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One framework, different approaches: Exploring graph theory for the assessment of sediment connectivity

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In this study, we demonstrate and discuss the application of graph theory as a methodological framework for the appraisal of sediment connectivity. We understand sediment connectivity as a system property, that is to say the degree to which system components (landforms, river reaches, subcatchments) are coupled, i.e. allow for sediment transfer from one to another. Additionally, connectivity affects system behaviour, e.g. its sensitivity with respect to changes. In this concept, sediment connectivity is governed by (a) the location and topology of the system's components and (b) the activity of geomorphic processes driving sediment transfer. The distinction (and the interaction) of these two modes of connectivity corresponds to the notion of connectivity in other disciplines. In landscape ecology and hydrology, connectivity resulting from the spatial configuration of system components (e.g. habitat patches, landscape units with similar hydrological properties) has been defined as structural connectivity, while a linkage of system components by processes (e.g. migration of individual animals, continuous surface runoff) constitutes functional connectivity.

We show how graph theory can be employed to model system components and their linkage for both modes of (sediment) connectivity. With respect to structural connectivity, landscape units, e.g. as delineated on a geomorphological map, are modelled as nodes which are connected by edges if two units share a common boundary and if this boundary can be crossed in the direction of flow (the resulting graph is directed because sediment pathways are governed by gravity and topography). In such a graph, even multiple flow directions could be accounted for. In order to assess functional connectivity, the activity of processes needs to be considered. This can be done by modelling potential sediment pathways (edges) between landscape or even smaller spatial units (forming the nodes); we demonstrate this approach for rockfall, debris flows and hillslope fluvial processes in an alpine catchment.

The resulting graphs can be analysed at the level of nodes (e.g. the number of incoming and/or outgoing edges), edges (e.g. importance within the network as conveyor of sediment from different sources), pathways (e.g. edge sequences leading to the system outlet or to storage landforms), or the whole graph. The information contained in the single nodes and edges of a graph can be summarised, thus establishing a conceptual model of system structure which can be useful in comparing catchments (or subcatchments within a larger study area).