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River network bedload model: a tool to investigate the impact of flow regulation on grain size distribution in a large Alpine catchment

Anna Costa and Peter Molnar

ETH Zurich, Institute of Environmental Engineering, Department of Civil, Environmental and Geomatic Engineering, Zurich, Switzerland (costa@ifu.baug.ethz.ch)

Sediment transport rates along rivers and the grain size distribution (GSD) of coarse channel bed sediment are the result of the long term balance between transport capacity and sediment supply. Transport capacity, mainly a function of channel geometry and flow competence, can be altered by changes in climatic forcing as well as by human activities. In Alpine rivers it is hydropower production systems that are the main causes of modification to the transport capacity of water courses through flow regulation, leading over longer time scales to the adjustment of river bed GSDs.

We developed a river network bedload transport model to evaluate the impacts of hydropower on the transfer of sediments and the GSDs of the Upper Rhône basin, a 5,200 km2 catchment located in the Swiss Alps. Many large reservoirs for hydropower production have been built along the main tributaries of the Rhône River since the 1960s, resulting in a complex system of intakes, tunnels, and pumping stations. Sediment storage behind dams and intakes, is accompanied by altered discharge due to hydropower operations, mainly higher flow in winter and lower in summer. It is expected that this change in flow regime may have resulted in different bedload transport. However, due the non-linear, threshold-based nature of the relation between discharge and sediment mobilization, the effects of changed hydraulic conditions are not easily deducible, and because observations of bedload in pre- and post-dam conditions are usually not available, a modelling approach is often necessary.

In our modelling approach, the river network is conceptualized as a series of connected links (river reaches). Average geometric characteristics of each link (width, length, and slope of cross section) are extracted from digital elevation data, while surface roughness coefficients are assigned based on the GSD. Under the assumptions of rectangular prismatic cross sections and normal flow conditions, bed shear stress is estimated from available time series of daily discharge distributed along the river network. Potential bedload transport is estimated by the Wilcock and Crowe surface-based model for the entire GSD. Mass balance between transport capacity and sediment supply, applied to each individual grain size, determines the actual transport and the resulting GSD of the channel bed. Channel bed erosion is allowed through a long-term erosion rate. Sediment input from hillslopes is included as lateral sediment flux. Initial and boundary conditions are set based on available data of GSDs, while an approximation of the depth of the mobile bed is selected through sensitivity analysis.

With the river network bedload model we aim to estimate the effect of flow regulation, i.e. altered transport capacity, on sediment transport and GSD of the entire Rhône river system. The model can also be applied as a tool to explore possible changes in bedload transport and channel GSDs under different discharge scenarios based, for example, on climate change projections or modified hydropower operation policies.