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Effects of the Spatial Variability of Rainfall and Hillslope-Channel Link Dynamics on the Scaling Structure of Peak Discharge

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We use a drainage network based rainfall-runoff model called CUENCAS and the Cedar River basin in Iowa (with drainage area A = 16,853 km^2) to systematically investigate the effect of spatial variability of catchment antecedent moisture state, rainfall, hillslope overland flow velocity, and channel velocity on the scaling structure of peak discharge (Q). We show that, in a nested watershed, scale invariance of peak discharge is preserved when these catchment physical properties are spatially variable and it follows a power law of the form $E\left[Q(A)\right] = \alpha A^{\theta}$, where $E\left[Q(A)\right]$ is the expected value of peak discharge, A is the drainage area, α is the intercept, and θ is the scaling exponent. The results further show that the variance of peak discharge estimate, which is due to the river network and the spatially variable catchment physical properties, is significant at smaller scales and decreases as the scale increases. Moreover, at larger scales, $E\left[Q(A)\right]$ evaluated using a spatially variable catchment antecedent moisture state and rainfall is equivalent to $E\left[Q(A)\right]$ evaluated using the mean catchment antecedent moisture state and rainfall that is applied uniformly in space. However, at similarly larger scales, $E\left[Q(A)\right]$ evaluated using a spatially variable hillslope overland flow velocity is less than $E\left[Q(A)\right]$ evaluated using the mean hillslope overland flow velocity that is applied uniformly in space. Furthermore, we show the existence of two types of scale breaks. The first one occurs at smaller scales that are in the range of 1 – 10 km^2 and it occurs when runoff generated on hillslopes is assumed to quickly enter the drainage network. The second one occurs, under our present channel and hillslope overland flow velocity assumptions, at scales in the order of 200 km^2 and is caused when rainfall duration is less than the catchment residence time (‘time of concentration’). In both cases, the scale break disappears as rainfall duration equals or exceeds the catchment residence time. Finally, we show that α and θ are systematically controlled by the interplay among rainfall duration, intensity, hillslope overland flow velocity, and channel velocity.