Geophysical Research Abstracts
Vol. 13, EGU2011-11184, 2011
EGU General Assembly 2011

Dissecting the variable source area – Four dimensional characterization of flow pathways and water mixing processes in VSAs

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Variable source areas (VSAs) are hot spots of hydrological (saturation excess runoff) and biogeochemical processes (e.g. nitrogen, phosphorus, organic carbon cycling) in the landscapes of the northeastern U.S. The prevalence of shallow, highly transmissive soils, steep topography, and impeding layers in the soil (i.e. fragipan) have long been recognized as first-order controls on VSA formation. However, understanding of the importance of flow pathways and scales of runoff production on hydrological connectivity and the risk of surface nutrient transport in these landscapes is still incomplete. This study uses an instrumented (trenched) 0.5 ha hillslope in the southern tier of New York State, U.S.A., to provide new data and insights on how variable source areas and associated flow pathways form and combine to connect rainfall with downstream water flows, and waterborne tracer and pollutant mass flows across a hillslope landscape. Measurements of water fluxes in the trench, upslope water table dynamics, surface and bedrock topography, and isotopic and geochemical tracers have been combined for a four-dimensional (space-time) characterization of subsurface storm flow responses. During events with dry antecedent conditions infiltrating rainwater was found to percolate through a prevailing fragipan layer to deeper soil layers, with much (33 – 71 %) of the total discharge from the hillslope then coming from deeper water flow below the fragipan. During these events runoff is the result of a relative unchanging ground water condition with an approximate flow rate of 0.08 mm/hr, which is independent of antecedent moisture conditions or storm magnitudes. During storm events with wet antecedent conditions and large rainfall amounts, shallow lateral flow of event and pre-event water above the fragipan occurred and was one magnitude greater than the deeper water flow contribution. Observed saturated area extents and similarity of water chemistry in the total discharge and in water sampled from upslope piezometer wells indicate that water from a distance of up to 56 m contributed runoff from the hillslope during storm events. These results clarify the range of hydrological connectivity that VSA can reach with the surrounding landscape and how important it is to include this understanding in watershed models to improve the performance of water quality models in these environments. The results have particularly implications for choices of measures to protect streams and other downstream water recipients from waterborne nutrient and pollutant loading.