Geophysical Research Abstracts
Vol. 13, EGU2011-11793-1, 2011
EGU General Assembly 2011

Process controls on scaling behavior of sediment delivery: Exploration with a physically based network scale coupled flow and sediment model

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Although sediment transport is extensively studied at the scale of a river reach, sediment dynamics at the watershed scale are still poorly understood. Sediment dynamics at this scale are largely determined by propagation of sediment pulses through the river network, which are driven mostly by the variability in flow conditions. Here, we present a model which simulates sediment export from small to medium size basins in two stages: (1) delivery of sediments from hillslope and bank erosion into the river channel, and (2) propagation of the sediments in the channel through the river network towards watershed outlet. The model conceptualizes a watershed as a collection of reaches associated with representative elementary watersheds (REW) that are connected to each other through the river network, and each REW comprises a lumped representation of a hillslope and channel component. The flow of water along the stream network is modeled through coupled mass and momentum balance equations applied in all the REWs and sediment transport within each REW is simulated through physically based sediment balance equations and closure relations. Every reach receives inputs of sediments from upstream REWs and also from the erosion of adjacent hillslopes, banks and the channel bed. We first tested the model using extensive data from Goodwin Creek, a small (21.3 sq. km) watershed in Mississippi, USA. The model yields good estimates of the timing and magnitude of sediment events as well as event-scale hysteresis in the sediment concentration-discharge relationship. Importantly, the model also captures reach scale degradation/aggradation dynamics at different locations within the watershed, which are useful in identifying primary erosion/deposition zones and the spatio-temporal patterns of sediment supply and depletion. These have a bearing on patterns of sediment delivery to the outlet, and how the sediment delivery ratio changes with increasing scale. The model is then used to explore the process controls on sediment delivery ratio, and to interpret observed scaling behavior of sediment delivery ratio in different climatic and geologic settings, and how they are affected by changes in land cover and land use.