Hydroecology and Ecohydrology: Past, Present and Future

Edited by

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Paul Wood for Maureen, Connor and Ryan
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Contents

Paul J. Wood is a Senior Lecturer in the Department of Geography at Loughborough University, UK. His interdisciplinary research centres on three themes at the interface of ecology and hydrology: (1) the interactions between hydrological variability and aquatic invertebrate populations and communities within headwater streams, springs and hypogean systems (including groundwater, caves and the hyporheic zone); (2) the influence of river flow regime variability upon lotic invertebrate communities; and (3) the role of hydrological disturbances (droughts and floods) in structuring aquatic faunal communities and the processes involved in change over varying time-scales.

David M. Hannah is a Senior Lecturer in Physical Geography at the University of Birmingham, UK. His research is interdisciplinary, focusing on three complementary themes within hydroclimatology (interface between hydrology-climatology): (1) hydroclimatological processes within alpine, mountain and glacierized river basins; (2) climate and river flow regimes; and (3) river energy budget and thermal dynamics. He has a strong crosscutting interest in hydroecology, specifically ecological response to hydroclimatological and physicochemical habitat variability/change. He has also developed new methods for monitoring, analysing and modelling environmental dynamics at a range of space-time scales.

Jonathan P. Sadler is a Reader in Biogeography and Ecology at the University of Birmingham, UK. His research activity is split between urban ecology, hydroecology, and the use and reconfiguration of knowledges associated with biodiversity. The central focus of his hydroecological work examines: (1) how the interaction of flow variability and fluvial geomorphology affects riparian animal communities; (2) how hydrological disturbance affects aquatic riparian animal community structure, food-web fluxes and subsidies, and species populations, and; (3) how riparian management and aquatic pollution affects both lotic and riparian animal communities.

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Preface

Water-dependent habitats are extremely diverse in terms of their nature (e.g., drylands, wetlands, streams/rivers and ponds/lakes), geography (poles to equator, low to high latitude) and many support communities and species of high conservation value, some of which are under threat from extinction. As pressure is increasing on water-dependent habitats due to global change and ever growing anthropogenic impacts, it is clear that balancing the water needs of people against those of ecosystems (terrestrial and aquatic) is, and will increasingly become, a premier environmental issue. This crucial, often precarious 'balancing act' involves some highly complex issues and, thus, it has compelled recent workers to identify the need, not only for new integrative science (between traditional fields of hydrology–ecology) and analytical approaches, but for truly interdisciplinary research. In this context, it has been argued that the 'new' discipline(s) of hydroecology/ecohydrology has the potential not only to unlock elements of this complexity, but also to provide a foundation for the sustainable management of water resources.

The terms ecohydrology and hydroecology have been used increasingly in the international scientific literature over the last decade, and this emerging interdisciplinary subject area has gathered considerable momentum as evidenced by the publication of textbooks, special issues of journals, over 150 peer-reviewed scientific journal papers, and the imminent launch of a dedicated John Wiley & Sons journal, *Ecohydrology*. Although there is a growing volume of research output at the interface between the hydrological and biological sciences, the terms hydroecology and ecohydrology and the scientific remit of the field remain remarkably poorly defined. Hence, this book aims to address this research gap and capture the vitality of this current scientific hot-topic in a cutting-edge research text that: (i) reviews the evolution of the discipline (past); (ii) provides detailed coverage of the present state of the art, and (iii) looks to the horizon for the ecohydrology/hydroecology of the future. To achieve this goal, we invited international leaders within their respective fields to author individual chapters. The resultant chapters present significant new results and methodological developments within the field of ecohydrology/hydroecology, while outlining key historical developments and identifying future research needs. The chapters are positioned at the forefront of their fields and draw together individuals from hydrological and biological/ecological sciences and engineering disciplines

to 'bridge the gap' between traditional academic disciplines and to ensure that the book is inclusive and truly interdisciplinary.

