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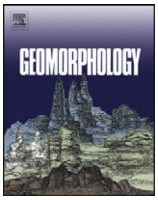

# Transformative geomorphic research using laboratory experimentation

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ABSTRACT

Laboratory experiments in geomorphology is the theme of the 46th annual Binghamton Geomorphology Symposium (BGS). While geomorphic research historically has been dominated by field-based endeavors, laboratory experimentation has emerged as an important methodological approach to study these phenomena, employed primarily to address issues related to scale and the analytical treatment of the geomorphic processes. Geomorphic laboratory experiments can result in transformative research. Several examples drawn from the fluvial and aeolian research communities are offered as testament to this statement, and these select transformative endeavors often share very similar attributes. The 46th BGS will focus on eight broad themes within laboratory experimentation, and a diverse group of scientists has been assembled to speak authoritatively on these topics, featuring several high-profile projects worldwide. This special issue of the journal *Geomorphology* represents a collection of the papers written in support of this symposium.

## 1. Introduction

The study of geomorphic systems—the analysis of the processes that shape the Earth's surface and their associated landforms—has been dominated by field research endeavors. This field tradition of geomorphic research can be traced back to the world's early explorers, which provided the impetus for physiographic mapping and the necessary context to consider landscape origin and evolution (Church, 2013). The focus on field geomorphic research is also logical because geomorphologists can conduct research activities at the exact locations where processes operate and landforms are created (McKenna Neuman et al., 2013). Butler (2013) and Harden (2013) recognized the invaluable insight and broader context gained by field experiences, which potentially can lead to epiphanies in the understanding of geomorphic systems as well as serendipitous and salutary observations and discoveries simply by being in the right place at the right time.

Yet field research is not the only methodological approach available to the geomorphic research community. A second approach is numerical modeling. Here, modeling is broadly defined to include empirical and statistical approaches to quantify geomorphic phenomena, analytical approaches to define or extend governing equations, and numerical models of varying complexity to simulate and heuristically investigate geomorphic systems. At present, a wide array of geomorphic models are available in the literature, some of which are summarized in Wilcock and Iverson (2003), Pelletier (2008), and Chen et al. (2014). A third methodological approach available to the geomorphic research community is physical modeling and experimentation using laboratory facilities. Here, physical modeling is broadly defined to include scaled models based on similarity principles, analogue models based on similarity in form and/or composition, and single-purpose facilities designed to explore specific geomorphic phenomena. Experimental investigation has been part of geomorphology for many decades, although few treatises or seminal papers report on the design and use of laboratory experiments and facilities in geomorphology. Some representative examples include Hjulström and Sundborg (1962), Mosley and Zimpfer (1978), Schumm et al. (1987, and references therein), Peakall et al. (1996), Paola et al. (2009), and McKenna Neuman et al. (2013).

The annual Binghamton Geomorphology Symposium (BGS) is one of the most recognizable geoscience meetings worldwide. For nearly 50 years, the symposium series has addressed a wide range of scientific and socially relevant topics in geomorphology, engaging a multitude of geoscientists (Sawyer et al., 2014). The continued success of the symposium is due, in part, to the dedication and commitment of the BGS Steering Committee composed of both long-term and rotating members. These individuals work closely with the geomorphology community to identify emerging topics of scientific importance, they facilitate in the organization and success of each symposium, and they ensure that the products from the symposium are disseminated to the global community in a timely fashion. The titles of previous symposia illustrate the timeliness and relevance of the selected topics (Sawyer et al., 2014). But the BGS has not yet organized a formal discussion of laboratory experiments in geomorphology, one of the principal methodological approaches embraced by the research community. The 46th Binghamton Geomorphology Symposium, entitled 'Laboratory Experiments in Geomorphology,' seeks to bring together leading experts and emerging

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scientists actively engaged in experimental geomorphic research. This special issue introduces those invited papers to be presented at the symposium. The objectives of this paper are as follows: (i) to define the motivations of the geomorphic laboratory experimentalist; (ii) to illustrate through select case studies the transformative nature of geomorphic experimental research; and (iii) to provide the rationale for the 46th BGS on laboratory experiments in geomorphology. Geomorphic research has been greatly enhanced and transformed by laboratory experiments and the future of geomorphic research depends on the continued complementarity and successful melding of the three approaches to geomorphic research: field work, numerical modeling, and laboratory experimentation.

## 2. Motivations of the geomorphic laboratory experimentalist

The term experimental geomorphology may be defined in several ways. Mosley and Zimpfer (1978) stated that it is the study of a physical representation or model of a selected geomorphic feature under laboratory conditions. Schumm et al. (1987) provided a brief historical context for experimental geomorphology, including some very early case studies.

