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Variability in suspended sediment concentration: the effect of spatially distributed rainfall and surface erodibility, and hillslope connectivity in sediment transport.

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In mountain environments, steep slopes and intense precipitation favour high rates of soil erosion and sediment delivery into rivers, which can cause major problems, such as agricultural soil loss, decreased water quality and excessive sedimentation. The understanding of cause-effect relationships between rainfall, runoff, sediment production and transport is therefore of primary importance to improve our ability to predict spatially-distributed erosion rates and sediment yields at the basin outlet.

When measuring suspended sediment concentrations at the outlet of a river basin, a large variability is usually observed in the rating curve, i.e. the suspended sediment concentration (SSC) as a function of discharge (Q). The source of this scatter is generally attributed to the inherent stochasticity of the sediment production and transport processes involved along the sediment pathways in a catchment.

In this study, we show that scatter in the SSC-Q relationship may also arise in fully deterministic modelling of catchment sediment production and transport by overland flow. For this purpose, we developed a hillslope and channel suspended sediment flow component in the spatially distributed hydrological model TOPKAPI-ETH.

By applying the model to the Kleine Emme watershed (Switzerland), we explore how variability in the SSC-Q rating curve is affected by (a) rainfall variability in space, (b) surface erodibility distribution in space and (c) spatial connectivity of sediment sources to the channel network. We complement the analysis by investigating the sediment delivery ratios (SDRs) as a measure of the connectivity of the sediment sources to the channel network.

We show that the variability in rainfall contributes to the scatter in the SSC-Q relation, because it activates localized sources of sediment production.
Based on the model assumption that sediment discharge equals the transport capacity of overland flow, spatially variable surface erodibility introduces areas of localized increased sediment productivity and others of low transport capacity where sediment may be deposited. Overall, this results in a reduction of SSC variability at the outlet, due to a decreased sediment connectivity at the catchment scale.

The SDR analysis supports this result, by showing a significantly lower sediment connectivity when spatially variable surface erodibility is considered, i.e. when the presence of sediment buffers is simulated. The analysis also shows that sediment connectivity increases in the downstream direction due to the absence of significant sediment sinks in the catchment. The upper part of the basin has a lower sediment connectivity than the tributaries, due to a Last Glacial Maximum landscape disconnected from the fluvial network.

To summarize, we conclude that (1) spatially-distributed deterministic models of rainfall-runoff-erosion processes can generate large variability in SSC for a given discharge; (2) the spatial distribution of rainfall and the connectivity of localized sediment sources to the channel network are key to capture the scatter in the SSC-Q relation. Furthermore, our results show that the connectivity of sediment transport can vary significantly within a catchment with a diverse geomorphology and the location of buffers of sediment transport on hillslopes plays an important role in determining the global sediment connectivity.