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Catchment residence times as independent criteria to evaluate model structural error

K. Vaché, J. McDonnell

(1) Department of Forest Engineering, Oregon State University, Oregon, USA
(kellie.vache@oregonstate.edu / Fax: +1 541-7374316 / Phone: +1 541-7376296)

Process representation in catchment model structure continues to be a vexing issue in hydrology. Complex hydrological descriptions at the hillslope scale have been difficult to incorporate within a catchment modeling framework due to the disparity between the scale of measurements and the scale of model sub-units. Despite this clear challenge, estimates of model predictive uncertainty generally assume that the process representation within the model is error free. The rationale for this assumption is that we have few means (beyond the predictive variable of discharge) to test the structural integrity of the model. This paper examines how estimates of catchment mean residence time may be used to subsume process complexity and provide a simple, scalable evaluative data source for conceptual model structural evaluation. We present a simple distributed hydrologic modeling framework and use Monte Carlo simulation to evaluate a set of model structures, from very simple to increasingly complex. We explore the identifiability of parameters represented by those structures and note which model structures are acceptable simulations of both catchment discharge and streamwater residence time. We show how many model structures are able to reproduce discharge or residence time, but not both. This combination of orthogonal model structure evaluations is a process-based rejectionist framework and provides significant insight into the evaluation of conceptual model structure. Given that contact time in the subsurface is a main control on water chemistry, this evaluation of structural error is especially useful for models involving the simulation of solute chemistry.