We have made every effort to encapsulate the variety of ecohydrological/hydroecological research currently being conducted across the globe and suggest that this book is significantly different from previous texts in providing coverage of: (i) a range of organisms (plants, invertebrates and fish), (ii) physical processes within terrestrial, riparian (aquatic–terrestrial ecotones) and aquatic habitats, and (iii) palaeo-ecological/hydrological perspectives. We have endeavoured to provide a comprehensive overview of the research conducted under the banner of ecohydrology/hydroecology. However, we acknowledge that, due to the rapidly developing nature of the subject, there are inevitably omissions. We hope that in capturing the state of the art, this book will provide a catalyst for future interdisciplinary research and a starting point for scientists, practitioners and end-users with an interest in hydrology–ecology interactions.

There are number of people that require acknowledgement for their contributions to this book. We would like to express our sincere appreciation to the teachers, mentors and colleagues that kindled our interest in hydroecology, and opened opportunities (and our eyes) to develop our work in this interdisciplinary research field. We would like to thank the following chapter reviewers for their important work in enhancing the quality and rigour of this book: Maureen Agnew, Patrick Armitage, Martin Baptist, Valerie Black, Chris Bradley, Lee Brown, Paul Buckland, Leopold Füreder, Jane Fisher, Rob Francis, Alan Hill, Etienne Muller, Pierre Marmonier, Yenory Morales-Chaves, Eric Pattee, Ian Reid, Christopher Robinson, Geoffrey Petts, Gregory Sambrook Smith, Barnaby Smith, Chris Soulsby, Klement Tockner and Larry Weber. We are also very grateful to several anonymous reviewers. We appreciate the support and efforts of John Wiley & Sons' staff at all stages in the preparation of this book, particularly Richard Davies, Colleen Goldring Richard Lawrence and Fiona Murphy.

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1

Ecohydrology and Hydroecology: An Introduction

Paul J. Wood, David M. Hannah and Jonathan P. Sadler

1.1 Wider Context

Water is essential for life on our 'blue planet' but just 2.5% of all the Earth's water comprises freshwater. Of this precious freshwater resource, 0.3% is estimated to be surface water, held in rivers and streams (2%), wetlands (11%) and lakes (87%) (see, for example, Oki and Kanae, 2006). This tiny proportion of global water supports at least 6% (>100 000) of all described species (Dudgeon *et al*., 2006). Water-dependent habitats are extremely diverse, located from poles to equator and low to high altitude, and comprise dynamic systems that vary in scale from individual plants to large complex vegetation communities, from the smallest headwater stream to the largest lowland river, complex floodplains, a myriad of wetland types, and lentic ecosystems ranging from ponds to vast lakes. Many of these habitats support communities and species of high conservation value, some of which are under threat from extinction (e.g., Grootjans *et al*., 2006; Hannah *et al*., 2007; Ricciardi and Rasmussen 1999; Sadler *et al*., 2004; Wilcox and Thurow, 2006). Because of water's many uses, humans have fundamentally altered natural hydrological processes and conditions in many areas and, consequently, freshwater ecosystems have experienced reductions in biodiversity at least as great as the most impacted terrestrial ecosystems (Dudgeon *et al*., 2006). When viewed against a backdrop of rapidly rising global population (predicted to reach about 8 billion by 2025; United Nations, 2000), it is clear that balancing the water needs of people against those of ecosystems (terrestrial and aquatic) is, and will increasing become, a premier environmental issue (see, for example, Petts *et al*., 2006a). This crucial, precarious 'balancing act'

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involves some highly complex issues and, thus, it has compelled recent workers to identify the need, not only for new integrative science and new analytical approaches (e.g. Newman *et al*., 2006; Petts *et al*., 2006b), but for truly interdisciplinary research (e.g. Hannah *et al*., 2004). In this context, it has been argued that the 'new' discipline(s) of hydroecology/ecohydrology has the potential not only to unlock elements of this complexity, but also to provide a foundation for the sustainable management of water resources (e.g. Zalewski, 2000; Zalewski *et al*., 1997).

