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Emergent effects of heterogeneity on discharge at hillslope and catchment scales, and implications for prediction

C.J. Harman (1), M. Sivapalan (2), and P. Kumar (1)

(1) University of Illinois at Urbana-Champaign, Department of Civil and Environmental Engineering, Urbana, IL, United States (charman2@illinois.edu, +1-(0)217-333-0687), (2) University of Illinois at Urbana-Champaign, Departments of Geography and Civil and Environmental Engineering, Urbana, IL, United States (sivapala@illinois.edu, +1-(0)217-244-1785)

The patterns, or 'signatures', present in hydrographs arise from the interaction of the heterogeneity of catchment properties and atmosphereic forcing in space and time. As such they offer vital, if narrow, windows into the hydrologic functioning of catchments. Many conceptual models of catchment hydrology derived from the hydraulics of flow through landscapes can reproduce these signatures, but are based on an assumption of homogeneous physical properties, and in practice rely on the identification of 'effective' properties calibrated from data. In reality though, catchment hydraulic properties are known to be highly spatially variable. This raises the question as to whether such models are getting the "right answer for the wrong reasons".

In this work we will show that two such signatures, the shape of the recession slope curve and hysteresis in the relationship between storage and discharge, can be explained in terms of the heterogeneity of catchment properties. A simple method for modeling catchment subsurface discharge is presented that assumes hillslopes behave as linear reservoirs, and represents catchment heterogeneity as a p.d.f. of reservoir characteristic timescales. We use this method to derive a number of useful results, including showing that under certain circumstances, the exponent of the recession slope curve is directly related to the coefficient of variation of catchment characteristic timescales. The degree of hysteresis is also related to this property. By applying the method to data from the Panola Mountain Research Watershed, we show that it is possible to estimate the pdf of timescales from the recession slope curve directly. The data suggests that the variance of characteristic timescales increases markedly with scale, while the mean varies much less.

These results suggest that parameterizing the heterogeneity of catchment properties offers an alternative basis to hydraulic theory for explaining the signatures present in hydrographs, and for prediction of the emergent catchment scale behavior. In reality, catchment signatures are affected by the non-linearities that arise from flow hydraulics and from heterogeneity. Getting the "right answer for the right reasons" will require the development of techniques for separating these effects, either through observation of the influence of catchment structure on flow (such as with tracers), or through a better understanding of the origins of catchment heterogeneity and structure.