-dimensional cumulative infiltration and the scaled difference between three- and one-dimensional (3D–1D) cumulative infiltration. Then the 1D scaled cumulative infiltration is analytically studied to derive the expressions for the two-term and steady state approximations and also their accuracy to reproduce the quasi-exact formulation. This last part leads to the definition for validity domains that take the form of two intervals. For the two term approximation, the interval extends from zero and to an upper boundary that depends upon the required tolerance and that is referred to as the two term validity time. For the steady state, the interval extends from a lower boundary to infinity, referred to as the steady state validity time. The use of the scaling procedure allows estimations of the validity intervals related to dimensional 1D and 3D cumulative infiltrations. The proposed validity times are also compared to rough approximations that were previously proposed such as the gravity time and proved to be much more adequate.

Haverkamp, R., P.J. Ross, K.R.J. Smetten, and J.-Y. Parlange. 1994. Three-dimensional analysis of infiltration from the disc infiltrometer. 2. Physically based infiltration equation. Water Resour. Res. 30:2931–2935