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The Physics of Unstable Infiltration, Seepage, and Gravity Drainage in Partially Saturated Tuffs

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Abstract.

To improve understanding of the physics of dynamic instabilities in unsaturated flow processes within the Paintbrush nonwelded unit (PTn) and the middle nonlithophysal portion of the Topopah Spring welded tuff unit (TSw) of Yucca Mountain, we analyzed data from a series of infiltration tests carried out at two sites (Alcove 4 and Alcove 6) in the Exploratory Studies Facility, using analytical and empirical functions. The analysis of infiltration rates measured at both sites showed three temporal scales of infiltration rate: (1) a *macro-scale* trend of overall decreasing flow, (2) a *meso-scale* trend of fast and slow motion exhibiting three-stage variations of the flow rate (decreasing, increasing, and [again] decreasing flow rate, as observed in soils in the presence of entrapped air), and (3) *micro-scale* (high frequency) fluctuations. Infiltration tests in the nonwelded unit at Alcove 4 indicate that this unit may effectively dampen episodic fast infiltration events; however, well-known Kostyakov, Horton, and Philip equations do not satisfactorily describe the observed trends of the infiltration rate. Instead, a Weibull distribution model can most accurately describe experimentally determined time trends of the infiltration rate. Infiltration tests in highly permeable, fractured, welded tuff at Alcove 6 indicate that the infiltration rate exhibits pulsation, which may have been caused by multiple threshold effects and water-air redistribution between fractures and matrix. The empirical relationships between the extrinsic seepage from fractures, matrix imbibition, and gravity drainage versus the infiltration rate, as well as scaling and self-similarity for the leading edge of the water front, are the hallmark

of the nonlinear dynamic processes in water flow (under episodic infiltration through fractured tuff). Based on the analysis of experimental data, we propose a conceptual model of a dynamic fracture flow and fracture-matrix interaction in fractured tuff, incorporating the time-dependent processes of water redistribution in the fracture-matrix system.

Keywords: fractured rock, infiltration, seepage, gravity drainage, infiltration equation