1.2 Hydroecology and Ecohydrology: A Brief Retrospective

The terms ecohydrology (eco-hydrology) and hydroecology (hydro-ecology), which include the subdiscipline of ecohydraulics, are being used increasingly by the international scientific community (see e.g. Janauer, 2000; Wilcox and Newman 2003, Wood *et al*., 2001). Although there is a growing volume of research output at the interface between the hydrological and life (biological) sciences (e.g. Gurnell *et al*., 2000; Zalewski, 2000), the terms hydroecology and ecohydrology and the scientific remit of the field are remarkably poorly defined, with limited consensus between many of the published definitions (e.g. Wassen and Grootjans, 1996; Zalewski *et al*., 1997; Baird and Wilby, 1999; Dunbar and Acreman, 2001; Eagleson, 2002; Nuttle, 2002; Bond, 2003; Rodriguez-Iturbe, 2005). Furthermore, it has been suggested that while physical scientists, and hydrologists in particular, are embracing the new 'hot topic', ecologists and biologists are less aware or less inclined to engage in the debate regarding its status as a 'new paradigm' or subdiscipline (Bond, 2003). Bibliographic analysis (for details refer to Hannah *et al*., 2004) has demonstrated the proliferation of the terms ecohydrology and hydroecology, and the breadth of subject matter; however, it has also identified a larger body of 'hidden' ecohydrological and hydroecological literature that does not flag itself as such (also see Bond, 2003; Bonell, 2002; Kundzewicz, 2002). Perhaps most significantly, the review of hydroecological/ecohydrological literature showed clearly that the majority of the research was undertaken within traditional subject boundaries (i.e., groups dominated by either physical or biological scientists) rather than interdisciplinary teams, uniting researchers from both traditions (Hannah *et al*., 2004). Whether or not the terms are widely recognised or accepted as something 'new' (or as a subdiscipline) by scientists, the fact remains that the terms are increasingly making an impact within the hydrological and ecological literature. Indeed, the yearly citation rate of the terms has more than doubled since 2004 (Figure 1.1).

1.3 A Focus

It is apparent from our previous literature review and bibliographic analysis (Hannah *et al*., 2004) that a definition identifying a theoretical core is needed before hydroecology and ecohydrology become established paradigms or disciplines. A definition including the discipline's aim and subject scope would serve as a focal point to help unite the research community. In this regard, a single definition that applies equally to hydroecology and ecohydrology is essential. At present, there is arguably no single accepted definition of either term, never mind a joint definition.

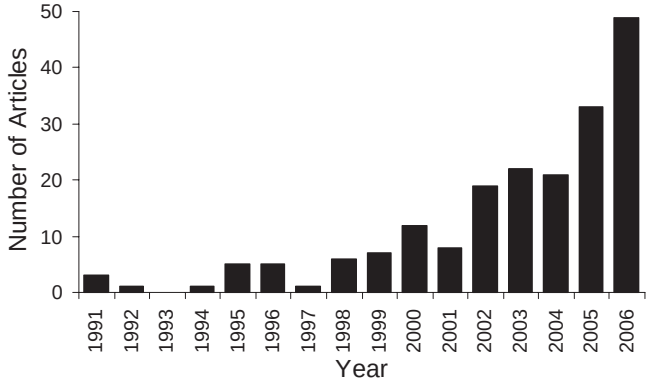

Figure 1.1 *Number of peer-reviewed journal articles using the terms ecohydrology, eco-hydrology, hydroecology and hydro-ecology (1991–2006)*

There has been specific use of the term ecohydrology to refer to plant–water interactions both in the past (e.g., Baird and Wilby, 1999; Eagleson, 2002) and increasingly more recently, with special reference to semi-arid/dryland/rangeland environments (e.g. Newman *et al*., 2006; Wilcox and Thurow, 2006). However, ecohydrology has also been employed to describe wider hydrology–ecology linkages (i.e. all biota and environments, e.g., Kundzewicz, 2002; Zalewski, 2002). Arguably, this specific versus generalist usage of ecohydrology could lead to confusion and misunderstanding. Therefore, we propose the use of the term hydroecology to refer to hydrology–ecology interactions in the broadest sense (cf. Dunbar and Acreman, 2001) and so provide an umbrella under which ecohydrology in its stricter form can be included.

