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Analysis of the interactions between rivulets and the surrounding soil domain in an integrated groundwater-surface water model

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The interaction of groundwater and surface flow is a key focus of interest in many hydrological, geological, and biological processes such as runoff generation, landslide/debris flow initiation, and aquatic habitat development. A number of modeling tools have been consequently developed for their joint treatment. The more computationally intensive approaches use shallow water equations (i.e., one- or two-dimensional approximation of the Saint-Venant equations) to describe overland and/or channel flow, coupled with a groundwater component treated by the Richards equation. The rate and direction of exchange fluxes at the land surface depend on the spatial and temporal distribution of rainfall and on the topographic and hydraulic characteristics of the land surface. As demonstrated in many laboratory and field studies, runoff over hillslopes initially starts as sheet flow, then it concentrates into a series of channels and rivulets according to topographic irregularities and differences in soil erodibility. It is important therefore to address the accurate conceptualization of water exchanges between a channel network and the surrounding soil domain. In this study, the planar and relief configuration of the rivulet/channel network is determined explicitly from grid-based digital elevation model data using detailed algorithms for the determination of single or multiple drainage directions. Rivulet and channel geometry is characterized by combining the concepts of at-a-station and downstream hydraulic geometry and by using relevant physiographic features such as upslope area and slope to allow parameter estimations. Surface runoff is propagated through the channel network using a diffusion wave conceptualization based on the Muskingum-Cunge method with variable parameters, which is capable of incorporating the channel network characteristics obtained from terrain analysis and from the application of

the hydraulic geometry concept. Flow characteristics are combined with terrain data to provide accurate estimates of water depth at the land surface for use as boundary conditions of the soil domain. Numerical experiments are carried out to evaluate the sensitivity of response variables to model parameters affecting the exchange of water at the interface between rivulets/channels and soil domain under different geomorphic and climatic settings. These numerical experiments aim to assess: (1) the relevance of using single or multiple drainage direction algorithms, (2) the sensitivity to channel network geometry parameters, and (3) the relative role of channel flow resistance coefficients and soil conductivity. Illustrative test cases considering simple synthetic drainage systems and complex real catchments are presented.