

Eco-geomorphology: an interdisciplinary approach to river science

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Abstract Eco-geomorphology is an interdisciplinary approach to the study of river systems that integrates hydrology, fluvial geomorphology and ecology. This approach facilitates a new understanding of river systems by bridging dominant paradigms from individual disciplines. Each discipline views river systems from a spatial and temporal perspective, but we suggest that one of the main impediments to further expansion of interdisciplinary study is the mismatch of scales between disciplines. A hierarchical and integrative framework for interdisciplinary study is required and would overcome scale issues by matching a problem with a river system process to identify causal explanations at the correct spatial and temporal scales. We use the example of environmental flows to demonstrate the utility of an eco-geomorphological approach for identification of characteristic scales of hydrological, geomorphological and ecological influence in the Condamine-Balonne River.

Key words fluvial geomorphology; hydrology; ecology; scale; environmental flows

INTRODUCTION

With increasing pressures on the environment, there is a strong trend to manage rivers as ecosystems. This type of management requires a holistic, interdisciplinary approach that simultaneously considers the physical, chemical and biological components of river ecosystems, as well as longitudinal (upstream–downstream), lateral (channel–flood plain) and vertical (channel–hyporheos) connectivity, and spatial and temporal scaling (Ward, 1989).

Many disciplines are often brought together to solve environmental problems in river systems. These include the scientific disciplines of hydrology, geomorphology, ecology and chemistry, and other disciplines such as engineering, social science and economics. For example, teams of scientists, managers and community interest groups have been involved in the formulation of environmental water allocations for Australian rivers (Cottingham *et al.*, 2002). However, the integration of disciplines is fraught with challenges that can potentially reduce the effectiveness of interdisciplinary approaches to environmental problems. Pickett *et al.* (1994) identify three consequences of disciplinary progress:

- (a) gaps in understanding appear at the interface between disciplines;
- (b) disciplines focus on specific scales or levels or organization; and
- (c) as subdisciplines become rich in detail they develop their own view points, assumptions, definitions, lexicons and methods.

These consequences impede the integrated disciplines producing a single applied understanding of the river ecosystem because attempts to produce an interdisciplinary outcome tend to remain dominated by the paradigms familiar to component disciplines. We lack a framework that fosters the combination of disciplines to provide a new and advanced understanding.

Successful interdisciplinary river science requires the “explicit joining of two or more areas of understanding into a single conceptual–empirical structure” (Pickett *et al.*, 1994). Integration of disciplines can be additive or extractive. In additive integration, two areas of understanding are combined more or less intact into a new composite understanding. In extractive integration, two or more areas of understanding may provide components that are combined to yield new understanding. Both processes are relevant in river science, depending on the nature of the problem at hand and the state of knowledge in component disciplines. As a mix of river ecology, hydrology and fluvial geomorphology, eco-geomorphology represents the integration of three well-advanced disciplines. It builds upon ecohydrology which is the discipline that brings hydrologists and freshwater ecologists together to predict the ecological response of changing flow regimes, physical channel structure and water quality (Dunbar & Acreman, 2001).

The lack of an appropriate framework that enables different disciplines to collaborate in an interdisciplinary setting is an impediment to the full realization of the benefits of such collaboration (Petts, 2000). This paper provides a framework for interdisciplinary research in eco-geomorphology and uses the example of environmental flows to demonstrate the potential for this framework to combine discipline-specific paradigms into a new and advanced understanding of river systems.

A FRAMEWORK FOR INTERDISCIPLINARY STUDY IN RIVER SYSTEMS

River scientists from all disciplines attempt to organize problems from a time and space perspective. However, individual disciplines contain dominant paradigms that drive the scales at which river systems are viewed. For example, in hydrology, four temporal hierarchical levels of hydrological behaviour are important for river ecosystem functioning (Thoms & Sheldon, 2000):

- (a) the flow regime (long-term, statistical generalization of flow behaviour— influences that extend over 100s of years);
- (b) flow history (the sequence of floods or droughts— influences between 1 to 100 years);
- (c) the flood pulse (a flood event— influences that generally extend less than one year); and
- (d) flow hydraulics (turbulence, velocity and depth— microscale influences that extend less than an hour).