We recognise the potential danger that definitions can become either too restrictive or nebulous to be effective and/or applicable. Like hydroecology, other 'new' scientific paradigms have begun life as 'hot topics' but they have faded away due to a problem of identity. If hydroecology is to avoid a similar fate, we must ensure that it is an identifiable and constructive discipline, and not a deconstructed version of existing paradigms or academic disciplines. A clear and inclusive definition of hydroecology should help to this end. Rather than debating and deliberating over the appropriate form of words in a revised definition, we suggest that it may be more instructive to provide a list of 'target elements' that outline the theoretical core and range of process interactions and scales that should encapsulate hydroecological research (Hannah *et al*., 2004):

(i) the bi-directional nature of hydrological–ecological interactions and importance of feedback mechanisms;
(ii) the requirement for fundamental process understanding, rather than simply establishment of functional (statistical) links without a probable chain of causality;
(iii) the subject scope to encompass: (a) the full range of (natural and human-impacted) water-dependent habitats/environments, and (b) flora, fauna and whole ecosystems;

(iv) the need to consider process interactions operating at a range of spatial and temporal scales (including palaeohydrological and palaeoecological viewpoints); and
(v) the interdisciplinary nature of the research philosophy (see Chapter 22).

1.4 This Book

Given the current upsurge in hydroecology and ecohydrology, we thought it important and timely to capture the current state-of-the art in one place as a research-level text. Our intention was to create a cutting-edge volume, which presents new results and methodological developments within the rapidly evolving field of hydroecology/ecohydrology. To achieve this goal, recognised international leaders in their subjects have written the individual chapters and have aimed to position their contributions at the research forefront. In terms of content, the book covers a range of hydrological and ecological processes, methodological approaches and hydroecologically sensitive habitats from an array of geographical locations (e.g., Australia, Europe, and North and South America). The book differs from others currently available not only in terms of its environmental breadth but it also covers a wide range of organisms (plants, invertebrates and fish) and their interactions with water.

The book is structured in three sections: Part 1 considers fundamental ecohydrological/hydroecological process understanding and how floral and faunal communities and ecosystem functions (e.g. nutrient cycling) are influenced and respond to water and its availability (Chapter 2 to Chapter 7). Part 2 of the book draws together up-to-date methodological approaches and critiques of how ecohydrological/hydroecological patterns and processes can (may) be monitored/modelled to maintain and protect the natural environment, and be managed to ensure the continued supply of water for human uses (Chapters 8–13). Part 3 comprises detailed ecohydrological and hydroecological case-studies of research undertaken on different floral and faunal groups in different environments across the globe (Chapter 14 to Chapter 21). The final chapter (Chapter 22) identifies some challenges and future prospects for hydroecology/ecohydrology.

We do not claim that this volume is all encompassing in its coverage of research that could be deemed to be hydroecology or ecohydrology. Indeed, we are conscious that this volume only begins to address palaeohydrology and palaeoecology. Palaeoecohydrology studies may provide valuable baseline information regarding pre-human influences on the environment and for climatic change/variability investigations (Lytle, 2005; Prebble *et al*., 2005). In addition, the chapters almost exclusively deal with freshwater and do not consider marine/brackish water ecosystems or terrestrial environments subject to salinisation (e.g. Williams and Williams, 1998; Brown *et al*., 2006). Saline water represents a challenging environment for floral and faunal communities and, as yet, these avenues of research have not been explored fully by ecohydrologists and hydroecologists.

1.5 Final Opening Remarks

It is clear that researchers actively involved in ecohydrological and hydroecological studies are increasingly aware of the need for a truly interdisciplinary philosophical