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Review

# Geomorphology within the interdisciplinary science of environmental flows

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ABSTRACT

The field tradition in geomorphology informs beyond studying landforms by also providing a stage for understanding how geomorphic elements influence the ecology of biota. The intersection between fluvial geomorphology and riverine ecology represents an ideal confluence to examine the contribution of the geomorphic field tradition to environmental flows, and show this area of riverine management as a research frontier for applied geomorphology. *Environmental flows* have consisted of a set of ecological-based stream flow guidelines designed to inform sustainable water resource management that supports healthy riverine habitats and provides sufficient water supply for society. Geomorphological understanding is central to environmental flows because it is the interaction between flow, form, and substrate that influences habitat type, condition, availability and biotic use across space and time. This relationship varies longitudinally, laterally, vertically, overtime, and across macro- to mesoscale morphologies within the riverine environment. The geomorphic template is, therefore, as integral as the flow. We reviewed studies where field evidence indicated that geomorphology impacts the effectiveness of environmental flow strategies and we make the case for the need to increase geomorphic considerations in environmental flows. Although flow is commonly referred to as the master variable in environmental flows, geomorphology mediates the effects of flow regime on ecological processes. Concepts and applications from this perspective on the role of geomorphology in riverine ecosystem research will inform the practice, policy, and implementation of environmental flows.



## 1. Introduction

The geomorphology, hydrology, and ecology of river systems interact through complex processes occurring across a range of spatial and temporal scales. The interface among these processes and the desire to manage river systems for natural and human benefit attract researchers from many disciplines. Several professional meetings have focused on the interdisciplinary advancement of river system sciences (cf. Table 1), including two previous Binghamton geomorphology symposia. Collectively, these meetings have increased engagement in collaborative, interdisciplinary studies of rivers and deepened our understanding of the structural and functional interactions that influence the physical, ecological, and chemical dynamics of riverine ecosystems. In the context of the 2012 Binghamton geomorphology symposium on *The Field Tradition in Geomorphology*, we examined the contributions of field geomorphology to the interdisciplinary river science of environmental flows; and we present this area of applied science as a research frontier for geomorphology.

Managing ecological water allocations — including the quantity, timing, frequency, duration, and quality of river flows for freshwater ecosystems, herein referred to as environmental flows — are increasingly being required to sustain an agreed-upon level of ecological condition for riverine biota and provide sufficient water supply for societal needs (Petts, 1996; Tharme, 2003; Newson and Large, 2006; Richter et al., 2006; Poff et al., 2010). Flow regulation downstream of dams and water withdrawals and returns are primary sources of flow alteration and are direct means to control or influence stream flows. This is precisely where environmental flow management can be used as a soft engineering tool to prevent further riverine degradation, protect extant resources, and/or restore ecological function. Geomorphology occupies a key realm in this arena because it is the process-based interactions among river flow, sediment, morphology, and organic materials that influence the ecological condition of habitat type, quality, and availability for biotic use across space and time (Poff and Ward, 1990; Thoms and Parsons, 2002; Jacobson and Galat, 2006; Tracy-Smith et al., 2012).

Habitat by default is interdisciplinary and assumes a combination of physical and biological components (Odum, 1971). Important physical factors include planform and channel-bed macro- and micromorphology features, substratum, hydraulics (velocity, depth), and thermal gradients (Poff and Ward, 1990). Important biological factors include the species behavioral, physiological, and life history characteristics for survival and reproduction strategies and also specific responses or adaptations to physical disturbances or environmental gradients (Poff and Ward, 1990; Lytle and Poff, 2004). The interplay between how these factors influence riverine habitat structure and function for a given species, population, or community is highly complex and variable across space and

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**Table 1**
Summary of professional meetings on the integration of physical and biological elements of riverine ecosystems.

