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A low-dimensional hillslope and catchment runoff model based on a subsurface variable-source area hypothesis with weathered bedrock groundwater

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Recent field studies have reported that groundwater in weathered bedrock underlying mountainous hillslopes plays a key role in baseflow and storm flow dynamics. On the other hand, many hillslope runoff models and catchment models composed with the hillslope building units treat the soil-bedrock boundary as essentially impermeable. The inadequate modeling may limit the capability of appropriately simulating rainfall-runoff processes and also understanding effects of the groundwater surface-water interaction in mountainous regions. In this study, we conceptualized the hillslope as permeable bedrock with an overlaying soil layer, and proposed a hillslope model that can easily extend to the catchment scale. The model assumes the exponential-decline hydraulic conductivity in the bedrock to avoid defining the unknown bottom boundary. For the soil layer, it employs a stage-discharge relationship to represent the unsaturated and saturated subsurface flows and the saturation excess overland flow. The set of equations used in this study resembles the one-dimensional Boussinesq equation after introducing the Dupuit-Forchheimer assumption. In the analysis of the simulation results, we primarily focused on the Brutsaert and Nieber recession plot (i.e. Q - dQ/dt relationship) to investigate the recession characteristics. Both hillslope- and catchment-scale results suggested that the bedrock layer creates a non-linear shape in the recession curve, which is similar to the solution of the one-dimensional Boussinesq equation at its early stage from the saturated condition, and also suggested that storm flow recession rates vary depending on the groundwater levels. These behaviors were consistent with field observations obtained from a catchment dominated by weathered bedrock groundwater.