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Early warning of emergent connectivity on an eroding hillslope

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Arable hillslopes are, from the perspective of soil erosion by water, 'reset' whenever agricultural operations significantly modify hillslope microtopography. The self-organized movement of overland flow along preferential flow paths incrementally modifies the hillslope's post-tillage microtopography, initiating connected flow between overtopping hollows. In some cases this eventually results in a fully-developed system of micro-rills and rills which efficiently convey water and sediment away from the hillslope. This emergent connectivity of flow (and of sediment transport, though the two are not identical) is then drastically modified, or even destroyed, by the next round of agricultural tillage.

Thus every eroding arable hillslope experiences, between episodes of tillage, a transition from relatively disconnected patterns of overland flow to relatively connected flow. This transition is of considerable hydrological and geomorphological importance, since until connected flow is established there can be little loss of water or sediment from the hillslope. The transition is, in essence, a change of state, or a phase transition, analogous to the change from ice to water.

Given the importance of this change of state for flow connectivity, some method of 'early warning' of its occurrence might well be of practical use (e.g. by indicating that the saturated hillslopes within a catchment would require little extra incident rain to generate a flash flood) as well as of theoretical interest.

Recent work on the occurrence of critical transitions in geomorphological and other systems (e.g. Karssenberg at EGU 2010) suggests that such early warning signals can be detected in both temporal and spatial patterns of data. Temporally, a large increase in the variance of some system property may constitute a warning. In the case of a laboratory flume representing a section of hillslope, for example, this increase in variance might take the form of large changes in the volume of flume-end runoff or sediment loss per unit time, with the flume-end runoff or sediment loss per unit time subsequently settling to a high but relatively constant value. This is intuitively reasonable, since during the period when preferential flow paths are being emergently established, there will be rapid fluctuations in runoff and sediment transport as individual hollows overtop. However, since this period of increased variance may well be short lived (lasting perhaps a few tens of seconds, or a minute or two), runoff and/or sediment would have to be sampled at a rather high temporal resolution in order to detect this burst of high flume-end variance.

An alternative is to use a modelling approach, such as is described in this study. The RillGrow series of soil erosion models were developed to represent an eroding hillslope area as a self-organizing system. Microtopography is considered to determine the spatial pattern of overland flow and hence of surface lowering; such lowering modifies the path of subsequent flow. This simple iterative relationship generates rill networks emergently, i.e. as a collective whole-system response to many local interactions. Version 5 of the RillGrow model is used here to evaluate the feasibility of detecting early-warning signals of emergent connectivity on an eroding hillslope.