Introduction to special issue on connectivity in water and sediment dynamics

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Connectivity has emerged in recent years as a significant conceptual framework within which to address the spatial and temporal variability in runoff and sediment transport (Bracken and Croke, 2007; Hopp and Mc Donnell, 2009; Heckmann *et al*., 2010; Wainwright *et al*., 2011). The concept has had particular application in the field of catchment hydrology (Ali and Roy, 2010; McGuire and McDonnell, 2007; Mueller *et al*., 2007; Ocampo *et al*., 2006; Tromp-Van Meerveld and McDonnell, 2006), but has also been employed in, for example, explaining rates of sediment transport in river channels (Hooke, 2003), soil erosion by water (Lesschen *et al*., 2009; Lexartza-Artza I. and Wainwright, J. 2011), in the study of aeolian processes (Okin and Gillette, 2001; Okin *et al*., 2009 and in fire propagation. This special issue draws together several of the papers that were presented in the session "Connectivity in water and sediment dynamics: how do we move forwards?" at the 2012 General Assembly of the European Geosciences Union in Vienna, Austria. The session drew a variety of types of presentation, and those submitted for this special issue fall into three groups. In the first group (Ali *et al*., 2014; Croke *et al*., 2013; Goulsbra *et al*., 2014; Pechenick *et al*., 2014 and Puttock *et al*., 2013) are empirical studies that address connectivity in a variety of specific environments and conditions. The second group (Baartman *et al*., 2013; Harel and Mouche, 2014 and Kirkby, 2014) employs a modelling approach to explore the effects of landscape complexity and spatial heterogeneity on connectivity and runoff and sediment yield. Finally, Bracken *et al*. present a more theoretical exploration of the interlinkages between sediment and water connectivity.

Empirical Studies

Ali *et al*.(2014) explore the use of wetness indices to predict the dynamics of connected saturation areas in two Scottish catchments. Specifically, they address the questions of whether they work equally well in wet and dry periods, if the inclusion of soil data improves the predictive power, and what role spatial resolution has in affecting predictive power. The study raises the question of how far can indices take us in predicting catchment responses to a range of rainfall inputs. Croke *et al*. (2013) undertake a study of an extreme flood event to assess both hydrological and sediment connectivity under such conditions. They address the roles of channel capacity in determining hydrological connectivity, channel banks as sources of sediment, floodplains as sinks of sediment during overbank discharges, and the non-linearity of responses due to spatial variability of channel floodplain connectivity. As these authors point out, it is often argued that extreme events are sufficiently large to ensure connection between various landscape elements. However, this study of one of the largest floods ever recorded in Australia reveals a more complex picture such that it is argued that the development of quantitative indices of connectivity will need to take account of spatially variable and non-linear changes in key variables such as channel capacity and flood conveyance. Goulsbra *et al*. (2014) employ a dense network of sensors to investigate the importance of flow in ephemeral channels in the hydrological response of a peat catchment. The study, again, highlights the importance of spatial variability in controlling overall connectivity and catchment response. The study of Pechenick *et al*. (2014) moves away from assessing responses of catchment to different inputs to consider the effects of anthropogenic structures on catchment connectivity. Roads, particularly in forested catchments, play an important role as conduits of water so that developing metrics that can quantify their effects is an important element in catchment management. In this study road metrics are shown to be effective in predicting downstream channel condition. The final study in this group (Puttock *et al*., 2013) addresses the impact of environmental change on water, sediment and carbon losses from catchments in New Mexico. The effects of vegetation change on catchment responses in this environment have been extensively studied (e.g., Abrahams *et al*., 1995; Parsons *et al*., 1996a), and particularly with respect to its effect on flow pathways (e.g., Parsons *et al*., 1996b; Mueller *et al*., 2008; Turnbull *et al*., 2011). This study employs a flow pathway metric to examine the effects of a grass-woody vegetation change. In common with many previous studies, this one finds more runoff, higher sediment and organic carbon yields from the woody sites. These changes are associated with longer flow pathways, and it is argued that increased hydrological connectivity is an emergent property of this type of vegetation change that can be used to classify and evaluate landscape hydrological response.