Several advantages are afforded the geomorphic laboratory experimentalist, but the motivations to employ such facilities—and to invest so heavily into methods, procedures, and infrastructure—can be reduced to two issues: scale and prediction. The temporal and spatial scales over which geomorphic processes operate often are very large. In general, spatial scales for geomorphic systems can span from $10^{-8}$ to $10^{7}$ km$^2$, and the time scales of persistence can span from $10^2$ to $10^9$ years (Bloom, 1998). Although technological advances and numerical models have facilitated the study of such systems in the field (Church, 2013), these large time and space scales potentially could pose insurmountable challenges to the geomorphologist. Consequently, geomorphologists have employed experimental facilities and physical analogues to compress time and shrink scale, while exerting experimental control, to examine the dynamics of these systems. In general, laboratory experiments have spatial scales that range from $10^{-2}$ to $10^2$ m$^2$ (or $10^{-8}$ to $10^{-4}$ km$^2$) and time scales of persistence for such processes that range from $10^0$ to $10^6$ s (or $10^{-7}$ to $10^{-2}$ years), or potentially even shorter in length (ms).

This large discrepancy in scale between natural geomorphic systems and many laboratory facilities remains the primary challenge to the experimentalist. Dimensional analysis and the use of similarity principles have long been employed successfully in the design and execution of laboratory experiments and their application to natural settings (Yalin, 1971; Peakall et al., 1996; Julien, 2002; Gallisdorfer et al., 2014). Unfortunately, application of similarity principles to experimental apparatuses typically employed for geomorphic research invariably requires some relaxation of these scaling requirements, as well as some distortion of select ratios and dimensions. In general, distortions often are accepted for the depth of the geophysical flow and the size and density of the sediment on the boundary or in transport. Paola et al. (2009) further loosened these rigorous requirements by arguing that even poorly scaled experiments seem to capture the primary characteristics of the geomorphic system under investigation, presenting several examples in support of this belief. They employed the phrase *unreasonable effectiveness* to refer to the consistency of observations made between these poorly scaled experimental systems and their field prototypes. Even with much analytical evidence presented and the unreasonable effectiveness of experimental systems, skepticism remains within the broader geomorphic community when laboratory experiments are compared to their natural analogues (Paola et al., 2009).

The second motivation for the geomorphic experimentalist is the focus on prediction. As noted by Paola et al. (2009), geomorphologists are moving away from reasoning by analogy toward reasoning by analysis. The equations governing geomorphic processes are often difficult to describe in analytic terms because of the large number of degrees of freedom that can occur in natural settings. This is particularly challenging in field-based research where temporal and spatial scales are large or where the processes themselves may not be observed or measured directly. This quest to define these fundamental relationships and their governing equations is what drives the geomorphologist into the laboratory. Through controlled experimentation, functional relationships and robust theory for geomorphic phenomena emerge so that these analytic arguments then can be tested against experimental and field data and further refined (see also Schumm et al., 1987; Paola et al., 2009). This iterative process between reasoning (see Kleinhans et al., 2010), experimentation, and field application leads to generalized theory, geomorphic transport laws, and predictive explanations of landforms (Dietrich et al., 2003).

Additional benefits are afforded to the geomorphic experimentalist. Experimental geomorphologists seek control, precision, and reproducibility in their work (Mosley and Zimpfer, 1978; Paola et al., 2009; McKenna Neuman et al., 2013). Control is derived from knowing exactly when and where a geomorphic event or process will occur so that all data collection activities can be planned in advance. Precision is derived from the use of technology and appurtenant devices that measure with great resolution and accuracy all parameters deemed important. Experimental uncertainties in measured parameters rarely exceed a few percent, even though the phenomenon under investigation can be highly dynamic. Reproducibility is derived from knowing that the experiments can be executed again and again, either by the initial scientist or by others, and that the results will (or should) be statistically invariant. Such opportunities for comprehensive study of geomorphic phenomena often are rarely possible in field research (Schumm et al., 1987; Paola et al., 2009). For these reasons, experimental geomorphologists also are expected to be meticulous scientists.

Major disadvantages to geomorphic experimental research, however, also have been identified. These disadvantages include: (i) problems with the boundary conditions of the physical model; (ii) materials used and processes observed in laboratory experiments may be dissimilar when compared to those in nature; and (iii) the study of a restricted number of processes or phenomena may mask more complex interactions observed in nature (Mosley and Zimpfer, 1978). Experimental geomorphologists are well aware of such potential problems.

## 3. Select examples of transformative experimental geomorphic research

A common phrase used in academia today is transformative research. A definition for transformative research can be found in a report prepared by the National Science Foundation (NSF, 2007):

> Transformative research is defined as research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research also is characterized by its challenge to current understanding or its pathway to new frontiers (p. 10).

While this definition appears to be self-explanatory, identifying examples of transformative experimental geomorphic research remains highly subjective. Below a few examples are provided of studies that are considered to be transformative, with the knowledge that these examples represent the obvious bias of the authors and that many more examples could have been presented.

### *3.1. Rill networks and landscape evolution*

In the late 1960s, faculty in the Civil Engineering Department at Colorado State University created a research initiative to investigate the hydrology of small watersheds (Dickinson et al., 1967). A specific research focus was the creation of an experimental research facility to examine