Fluvial geomorphology also views river channel structure in a hierarchical manner. Geomorphological factors sit within a hierarchy of influence, where larger-scale factors set the conditions within which smaller-scale factors form. As a result, river systems can be divided into nested levels that encompass the relationships between a stream and its catchment at a range of spatial and temporal scales. The approach of Petts & Amoros (1996) is typical. At the top of the hierarchy, catchments persist at

larger spatial scales and longer time scales (Table 1). This pattern continues through the hierarchy of river system, functional process zone, reach, functional channel set and functional unit levels until at the bottom of the hierarchy, mesohabitats persist at small temporal and spatial scales (Table 1).

In ecology there are also distinct levels of biological organization. Typically these correspond to individuals, populations, communities and ecosystems (Table 2). While these units are not scales (Petersen & Parker, 1998) they operate in characteristic spatial and temporal domains and are used to stratify components within the biological system. For example, physiology and behaviour are generally studied at the level of the individual, species richness and diversity are studied at the community level and energy and nutrient fluxes are studied at the ecosystem level (Table 2).

Viewing river systems from an interdisciplinary perspective requires links to be established between disciplines. Pickett *et al.* (1994) argue that an interdisciplinary philosophy of science should be scale-sensitive and move away from the conventional reductionist falsification approach which limits understanding of complex systems such as rivers. This would demand a scale-based approach that integrates description, causal explanation, testing and prediction (Pickett *et al.*, 1994). Hierarchy is the common thread running through hydrology, fluvial geomorphology and freshwater ecology and is therefore a fundamental tenet of eco-geomorphology. However, identification of the appropriate scales or levels of organization that link similar

Table 1 A geomorphological characterization scheme for river systems (modified from Petts & Amoros, 1996).

Scale	Spatial extent (km)	Temporal extent (years)	Description
Basin	10^5	10^7-10^6	Area of the primary drainage basin
River system	10^4	10^6-10^5	The river channel and flood plain from its source to its mouth or a defined distance downstream
Functional process zone	10^3-10^2	10^4-10^3	Lengths of the river system that have similar discharge and sediment regimes, can be defined from major breaks in slope and from style of river channel or flood plain
River reach	10^2-10^1	10^2-10^1	Repeated lengths of river channel within a process zone that have similar channel style
Functional channel set	10^0	10^0	Units associated with specific landforms such as major cutoffs, aggrading flood plains, main channels
Functional unit	10^{-1}	10^{-1}	Characterized by a typical aquatic community that is indicative of the habitat conditions present at a site
Mesohabitat	$10^{-2}-10^{-3}$	$10^{-1}-10^{-2}$	Areas sensitive to variations in control variables that may change from year to year reflecting the sequence of discharge and sediment loads, examples include sand bars, gravel patches, scour holes

Table 2 Levels in the ecological hierarchy (levels are given from smallest to largest). After Colin Townsend (University of Otago, New Zealand, personal communication).

Level of hierarchy	Attributes of the hierarchy
Individuals	Physiology, behaviour
Populations	Rates of births and deaths
Communities	Species, composition, diversity, richness
Ecosystems	Energy and nutrient fluxes

attributes across disciplines is rarely attempted because of entrenched views within individual disciplines.

A framework for the interdisciplinary study of river ecosystems would need to be hierarchical, integrative, holistic and process-based. The overarching goal of the framework is to match a problem with a river system process, so that the appropriate causal explanations can be identified at the correct spatial and temporal scales. In turn, this allows consideration of paradigms from different disciplines that may be descriptive, explanatory or experimental but which ultimately lead to multiscale prediction of pattern–process and process–pattern relationships. The primary components of the framework are:

- (a) There should be an emphasis on the need to define the study domain (bounded universe in which the dialogue between conceptual construct and reality is conducted) which is scale dependent.
- (b) Ecological and geomorphological complexity can only be deconstructed by research at multiple scales. Multiscale studies provide a mechanism for embedding small-scale understanding within the context of larger-scale understanding.
- (c) Studies at different scales are amenable to different approaches. At large scales there is seldom the luxury of replication and controls so that generalization (pattern seeking) and causal explanation are more appropriate than experimental testing.
- (d) The classic emphasis on falsifiability is too restrictive for ecology and geomorphology because the prerequisites for its use: universality and simple causality, seldom apply in natural systems where organisms and their abiotic environment are characterized by multiple causality.

