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Integrated Coupling of Surface and Subsurface Flow with HYDRUS-2D

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Describing interactions between surface and subsurface flow processes is important to adequately define water flow in natural systems. Since overland flow generation is highly influenced by rainfall and infiltration, both highly spatially heterogeneous processes, overland flow is unsteady and varies spatially. The prediction of overland flow needs to include an appropriate description of the interactions between the surface and subsurface flow. Coupling surface and subsurface water flow is a challenging task. Different approaches have been developed during the last few years, each having its own advantages and disadvantages. A new approach by Weill et al. (2009) to couple overland flow and subsurface flow based on a generalized Richards equation was implemented into the well-known subsurface flow model HYDRUS-2D (Šimůnek et al., 2011). This approach utilizes the one-dimensional diffusion wave equation to model overland flow. The diffusion wave model is integrated in HYDRUS-2D by replacing the terms of the Richards equation in a pre-defined runoff layer by terms defining the diffusion wave equation. Using this approach, pressure and flux continuity along the interface between both flow domains is provided. This direct coupling approach provides a strong coupling of both systems based on the definition of a single global system matrix to numerically solve the coupled flow problem. The advantage of the direct coupling approach, compared to the loosely coupled approach, is supposed to be a higher robustness, when many convergence problems can be avoided (Takizawa et al., 2014). The HYDRUS-2D implementation was verified using a) different test cases, including a direct comparison with the results of Weill et al. (2009), b) an analytical solution of the kinematic wave equation, and c) the results of a benchmark test of Maxwell et al. (2014), that included several known coupled surface subsurface flow models. Additionally, a sensitivity analysis evaluating the effects of various model parameters on simulated overland flow (while considering or neglecting the effects of subsurface flow) was carried out to verify the applicability of the model to different problems. The model produced reasonable results in describing the diffusion wave approximation and its interactions with subsurface flow processes. The model could handle coupled surface-subsurface processes for conditions involving runoff generated by infiltration excess, saturation excess, or run-on, as well as a combination of these runoff generating processes. Several standard features of the HYDRUS 2D model, such as root water uptake and evaporation from the soil surface, as well as evaporation from runoff layer, can still be considered by the new model. The code required relatively small time steps when overland flow was active, resulting in long simulation times, and sometimes produced poor mass balance. The model nevertheless showed potential to be a useful tool for addressing various issues related to irrigation research and to natural generation of overland flow at the hillslope scale.

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