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Similarity analysis of subsurface flow response of hillslopes with complex geometry

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Recently, Troch et al.(2003) introduced the hillslope-storage Boussinesq (hsB) equation to describe subsurface flow and saturation along complex hillslopes. The hsB equation can be linearized and further reduced to a diffusion-advection equation for hillslopes with constant bedrock slopes and exponential width functions. We present a dimensional analysis of this equation in order to study the characteristic subsurface flow response, defined as the hydrograph at the hillslope outlet during drainage. In the Laplace domain, an analytical expression for the discharge is obtained and used as moment generating function to derive the analytical expressions for the moments of the characteristic response time distribution (CRTD), defined as the hydrograph normalized by the flow volume. These moments, in a dimensionless form, can be expressed as function of a subsurface flow similarity parameter, hereafter called the hillslope Péclet number, and a group of dimensionless numbers accounting for the initial and boundary condition effects. The analysis of their respective influences on the first four CRTD central moments shows that the first studied type of initial condition (uniform water table depth) has a strong impact on the dimensionless mean response time of the CRTD but negligible effect on the higher order moments, while the second studied type of initial condition (steady state water table profile) has a limited effect on all first four CRTD moments. Hence, in the latter case, the hillslope Péclet number completely defines the subsurface flow similarity between hillslopes, that is the characteristic response, once normalized, is only determined by the value of the Péclet number.