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Spatio-temporal organization of sediment dynamics at the hillslope scale.

In hilly landscapes, where erosion rates do not exceed the weathering rates of bedrock material, the shape of hillslopes is typically convex near the hilltop and becomes increasingly planar further downslope with the steepest descent in the middle of the slope and a concave shaped hillfoot. This convex-concave shape is the result of long term erosion and sediment redistribution processes driven by tectonic and climatic forcing. We hypothesize that this typical shape is related to optimized sediment transport dynamics when examined in a thermodynamic perspective. We used the process based model CATFLOW-SED to analyze the spatio-temporal organization of sediment dynamics at the hillslope scale. The model simulates overland flow using the diffusion wave equation. Soil detachment is related to the attacking forces of rainfall and overland flow. The detachment rate further depends on the model parameter erosion resistance, which is characterized by soil properties, land use and management practice. Transport capacity and deposition are modeled for different grain size fractions. For the hillslope studies, data of the Weiherbach catchment was used, which is located in an intensively cultivated loess region in Southwest Germany. We designed convex and convex/concave shaped slopes similar to the hillslopes in the Weiherbach catchment, with identical gradients, slope lengths, soil properties and vegetation but varying curvatures. Then we modeled sediment dynamics using observed rainfall and climate data and quantified the power generated by water and sediment flux for the different slopes. We found a minimum of the power generated by sediment flux for the convex-concave shaped hillslopes which represent the hypsometric curve of the Weiherbach catchment. The typically shaped hillslopes are thus in a state of minimum work performed on the hillslope, resulting in a steady hillslope shape and minimum sediment export. This tendency for a hillslope to develop towards an ‘optimal’ shape and sediment export rate should be generally applicable; a thermodynamically formulated principle of minimum work performed on hillslopes in steady state could hence serve as a constraint when estimating sediment export rates in ungauged catchments in similar landscapes.