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Climate, soil and vegetation controls on the temporal variability of recharge and solute delivery to groundwater

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The stochastic variability of rainfall and the uptake of water by plants are an important drivers of the temporal patterns of solute transport and transformation through the vadose zone. In this work we develop a framework for examining the role of the hydrologic filtering, and in particular the effect of evapotranspiration, in determining the travel time and delivery of sorbing, reacting solutes transported through the vadose zone by stochastic rainfall events. We describe a 1-D vertical model of solute transport that treats solute pulses as point loads. These are transported to depth by a series of discrete infiltration events (storms). A comparison to the Richards equation-based HYDRUS model demonstrates that this model performs very well for some typical cases of climate, soils and solutes. Utilizing existing theory of the stochastic dynamics of soil moisture, we derive analytical and semi-analytical expressions for the PDFs of solute travel time and delivery, as well as their mean and standard deviation. These simple expressions capture the controls of the soil, climate and vegetation on the travel time and delivery ratio. In particular they show how three dimensionless numbers can be used to predict how evapotranspiration will reduce (and make more uncertain) the mass of a degrading solute delivered to the base of the vadose zone. These expressions also provide insight to the shifting importance of different controls across a range of conditions. Results suggest that in dry climates, rare large storms can be an important mechanism for leaching to groundwater. The framework suggests a classification of different regimes of process dominance in solute transport through the vadose zone.