Modelling studies

Baartman *et al*. (2013) test the hypothesis that increasing landscape complexity (overall relief, slope variability and stream order) is associated with decreasing sediment connectivity (expressed as the sediment-delivery ratio) using the landscape evolution model LAPSUS (Schoorl *et al*., 2002) to simulate erosion and deposition by overland flow within both virtual and real landscapes. The study predicts an inverse logarithmic relationship between the two. Harel and Mouche (2014) take us back to the issue of spatial heterogeneity that was examined in several of the empirical studies to explore the effects of spatial soil infiltrability in runoff production. The study suggests that increased runoff is not necessarily related to increased connectivity; a result which if supported by empirical studies would undermine the argument for connectivity as a useful tool in predicting runoff responses to rainfall. In the last of this group of papers, Kirkby (2014), similarly, addresses issues of landscape complexity and spatial heterogeneity in determining the runoff response of landscapes to spatially uniform rainfall input of varying intensities and durations. In a series of simulations, he explores runoff responses in terms of hydrograph shape in relation to connectivity structure, and investigates the probability that rainfall landing on a particular part of a hillslope will be delivered to the base of the slope as runoff. The paper highlights a growing awareness of the role of rainfall inputs on emerging connectivity, underlining the move towards a more process-based approach to understanding connectivity.

Conceptual Development

In the final paper of this special issue Bracken *et al*. (2014) evaluate the concept of connectivity as a framework for understanding sediment transfer across multiple scales. Specifically they examine the relationships among the frequency-magnitude distributions of sediment detachment and transport processes, the spatial and temporal feedbacks between sediment-detachment and transport processes, and mechanisms of sediment detachment and transport to develop a new framework for sediment connectivity. The framework is illustrated with reference to fluvial systems, but it is argued that it could be readily expanded to other process domains.

Synthesis

Although the papers that form this special issue are a self-selected subgroup of those presented at the EGU session, they reflect the current state of the art in connectivity. Numerous empirical and modelling studies couch the findings of non-linear responses in runoff and sediment yield in terms of connectivity (Lexartza-Artza and Wainwright 2009, 2011; Okin *et al*., 2009; Bracken *et al*., 2013, Fryirs, 2013), and efforts have been made to develop indices of connectivity (Borselli *et al*., 2008; Wichmann *et al*., 2009; Ali and Roy, 2010; Cavalli *et al*., 2013; Heckmann *et al*., 2013). The term has been refined to distinguish between so-called structural and functional (or process-based) connectivity (Turnbull *et al*., 2008; Wainwright *et al*., 2011;Bracken *et al*., 2013). Although it may be evident that the concept helps us to express the complexity (in terms of water and sediment yields) of landscape responses to rainfall inputs, does it improve our ability to understand or predict those responses? Is connectivity no more than old wine repackaged into new bottles, as Bracken *et al*. (2014) suggest? Notwithstanding the efforts made by Bracken *et al*. (2014) there would still seem to be some way to go in connectivity research before this nagging concern can be assuaged. That it can be will undoubtedly be an important task for a number of ongoing research initiatives. First, COST Action ES1306 (Connecteur: Connecting European Connectivity Research), which commenced in 2014 was also spawned by the EGU session. The COST Action underpins sessions at the 2015 EGU meeting and a range of future workshops on connectivity in water and sediment dynamics (see http://connecteur.info/). Secondly, The Gordon Research Conference in 2015 will focus on 'Interactions of hydrology, biology and geochemistry; thresholds in time and space'. Connectivity will be a central theme of presentations and discussions. Finally, the 2016 Binghamton Symposium will also focus on 'Connectivity in Geomorphology' and will continue to maintain the international interest in connectivity in water and sediment dynamics. By the end of 2016, it may be hoped that consensus will have emerged about the usefulness of connectivity as a significant conceptual framework within which to address the spatial and temporal variability in runoff and sediment transport.

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