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Investigating preferential flow dynamics in idealized porous fracture networks via (quasi) 2-D lab experiments – Controls of fracture and matrix properties on flow behavior

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Quantification of infiltration processes in the vadose zone of fractured-porous media and karst systems (epikarst), especially onset and magnitude of preferential flow, as well as the interaction between fast (fractures, macropores) and slow pathways (matrix), is still lacking a sound conceptualization.

This study presents results from laboratory experiments which were designed to delineate the control of network topology, fracture aperture, matrix imbibition and infiltration conditions on preferential flow dynamics. We create vertical 2-D fracture networks using a set of equally sized (Seeberger) sandstone blocks placed in between two transparent glass plates. Blocks are arranged to create an orthogonal network with vertical and horizontal fractures of constant aperture. Water is injected with a constant rate directly into the middle vertical fracture on the upper network boundary by a pump. Mass flux across the lower network boundary is measured by a scale to register first arrival. In addition, flow partitioning at intersections and advance of the wetting front were visually captured.

Two experiment series were carried out: (1) the effect of horizontal offset (2, 5, 10, 15, 20 and 24 mm) was studied for two different fracture apertures (1 and 3 mm), but constant infiltration rate (1.5 ml/min). (2) The fracture aperture was kept constant (1 mm) and infiltration rate was varied (0.75, 1.50 and 3.00 ml/min), as well as the offset. The first series demonstrates that greater offset is associated with pathway spreading and hence divergent behavior of the wetting front, as well as later arrival times. Pathway spreading increases the fracture-matrix interface area in total, thus preferential flow is slowed down more efficiently by the imbibition process. Less pathway spreading, and faster arrival times were observed for the larger aperture configuration (3 mm). Aperture (and infiltration rate) strongly controls flow modes. Whereas slug flow (liquid in contact with both fracture walls) is a dominant flow mode in the 1 mm aperture configuration due to capillary forces, it is not the prevailing mode in the 3 mm aperture configuration. The second series reveals faster arrival times for higher inflow rates (3.00 > 1.50 > 0.75 ml/min), as well as smaller differences between arrival times of different offsets as flow rate increases.

To capture bulk infiltration dynamics, the results can help to parameterize analytical infiltration

models such as the source-responsive dual domain model, which was developed by Nimmo (2010, VADOSE ZONE J) to capture preferential flow dynamics in soils.