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Alpine catchment sediment budget modelling through a quantitative sediment cascade procedure

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Small alpine catchment prone to intense erosion processes and debris flow events can transport large amount of sediment out of the watershed over a certain period of time, requiring the development of proper strategies of mitigation and solid waste management. Here is introduced a quantitative approach that enables assessing sediment budget at short, middle and long time that potentially accumulate at the outlet of an alpine torrent. The sediment budget modelling is illustrated by two small but active alpine torrents having a common outlet that are situated upon the Zinal region (southern walliser Alps – Switzerland).

Catchment erosion activity is simulated in terms of sediment detachment, transportation and transient deposition in a spatial-structured conceptual model reflecting the hillslope and torrent processes. The torrent (the channel network) is subdivided into reaches implying homogeneous geomorphic processes deduced from morphological features and from the mode of sediment transfer (sediment flux dynamic). Each channel segment is connected to its contributive area and forms a subsystem corresponding to a link of the sediment cascade. Each subsystem is composed of several individual sediment reservoirs supplying the cascade link with material directly (through bed and bank erosion) and indirectly (through potential and effective slope instabilities) according to its corresponding hillslope activity. These reservoirs have a limited storage capacity and are linked to each others with parameters estimates governing the exchange of sediment flux. At each simulation time step, each sediment cascade link performs an internal sediment balance before being propagated into the cascade next links and the sediment volumes are updated after each exchange of sediment flux. The cascade is activated on an event-based approach, whereas the sediment production and transport capacity is governed through several stochastic processes simulating the effect of rainfall and debris flow intensities with a frequency empirically defined.

The hillslope erosion processes and sediment volumes of the different reservoir were obtained through geological maps, high-resolution DEM and detailed field mapping. Maximum sediment supply coming directly from the bed and the banks were estimated with the slope local base level (SLBL) method that enables a 3D estimation of the maximum sediment volume potentially deliverable during an extreme event. Erosion rates and quantitative sediment production for the different geomorphic processes were estimated through mean value deduced from long term observation. The dynamic (entrainment/deposition) and transfer rate of sediment flux through the cascade links were defined according to the hypothesis that the channel network attempts to approach its longitudinal profile in equilibrium. Hence, the difference between the theoretical and channel profile provides qualitative information about the transient storage/re-entrainment of sediment volumes routed through the cascade.

The cumulative sediment budget simulations in the two alpine torrents reveal a mean sediment yield at the catchment outlet of 160‘000 to 210‘000 m3 over 100 years. In the perspective of climate change, and rainfall of high intensity would double, the sediment yield could rise up to 450‘000 m3. Several situations were simulated considering different process interaction between the subsystems (e.g. limited supply of sediment recharge, occurrence of extraordinary landslide events of Mm3). This distributed model based on channel units and individual process-response systems attempts to include the geological, morphological and sediment flux knowledge in each element of the sediment cascade. The scales of the hillslopes processes in space and time can be adapted and their implication along the sediment cascade links can be individually analysed.