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HESS Opinions: Unsaturated infiltration: from unproven capillary flow to viscous flow

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Abstract Briggs (1897) deduced capillary flow from deviation of the equilibrium between capillarity and gravity. Richards (1931) raised capillary flow to an unproven soil hydrological dogma. Apparent corrections of the dogma led to non-equilibrium flow, macropore flow, and preferential flow during infiltration. Viscous flow is proposed as alternative to capillary flow during unsaturated infiltration.

1 Introduction

Why does water know / where to flow? / is the strongest force / dictating the course? / Is the weakest resistance / controlling the distance? / Or is soil hydrology nothing but mental strength / fiddling with mass, time, and length? (Germann, 2014)

2 How capillary flow got its position in unsaturated porous media flow

The success of terrestrial plants relies, among other phenomena, on the simultaneous supply of oxygen and water to the root tips in the range of < 5 to > 50 μm. A mandatory prerequisite is the inferior water pressure relative to the air pressure around the tips. That again is the result of the water's surface tension against the air and its affinity towards the solid particles, resulting in the capillary potential ψ. As a physicist with the US-Bureau of Soils, Briggs (1897) formalized the relationships mathematically and physically. He also reported about a sand column, 42 inches high, that was completely water saturated and then left to drain for 40 days. He deduced ψ from the height in the column. The volumetric water contents θ at the corresponding heights produced points on the sand-specific retention curve $\psi(\theta)$ that expresses equilibrium between gravitational and capillary forces on one side, and ψ and θ on the other side. Conveniently, Briggs' capillary flow results from any deviation from the $\psi(\theta)$ static equilibrium. He further postulated the concept of hydraulic conductivity in partially water saturated soils. Buckingham was also a physicist with US-Bureau of Soils. His report on the movement of soil moisture is frequently viewed as the origin of modern concepts of capillary flow (Buckingham, 1907): He extended Darcy's law to unsaturated soils, and he proposed hydraulic conductivity, diffusivity and the water capacity as functions of soil moisture. However, " .. Buckingham did not manage to formulate a clear cut physical-mathematical flow theory that quickly inspired other soil physicists" (Raats and Knight, 2018). The inspiration came with Richards'(1931) "Capillary Conduction of Liquids Through Porous Mediums", where he presented the three-dimensional form of the second-order convection-diffusion equation, that bears his name. He also presented the experimental procedures for the determination of the parameters. He authoritatively stated "If there is a steady flow of liquid through a porous medium which is only partially saturated, then the larger pore space containing air and the effective cross-sectional area of the water conducting region is reduced. If these air spaces could in some way be filled with solid, the condition of the flow would be unchanged and the proportionality between the flow and the water-moving force would still hold because Darcey's law is independent of the size of particles or the state of packing". The statement reveals the fundamental, but scientifically unproven exclusivity he put on capillary

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flow during infiltration, raising it to the soil hydrological dogma still confronting us today. Increasing the flow rate in a partially saturated porous medium mandatorily requires the increase of the hydraulic gradient by locally either increasing or decreasing capillary potential that, in turn, has to equilibrate in either case with the water content. In Richards' context this is only feasible during infiltration when flow remains sequential i.e., finer pores have to fill before coarser pores are allowed to (Germann, 2018).

3 Alternative approach to infiltration and drainage

Getting away from the dominance of Richards'(1931) capillary pproach to infiltration and drainage demands a concept that excludes capillarity. In an early attempt, Germann (1985) successfully approached transient infiltration/drainage with kinematic wave theory. More recently, Germann and al Hagrey (2008) summarize the features of viscous flow during transient infiltration and drainage in the Kiel sand tank. (i) constant velocity of the wetting front; (ii) collapse to atmospheric pressure of capillarity behind the wetting front; (iii) infiltration and drainage follow the same simple rules of viscous flow. Moreover, no pore classification is required to the application of viscous flow.

4 What happens at the soil surface during infiltration?

Infiltration summarizes water flow from above ground, usually in the shape of drops, to water flow below ground. Drops have internal pressures higher than atmospheric. According to Laplace-Young, pressures against the atmosphere in drops increase from about 15 to 750 Pa as their diameters reduce from 5 to 0.1 mm. Drops hit the soil surface and burst. The remains join and form local films at atmospheric pressure. There are two ways for water to continue. Either, water has to follow the strongest gradient, as in capillary flow. Richards' (1931) forceful conjecture of the dominance of capillarity during infiltration in unsaturated porous media works well under steady-state conditions, however, increasing the flow rate causes the well-known phenomena of non-equilibrium flow, macropore flow, and preferential flow. Or, water follows the way of least resistance, as in viscous film flow. This type of flow occurs under atmospheric pressure, regardless of the films' thicknesses and path widths, as Flammer et al. (2000) have demonstrated with acoustic velocity measurements across soil columns, and Germann (2018) has further explained.

5 Where are we now?

On the one hand, the story of Richards' (1931) dogmatic capillary flow and its hydro-mechanical inconsistencies leading to preferential, non-equilibrium, and macropore flow continuously produce a wealth of review articles that have not to be listed here. On the other hand, there are hardly continuing research efforts, both theoretical and experimental, on applying viscous flow to infiltration in unsaturated soils outside the author's reach. Thus, instead of re-hashing here previously achieved bits and pieces of viscous flow research, readers are invited to visit *GOOGLE SCHOLAR- Peter Germann*.

In conclusion: Briggs (1897) convenient and, within his concept correct definition of capillary flow led to Richards' (1931) dogma of capillary flow's unproven dominance during infiltration. As it turned out, capillary flow relies on the strongest force exerted on water during infiltration. Beven's (2018) contemplation on "A century of denial: Preferential and nonequilibrium water flow in soils 1864-1984" builds a bridge to the dominance of the weakest force during infiltration into permeable media, that is viscous flow.

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References

Beven, K. 2018. A century of denial: Preferential and nonequilibrium water flow in soils 1864-1984. Vadose Zone J. 17:.180153. doi:10.2136/vzj2018.08.0153

Briggs, L. J. 1897. The mechanics of soil moisture. Bulletin No. 10, U.S. Department of Agriculture, Division of Soils.

Buckingham, E. 1907. Studies on the movement of soil moisture. U.S. Department of Agriculture, Bureau of Soils, Bulletin No. 38.

Flammer, I., A. Blum, A. Leiser, and P. Germann. 2001. Acoustic assessment of flow patterns in unsaturated soil. J. of Applied Geophys. 46:115-128.

Germann, P. F. 1985.Kinematic wave approach to infiltration and drainage into and from soil macropores. Trans. ASAE, 28(3): 745-749.

Germann, P. 2014. Preferential flow - Stokes approach to infiltration and drainage. Geographica Bernensia, Bern (Switzerland), 199 p. https://boris.unibe.ch/119081/1/preferential_flow.pdf.

Germann, P. 2018. Viscosity - the weak link between Darcy's law and Richards' (1931) capillary flow. Hydrol. Process. 32: 1166-1172.

Germann, P.F., and S. A. al Hagrey. 2008. Gravity-driven and viscosity-dominated infiltration in a full-scale sand model. Vadose Zone J. 7: 1160-1169. doi: 10.2136/vzj2007.0172.

Raats, P. C. A., and J. Knight. 2018. The contributions of Lewis Fry Richardson to drainage theory, soil physics, and the soil-plant-atmosphere continuum. Frontiers of Environmental Sciences 6:13. Doi: 10.3389/fenvs.2018.00013

Richards, L.A. 1931. Capillary conduction of liquids through porous mediums. Physics 1:318- 333.