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Using graph theory to quantify coarse sediment connectivity in alpine geosystems

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Networks are a common object of study in various disciplines. Among others, informatics, sociology, transportation science, economics and ecology frequently deal with objects which are linked with other objects to form a network. Despite this wide thematic range, a coherent formal basis to represent, measure and model the relational structure of models exists. The mathematical model for networks of all kinds is a graph which can be analysed using the tools of mathematical graph theory. In a graph model of a generic system, system components are represented by graph nodes, and the linkages between them are formed by graph edges. The latter may represent all kinds of linkages, from matter or energy fluxes to functional relations.

To some extent, graph theory has been used in geosciences and related disciplines; in hydrology and fluvial geomorphology, for example, river networks have been modeled and analysed as graphs. An important issue in hydrology is the hydrological connectivity which determines if runoff generated on some area reaches the channel network. In ecology, a number of graph-theoretical indices is applicable to describing the influence of habitat distribution and landscape fragmentation on population structure and species mobility. In these examples, the mobility of matter (water, sediment, animals) through a system is an important consequence of system structure, i.e. the location and topology of its components as well as of properties of linkages between them. In geomorphology, sediment connectivity relates to the potential of sediment particles to move through the catchment. As a system property, connectivity depends, for example, on the degree to which hillslopes within a catchment are coupled to the channel system (lateral coupling), and to which channel reaches are coupled to each other (longitudinal coupling).

In the present study, numerical GIS-based models are used to investigate the coupling of geomorphic process units by delineating the process domains of important geomorphic processes in a high-mountain environment (rockfall, slope-type debris flows, slope aquatic and fluvial processes). The results are validated by field mapping; they show that only small parts of a catchment are actually coupled to its outlet with respect to coarse (bedload) sediment. The models not only generate maps of the spatial extent and geomorphic activity of the aforementioned processes, they also output so-called edge lists that can be converted to adjacency matrices and graphs. Graph theory is then employed to explore 'local' (i.e. referring to single nodes or edges) and 'global' (i.e. system-wide, referring to the whole graph) measures that can be used to quantify coarse sediment connectivity. Such a quantification will complement the mainly qualitative appraisal of coupling and connectivity; the effect of connectivity on catchment properties such as specific sediment yield and catchment sensitivity will then be studied on the basis of quantitative measures.