Geomorphology 200 (2013) 50–58

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The complexity of the real world in the context of the field tradition in geomorphology

Ellen Wohl *

Dept. of Geosciences, Colorado State University, Fort Collins, CO 80523-1482, USA

ARTICLE INFO

Article history:
Received 27 June 2012
Received in revised form 14 December 2012
Accepted 18 December 2012
Available online 27 December 2012

Keywords:
Nonlinear
Complex system
Thresholds
River metamorphosis
Process domains
Colorado

ABSTRACT

Among the dominant twentieth century conceptual models of geomorphology that rely on insights resulting from field-based research are Stanley A. Schumm's formulations of complex response, intrinsic thresholds, river metamorphosis, and spatial zonation of drainage basins. Schumm's research focused primarily on finer grained alluvial channels in lower relief environments. As a result of his work, most investigators now approach river process and form within a framework based on three fundamental assumptions. First, channel changes are abrupt and driven by crossing external and internal thresholds. Second, channel change is likely to be asynchronous, resulting in different portions of a river or a river network behaving in very different manners at a given point in time. Third, different portions of a river network are dominated by distinct disturbance regimes and resulting suites of geomorphic processes and forms. More recent research on resistant-boundary mountain channels illustrates how field evidence demonstrates that river process and form are inherently nonlinear, with spatial and temporal thresholds. Multithread channels can form within unconfined valley segments in mountainous river networks of the Colorado Front Range, but only in the presence of biotic drivers in the form of (i) old-growth forest that facilitates the formation of closely spaced, channel-spanning logjams or (ii) beavers that build dams. Thresholds of channel and valley geometry govern the occurrence and persistence of jams and dams, and these channel obstructions initiate specific nonlinear responses in valley and channel form. When the biotic drivers are removed, river metamorphosis occurs. Alluvial channels, which are typically regarded as being relatively responsive to changes in water and sediment yield and substrate composition, and channels with more resistant boundaries that typically respond to external changes over longer timespans exhibit nonlinear complex behavior. In both cases, the nonlinear behavior of rivers with numerous interdependent variables, multiple internal and external thresholds, and complex responses would be difficult to conceptualize and quantify in the absence of extensive field data. One of the management implications of complex, nonlinear behavior is that a one-size-fits-all approach to managing rivers is inadequate. Field research, initially focused on understanding specific examples of river process and form, revealed underlying patterns that give rise to conceptual models broadly applicable within fluvial geomorphology.

1. Introduction

The inherent aim of science is to recognize patterns in order to deduce or infer the underlying processes that create those patterns and govern the behavior of natural systems. The ultimate, fundamental source of pattern recognition for geomorphologists is the natural world. Other methods of studying surface process and form, such as physical experiments and numerical simulations, also rely on detection of pattern for insights. All three approaches require an underlying conceptual model that governs what is measured or observed and analyzed (Odoni and Lane, 2010, 2011). Although physical experiments and numerical models can be used to gain insight into situations in which we cannot measure the parameters of interest (Lane, 2011), experiments and models at some level refer back to what is known of the real world, and this knowledge comes from field-based data.

Strict observation of patterns and inference of sequences of events at a place can be limiting and lead to collections of poorly integrated case studies. Individual case studies can reveal fundamental mechanisms through intensive study of a particular place and its evolution through time (Pitty, 1979; Richards et al., 1997). Richards (1996) described such approaches as small-N studies that can lead to generalization by theoretical reasoning (e.g., Dietrich and Smith, 1984), in contrast to large-N samples that lead to generalization by empirical statistical methods (e.g., Cadol et al., 2009). Numerous case studies can also be integrated to detect the underlying consistent mechanisms or similarities in order to formulate more basic, broadly applicable conceptual models. As in other disciplines that have grown from field-based research, however, a tension remains in geomorphology between case studies that focus on contingency, or the importance of site-specific history and controls, and studies that emphasize universal process and form. Studies of the former type run the risk of being so site-specific as to result in very limited insight applicable to other sites. Studies of the latter type risk over-simplifying real

* Tel.: +1 970 491 5298; fax: +1 970 491 6307.
E-mail address: ellen.wohl@colostate.edu.

0169-555X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2012.12.016

systems by ignoring the role of contingency. The physicist Ernest Rutherford famously claimed that science is either physics or stamp collecting. Geomorphology is neither solely physics (universal) nor stamp collecting (site-specific case studies) because of the influence of contingency on geomorphic form and process, as well as the existence of consistent patterns of form and process. Contingency and patterns can be most effectively elucidated using field-based data. Numerical or physical models can be validated for a set of boundary conditions, and the boundary conditions can then be adjusted to quantify the impacts on model outcomes (e.g., Bradbrook et al., 2000, 2001; Hardy et al., 2011), but the range of realistic boundary conditions remains based on insights from field sites. Physical experiments and numerical simulations can provide extremely valuable insights, but can be too simplistic to realistically capture all relevant parameters in multivariate systems (Just as field data can be too complex to infer the underlying processes, or processes can be very difficult to measure.).

