Comments

Comment on "Understanding preferential flow in the vadose zone: Recent advances and future prospects" by N. Jarvis et al.

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There is increasing agreement that preferential flow in soils is fast, limited to infiltration, and occupies but small portions of porosity. However, how fast is it, how much water is involved, what is its flow rate, and how far does it carry? Jarvis et al. (2016) hardly touched an approach that bears the potential of providing some answers: "A parsimonious alternative is to simulate gravity-driven variably-saturated flow in the macropore domain with a kinematic wave equation that can be derived from a generalization of pore-scale flow equations (Beven and Germann, 2013)." Early on, Germann (1985) indeed relied on the kinematic wave theory by Lighthill and Witham (1955). But the theory has evolved since to a powerful mathematical tool dealing with viscous flow where only the exponent in the flow equation is restricted to the third power (Germann, 2014). The focus has shifted on viscous flow that complements Richards' (1931) capillary flow in porous media to the completion of flow in permeable media containing pores, fissures, cracks, and channels. Gerke et al. (2010), for instance, concluded that ".. preferential flow may be viewed as Stokes [i.e., viscous flow] flow penetrating Richards flow. The two mutually penetrating flow concepts differ in the dimensionality of time..." There is a coherent stream of concepts from Newton's law of shear, "the resistance, arising from the want of lubricity in the parts of a fluid, is, caeteris paribus, proportional to the velocity with which the parts of the fluid are separated from each other" (Newton, 1729, p. 184) on to Stokes' (1845) laminar flow, to Poiseuille's (1846) law, Darcy's (1856) law, and general viscous flow (Lamb, 1932). Germann and Karlen (2016), for instance, adapted it to preferential flow in permeable media, including the experimental protocol. Similar to Nimmo (2010), Hincapié and Germann (2009) presented viscous flow as a moving water film gliding over the resting soil parts. The essential parameters of viscous flow are the film thickness F (μm) and the specific contact area L (m^2 m^{-3}) of the film per unit volume of the medium. The velocity v (m s^{-1}) of the wetting front and the volumetric water content increase w (m^3 m^{-3}) during a film's passing are the two parameters to measure that lead to F and L. Both v and w are relatively easy to determine in situ in partially saturated permeable media with equipment available in most soil physics units. Based on more than 200 recordings of preferential viscous flow in profiles and columns of undisturbed soils, Hincapié and Germann (2009) presented frequency distributions of w, F, and L in the ranges of $0.005 \leq w \leq 0.16$ m^3 m^{-3}, $5 \leq F \leq 120$ μm, and $400 \leq L \leq 20{,}000$ m^2 m^{-3}, respectively. The variable F indicates the minimal width of preferred-flow paths, while L is considered the exchange locus for water, solutes, particles, and heat between the moving film and the sessile parts of the medium. Unfortunately, this kind of information is not mentioned in the review on understanding preferential flow. Quite the opposite: Jarvis et al. (2016) criticize the procedure of Germann and Hensel (2006) by referring to Hunt et al. (2013), who noted that errors and misunderstandings can arise from such indirect approaches if they are based on oversimplified or incorrect conceptual models. Jarvis et al. (2016) are not specific about what is incorrect in the measurement-based approach of Germann and Hensel (2006), who applied the same principle to preferential flow in soils as Hagen and Poiseuille (Poiseuille, 1846) did to blood flow vessels. The procedure yields densities and diameters of cylindrical pores in the ranges from 10^6 to 10^8 m^{-2} and from 7 to 30 μm, respectively. Without referring to sources, Jarvis et al. (2016) postulate path widths of preferential flow of approximately 300 to 500 μm.

Germann and al Hagrey (2008) analyzed flow in a Kiel sand tank using the viscous flow approach, demonstrating that the parameters F and L, as derived from time domain reflectometer recordings of the water content wave gliding through the sand, also quantified the associated drainage reasonably well. Additionally, viscous flow predicts a constant wetting front velocity. The sand tank experiment yielded a coefficient of determination of 0.99 in a linear regression of the arrival time of the wetting front vs. the depths of the arrival time recordings.

Dual permeability "models implicitly assume that a representative elementary volume (REV) can be defined for macropores at the relevant scale of interest ..." (Jarvis et al., 2016). However, only capillary flow requires a REV because of the relationship between the total water content and the capillary potential that, in turn, affects the hydraulic capillary gradient. In contrast, besides the static structure of the permeable medium, viscous flow depends solely on the two boundary conditions of volume flux density and its duration. Wetting front velocities may illustrate the scale tolerance of viscous flow. Hincapié and Germann (2009) also reported their frequency distribution within $6 \times 10^{-5} \leq v \leq 2 \times 10^{-2}$ m s^{-1}. Dubois (1991) reported tracer injection 1800 m vertically above the Mont Blanc car tunnel that connects France and Italy. He found the tracers after 108 d in low-pressure seeps in the tunnel. This yields a flow velocity of about 2×10^{-4} m s^{-1} that scores in the lower third of the above distribution, and that is about six times faster than the wetting front moving at 3×10^{-5} m s^{-1} through the dry sand of the Kiel sand tank (Germann and al Hagrey, 2008).

Finally, neither Darcy (1856) nor Buckingham (1907) nor Richards (1931) stressed a priori the separation of pores and presumed flow paths. They rather postulated models that are solidly based on theoretical principles representing well the relationships that they envisioned from experience. They also provided the procedures for the experimental determination of the associated parameters and functions. They should serve as role models in the development of quantitative approaches to preferential flow. Their examples may downsize to a realistic scale the "... significant advances that we expect to see in computational techniques, computer hardware and measurement technologies, this improved process understanding should eventually lead to more reliable predictive modeling tools." (Jarvis et al., 2016).

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