INTERDISCIPLINARY UNDERSTANDING OF ENVIRONMENTAL FLOWS

Allocating water to sustain natural ecosystems, restore rivers degraded by over abstraction and to protect biodiversity has become a key issue in river management. One of the goals of environmental flows is to allocate water to maintain riverine habitats (e.g. PHABSIM, Gore & Nestler, 1988; Tennant (Montana) method, Tennant, 1976). However, the notion of habitat varies within hydrology, fluvial geomorphology and ecology. Regardless of discipline, there are two overarching components to habitat. First, habitat should be defined with reference to the species being considered and second, habitat must be defined in terms of physical and biological properties. As such, habitat is interdisciplinary rather than discipline specific. Habitat also sits within a hierarchical context where biotic and abiotic processes that shape habitats occur at multiple spatial and temporal scales. Thus, maintenance of habitat as an endpoint in environmental flow approaches is meaningless without reference to an ecological entity and the hierarchical organization of river systems.

Environmental flows management is frequently concerned with the question “how much water do we need to allocate to the environment, to protect and conserve river function?” Outside of an interdisciplinary framework, this question is likely to have three answers, because a hydrologist, a geomorphologist and an ecologist view river systems from the experience of their own disciplines. For example, from a geomorphological perspective, water allocation is required to maintain the structure

and function of natural physical features of the river channel (Gippel & Stewardson, 1998). From a biological perspective, water allocation is required to maintain individuals, populations, communities and ecosystem processes. Hence, environmental water allocations generated outside of an interdisciplinary approach may never fully protect and conserve river function, because they do not consider all components of river systems, and are not cognizant of multiscale linkages among disciplines.

Using an interdisciplinary framework, environmental water allocations can be placed within a spatial and temporal context that considers key hierarchical links between hydrology, fluvial geomorphology and ecology. This framework changes the issue of water allocation from one of discipline-specific effects to one that must consider complex multiscale interactions among biota, physical structure and hydrological processes (Fig. 1). At a microscale, flow hydraulics influences the character of the river-bed substratum (Lancaster & Belyea, 1997) and the corresponding level of biological organization is that of an individual organism. At a larger scale, the flow history partly determines the morphology of river zones and the corresponding level of biological organization is that of the community (Fig. 1). Environmental water allocations rely on the manipulation of the hydrological component of river systems. It is important to know at what scale these hydrological manipulations are based, in order to predict physical and biological responses.