Many of the dominant twentieth century conceptual models of geomorphology rely on insights that resulted from field-based research, coupled with physical experiments and numerical simulations used to explore and test patterns observed in the field. Research conducted by Stanley A. Schumm exemplifies this tradition and illustrates the ideal synergy that can exist between different methods of investigation: in Schumm's case, field-based research and physical experiments. The ideas of complex response, intrinsic thresholds, river metamorphosis, and spatial zonation of drainage basins are among Schumm's most powerful conceptualizations. Schumm worked primarily in fine-grained (sand-bed and finer) alluvial channels in lower relief environments. My research has concentrated on resistant-boundary (boulder-bed and bedrock) channels in higher relief environments, but complex response, intrinsic thresholds, river metamorphosis, and spatial zonation provide extremely useful conceptual frameworks for these types of channels. In this paper, I use the history of field-based studies at Colorado State University to explore how field evidence consistently demonstrates that river process and form are inherently nonlinear, with spatial and temporal thresholds, and how these characteristics challenge our ability to understand and manage rivers. After reviewing Schumm's foundational work on complexity in rivers, I use my own continuing research to illustrate evolving understanding of headwater streams in the Colorado Front Range in the context of complexity.

2. Rivers as complex systems: the legacy of Stanley Schumm

A complex system is one with interconnected parts that as a whole exhibit one or more properties (including behavior) not immediately obvious from the properties of the individual parts. A complex system exhibits self-organization over time and emergence with increasing scale, with emergence defined as patterns that arise from a multiplicity of relatively simple interactions. A nonlinear system is one in which output is not directly proportional to input such that, mathematically, the variable to be solved for cannot be written as a linear combination of independent components because of interactions among the components. Although the phrases 'nonlinear' and 'complex systems' were not commonly used in geomorphology until the 1990s, the behavior described by these phrases was recognized earlier, in papers such as Graf's (1979) application of catastrophe theory to fluvial processes. Such behavior was also recognized by Stanley Schumm during field work in the 1950s. In "Arroyos and the semiarid cycle of erosion," Schumm and Hadley (1957) described longitudinally discontinuous incision of ephemeral alluvial channels in the arid western United States. Schumm and Hadley observed that tributaries and the main channel could be out-of-phase with respect to incision and aggradation. They interpreted the lack of integrated, synchronous behavior along a channel and throughout a network as resulting from downstream decreases in discharge caused by infiltration into the streambed. Decreasing discharge caused local aggradation, steepened channel gradients, and incision, but this sequence of events occurred at different times in different portions of the channel network. The cycle of erosion occurred when

> An alluviated tributary valley is united with the main drainage channel by the development of a trench in the recent alluvium clogging the tributary channel. The gully is extended headward by upstream headcut migration… As the headcut migrates up channel the lower section of the tributary drainage … becomes very efficient for sediment transport, for the runoff is concentrated in a clearly defined channel. The headcut continues to work up the channel, passing tributaries … and rejuvenating them in turn … (Schumm and Hadley, 1957, p. 171).

Schumm and Hadley also noted that

> The cycle of erosion within a large drainage system may be made up of major cycles of arroyo cutting on the main channel, but within these major cycles are a number of epicycles in which alluviation and erosion alternate in the smaller valleys, making them temporarily independent of the main drainage channels (Schumm and Hadley, 1957, p. 172).

Inherent in these descriptions of the behavior of ephemeral channels are three ideas. First, that channel behavior can switch abruptly between incision and aggradation when a threshold involving channel gradient, discharge, and transport capacity is crossed. Second, that this threshold can be crossed in the absence of changes in external variables such as sediment yield and runoff. And third, because the spatial and temporal distribution of threshold-crossing events depends on the site-specific history of discharge and sediment transport, different portions of a drainage network that have experienced slightly different histories are likely to cross thresholds asynchronously and thus exhibit dramatically different behavior at any point in time. In other words, Schumm and Hadley (1957) described a nonlinear complex system.

Schumm (1973) expressed these ideas more formally and systematically in the paper "Geomorphic thresholds and complex response of drainage systems," which was part of a Binghamton meeting on fluvial geomorphology. This appears to be the first time that Schumm used the phrase 'complex response' in print, and the paper effectively introduced the concept of geomorphic thresholds into broad use within the geomorphic community. (As Schumm noted, the underlying idea of thresholds had been mentioned by other authors in earlier publications (e.g., Chorley and Kennedy, 1971)) The 1973 paper distinguished extrinsic and intrinsic thresholds. Extrinsic thresholds involve responses of a system to an external influence, and intrinsic thresholds occur when a progressive change of the system itself renders the system unstable, despite relatively constant input. This distinction was of particular importance, as most previous work had focused on external drivers of change within a river network. Schumm cited evidence of thresholds operating in discontinuous gullies, referring to field observations throughout the arid western U.S., and in river patterns, based on physical experiments conducted at Colorado State University. As Schumm wrote in this paper

> Although we continually speak and write about the complexity of geomorphic systems, nevertheless, we constantly simplify in order to understand these systems… Simplification and the search for order in simplicity caused intrinsic thresholds to be overlooked in preference to explanations based on external controls (Schumm, 1973, pp. 307–309).

In a swift succession of papers, Schumm used the ideas of complex response and thresholds to examine several aspects of river form and process. He discussed the difficulty of interpreting and correlating Holocene alluvial deposits in the southwestern U.S., drawing also on physical experiments of channel response to base level lowering for insights into process and form (Schumm and Parker, 1973). He interpreted unpaired