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Ephemeral saturated layers in the vadose zone: some theoretical results for gradually variable soils

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The upper soil layers are often characterised by variable hydraulic parameters with depth, as a consequence of the pedogenetic processes which lead to the soil formation. In mountain non-mature soils, where a non-complete stratification takes place, the soil-water parameters can vary gradually, with a sharp discontinuity when the underlying parent rock is reached. Particularly, focusing on the vertical hydraulic conductivity at soil saturation (K_s), it is expected to decrease at increasing soil depth, with a significant effect on the water movement. As indicated by field data reported in the literature and collected during our surveys in mountain catchments, the vertical profile of K_s can be fairly represented as an exponential decay. With the aim of better understanding and evaluating its effect on the water movement, two meaningful cases of water content dynamics were considered and analysed.

In the first case the initial stage of the process was considered. The Richards equation, particularised for exponentially decaying K_s and linearised by means of Gardner's constitutive laws, was solved in a semi-infinite one dimensional domain under Dirichlet boundary conditions. Some time after the beginning of the imbibition, the water content profile diverges from the monotonically decreasing solution expected for a homogeneous soil. After few more time a water content peak onsets at the soil surface and the profile looses its monotonicity. This behaviour, which drives to a reduction of the potential infiltration rate, is consistent with the structure of the theoretical framework. In fact as K_s monotonically decreases with depth, the hypothesis usually required in order to proof the maximum principle are not satisfied. The dimensionless time, at which the water content peak onsets, is highly sensitive to the soil parameter $\varphi = \frac{A-L}{A}$ and increases at increasing φ (A and L are respectively the constants of exponential decay of the Gardner's soil-water retention relationship and of the K_s profile).

This solution is valid until any point is unsaturated, otherwise a perched water is expected to onset at the peak depth, and the constitutive laws change. Therefore in order to define the conditions for the perched water to onset and the hydraulic head profile across to it, a steady vertical downward flux was studied. The Darcy's law, with exponentially decaying K_s, was integrated across the vadose zone. The solution shows that a perched water, with positive pressure head, is required to sustain a vertical flux greater than the value of K_s at the underlying water table. As the vertical flux approaches the equivalent conductivity of the vadose zone, then the upper water table reaches the soil surface.