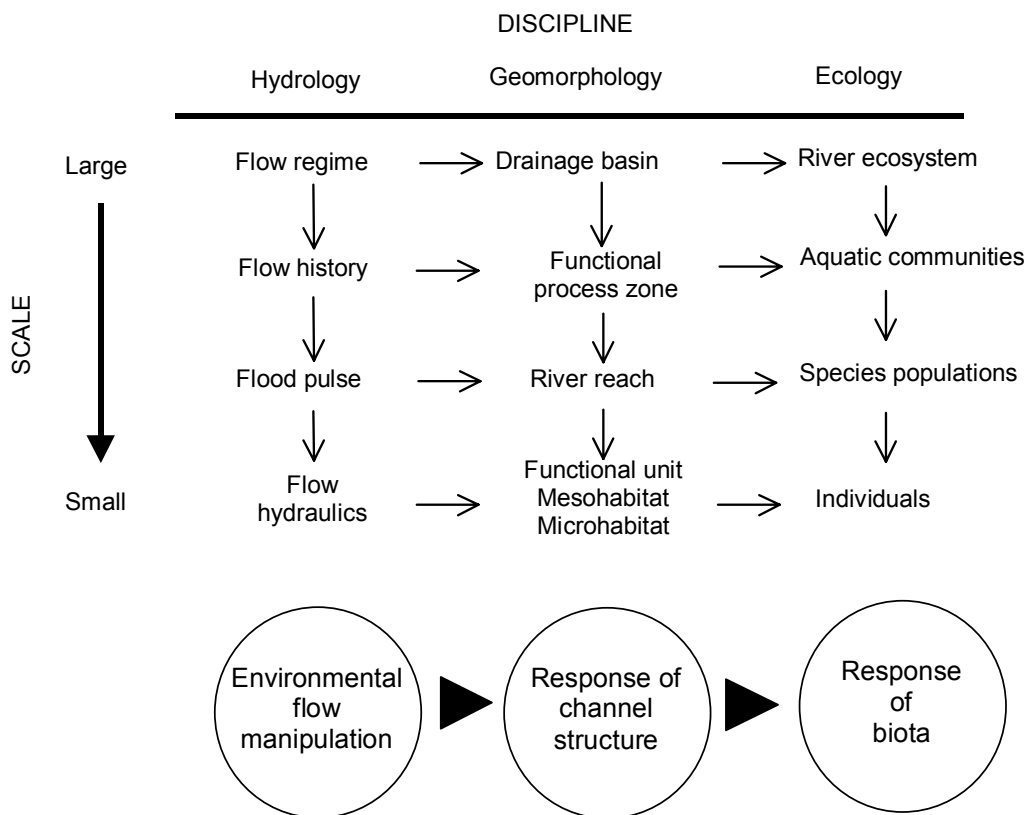


Fig. 1 Multiscale relationships between hydrology, fluvial geomorphology and ecology. Environmental flow strategies need to monitor geomorphological and ecological responses to hydrological manipulation at the appropriate scale and need to conduct hydrological manipulations at the appropriate scale to produce a geomorphological or ecological benefit.

In heavily managed river systems it is often compulsory to allocate water to the environment. The aim of these allocations is to produce an environmental benefit of improved river ecosystem functioning. River scientists frequently grapple with the measurement of this benefit and often fail to detect a physical and or biological response to a water manipulation. This is not necessarily because the response is not occurring. Rather, hydrological manipulation may produce a response at a different scale from that which is being measured. This mismatch may be overcome by the use of an interdisciplinary framework that facilitates an *a priori* expectation of the biological and physical responses that may occur at different scales with various hydrological manipulations.

Currently in Australia and elsewhere, environmental flow approaches view rivers as uniform and fail to consider spatial and temporal complexity within a river system. A recent study by Thoms & Parsons (in press) demonstrated a complex spatial and temporal dimension of hydrological character in the Condamine-Balonne River, Australia. Spatially, six distinct hydrological zones were identified along the river using multivariate statistics. These hydrological zones corresponded to geomorphological river zones (Thoms & Sheldon, 2002). Temporally, the dominant scale of hydrological influence differed between river zones. For example, pulse scale variables were important in the headwater zones, flow history scale variables were important in the mid zones and flow regime scale variables were important in the lower zones. Hence, hydrological character differed in a spatial and temporal dimension.

Spatial and temporal complexity of hydrological character has implications for environmental flow strategies. Commonly, biological attributes are used to monitor the effectiveness of hydrological manipulations. In Australia, macroinvertebrate communities collected at the site scale are used as a primary biological indicator in environmental flow assessments, but in the Condamine-Balonne River, these community-level attributes may be inappropriate because of inherent spatial and temporal complexity in hydrological and geomorphic character. For example, given the dominance of pulse-scale hydrological variables in headwater zones it would be more appropriate to monitor populations of individual organisms at small habitat patches within a reach (Fig. 1). In the mid river zones, where flow history variables dominate, community level attributes should be monitored along segments of the river zone (Fig. 1). In the lower zones, ecosystem level attributes should be used because flow regime variables dominate the hydrological character of this area (Fig. 1). Therefore, the biological indicators used to monitor environmental flows should match the scales of physical and hydrological processes that occur in the river system.

CONCLUSIONS

As an interdisciplinary framework, eco-geomorphology has the potential to bring about fresh solutions to environmental problems in river systems. Eco-geomorphology recognizes that the hydrological, geomorphological and ecological components of river systems interact at multiple spatial and temporal scales. In the context of environmental flows, hydrological factors will have a variable influence on geomorphological and biological factors and *vice versa*. Indeed, hydrological attributes

may have an important role in certain areas of a river but have little or no influence in other areas. Identification of the key spatial and temporal scales of interaction throughout a river system is essential for effective management of environmental flows. At present, many management strategies do not adequately examine what part(s) of the river system can or need to be managed and often fail to provide scientific knowledge at the appropriate scale. Moreover, the interface between science, in this case hydrology, geomorphology and freshwater ecology and policy-management is turbulent but potentially exciting. Communicating knowledge to the water industry can only improve with the development of an interdisciplinary eco-geomorphological framework that guides the study of river systems.

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