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Propagation of Nonlinearities from the hillslope scale to the watershed scale

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In this work we address the question of how nonlinearities in rainfall-runoff transformation that occur at the hillslope scale propagate through the river network to a watershed outlet using a theoretical model of runoff generation and runoff transport. We use a system of ordinary differential equations (ODEs) to represent simultaneously the aggregated behavior of changes in water storage in the surface, the unsaturated and the saturated soil layers of a hillslope element. The ODE system can be modified to exhibit nonlinearities observed in data but can also be reduced to a simpler linear system that only partially captures the hillslope dynamics. The ODE system is coupled to a runoff routing scheme to propagate runoff generated at the hillslope scale through the river network to the watershed outlet. We assess the differences in the response of the system for the linear and nonlinear hillslope response models. It is shown that the differences in the hydrographs at the watershed scale decrease with increasing scale (i.e. upstream basin area). Our results reveal the role of the self-similar river network in smoothing out, not only spatial variability present in the system, but also aspects of the local-scale complex dynamics. Our work also helps explain how the performance of overly simplified watershed models can be comparable to more sophisticated, realistic and physically-based ones.