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## Nature of the Dry Shadow below Cavities in Vadose Zone

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Several theoretical studies have indicated that the presence of subsurface cavities in the vadose zone results in complete or partial diversion of flow around cavities. As a result, the region immediately below the cavities is partially shielded from the downward flux. This shadowing effect of cavities can be exploited in the design of dry subsurface storage facilities as an additional barrier to contain waste within or around the cavities. However, empirical evidence that supports these theories is lacking. This study is motivated by the inherent difficulty to make direct observation of the shadow zone as it occurs under very dry conditions. To aid future field and laboratory scale investigations of the shadow zone, we performed rigorous theoretical scrutiny of the conditions that result in the shadowing effect. We formulated relative permeability and saturation based criteria to identify the boundaries of the shadow zone. Analytical and numerical tools were used to develop dimensionless scaling laws that define the size of the shadow zone. Moreover, we analyzed the effect of natural perturbations (heterogeneity and fracturing) on the integrity of the shadow zone. The results will be used in selecting study sites; identifying observation locations and methods; and designing active tests to test the concept of shadow zone.

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