| Year | Meeting | Description, goals, or objectives, of symposium | Journal, year | Organizers |
|---|---|---|---|---|
| 1987 | Invited Symposium on: "Community structure and function in temperate and tropical streams", Hosted by Flathead Lake Biological Station of the University of Montana Foundation | Meeting of forty-eight scientists from 13 countries sponsored by the Ecology Program of the U.S. National Science Foundation (NSF) | Journal of North American Benthological Society, 1988:7 | Stanford J.A. and A.P. Covich |
| 1993 | Third International Geomorphology Conference, Master University, Hamilton, Ontario, Canada | Addressed research topics at the interface between fluvial geomorphology and vegetation | Geomorphology, 1995: 13 (4) | Osterkamp, W.R., and C.R. Hupp |
| 1995 | Binghamton Geomorphology Symposium: Biogeomorphology, Terrestrial and Freshwater Systems | Examine relationships between biota and geomorphic form and process | Geomorphology, 1995: 13 (1–4) | Hupp, C.R., W.R. Osterkamp and A.D. Howard |
| 2001 | First International Symposium on Riverine Landscapes, Switzerland | Synthesized the present understanding of riverine landscapes from the perspectives of different disciplines. | Freshwater Biology, 2002: 47 | Tockner, K., J.V. Ward, P.J. Edwards, and J. Kollman |
| 2002 | Joint Meeting on Environmental Flows for River Systems and 4th International Ecohydraulics Symposium, Cape Town, South Africa | Demonstrated progress on advancing research on the assessment and implementation of environmental flows | River Research and Applications, 2003: 5–6 | Petts, G.E. |
| 2002 | The Structure, Function, and Management Implications of Fluvial Sedimentary Systems, International Symposium, Alice Springs, Australia | Discuss management objectives for sustaining riverine ecosystems focus on spatial and temporal variability, ecogeomorphology, floodplain ecological processes, and techniques | IAHS Publication, 2002, No. 276. 484 pp. | Dyer, F.J., M.C. Thoms, J.M. Colley |
| 2003 | Ninth International Symposium on River Research and Applications:"The Nature Causes, Consequences, of Variability in Riverine Ecosystems", Albury, Australia | Addressed concepts of variability in the structure and function of riverine ecosystem and incorporating variability into the management and restoration of riverine ecosystems. | River Research and Applications, 2006: 22 | Thorp, J.H., M.C. Thoms, M.D. Delong |
| 2005 | Binghamton Geomorphology Symposium: Geomorphology and Ecosystems | Examined current status of disciplines, difficulty in bridging the disciplines, and emerging research priorities | Geomorphology, 2007: 89 (1–2) | Renschler, C.S., M. W. Doyle, and M.C. Thoms |
| 2008 | American Geophysical Union Special Session: Multiscalar Feedbacks in Ecogeomorphology | Elucidated interdisciplinary research that shows clear physical-biological feedbacks | Geomorphology, 2010: 126 | Wheaton, J.M., C. Gibbons, J. Wainwright, L. Larsen, B. Elroy |
| 2008 | Integrating Science into the Restoration and Management of Floodplain Ecosystems of the Southeast | Evaluate current management and restoration practices for supporting sustainability of southeastern floodplain ecosystems. | Wetlands, 2009: 29 (2) | King, S.L., R.R. Sharitz, J.W. Groniger, and L.L. Battaglia |
| 2010 | Meeting of Young Researchers in Earth Sciences (MYRES): Dynamic interactions of life and it's landscape | Examined research at the interface of biology and geomorphology: co-evolution of landforms and biological communities, and humans as modifiers of the landscape. | Earth Surface Processes and Landforms, 2010:35 | Reinhardt, L., D. Jerolmack, B.J. Cardinale, V. Vanacker, and J. Wright |
| 2007–2010 | Special Issue in Freshwater Biology which includes resources from the Brisbane International Environmental Flows Conference (2007) and the Third International Symposium on Riverine Landscapes (2007) | Presented new analytical and modeling approaches to support hydroecological models and environmental flow standards at multiple scales and all rivers, to achieve water-related goals of the Millennium Ecosystem Assessment | Freshwater Biology, 2010: 55 | Arthington, A.H., R.J. Naiman, M.E. McClain, and C. Nilsson |

time (Poff and Ward, 1990; Poff et al., 1997; Newson and Newson, 2000; Fausch et al., 2002; Thorp et al., 2008).

The integration of bio-eco-geo-hydro focused research has emerged over the last few decades in response to growing popularity of interdisciplinary studies. Biogeomorphology (Viles, 1988; Hupp et al., 1995; Naylor et al., 2002; Stallins, 2006; Francis et al., 2009; Stine and Butler, 2012) and ecogeomorphology/ecomorphology (Frothingham et al., 2002; Thoms and Parsons, 2002; Parsons et al., 2003; Fisher et al., 2007; Murray et al., 2008) are the terms most widely used for describing the study of *bidirectional influences of geomorphic and biologic processes* on each other. Other common interdisciplinary riverine-related terms include ecohydrology, hydroecology (Baird and Wilby, 1999; Kundzewicz, 2002; Hannah et al., 2004) and hydrogeomorphology (Sidle and Onda, 2004; Wheaton et al., 2011); however, the former two lack a geomorphic element, whereas the latter lacks a distinct biological inference. Clarke et al. (2003) and Vaughan et al. (2009) suggested the development of an ecohydromorphology field of river sciences which is defined as 'the interactions of the biological entities and ecological processes of a river with the hydrological and geomorphological forms and dynamics'. Ecohydromorphology includes processes and causal mechanisms, spatial structure of the riverine landscape, and variability of spatial and temporal scales. Ecohydromorphology is the most inclusive of all the integrated terms and as such, we use it throughout this review when referring to interdisciplinary-based riverine ecosystem processes.

The process for determining environmental flows requires input from many specialists including hydrologists, geomorphologists, biologists, and ecologists; as well economists, social scientists, and lawyers. Geomorphologists' greatest strength within this collaboration is their ability to address the complex questions surrounding flow, sediment, and morpho-dynamics — a task which is fundamental to the field tradition in geomorphology. The classic studies by Wolman and Miller (1960) and Leopold and Wolman (1960) provide context for large-scale sediment dynamics and planform channel patterns, which more recent studies have detailed as drivers of morphological complexity capable of creating habitats for a variety of riverine biota (Rhoads et al., 2003; Jacobson and Galat, 2008; Pritchett and Pyron, 2011). Contributions such as these can only be realized by deliberate engagement in interdisciplinary applied riverine management situations. As Graf (1996) argued, geomorphologists have a responsibility to extend themselves beyond basic research and apply their knowledge to environmental resource management, public policy, and social issues. However, the involvement of geomorphologists in environmental flow management has (to date) been limited, with exceptions (Gippel and Stewardson, 1998; Schmidt et al., 2001; Graf et al., 2002; Thoms and Sheldon, 2002; Jacobson and Galat, 2006, 2008; Newson and Large, 2006; NRC, 2008). In support with Graf (1996), we encourage more field-oriented fluvial geomorphologists to become involved with environmental flow assessments to ensure that geomorphic considerations are adequately accounted for in policy and implementation.

In this review we illustrate how geomorphology influences the biota or riverine ecosystems at a range of scales; and show geomorphology to be as integral as hydrology for maintaining ecological function and