River Confluences, Tributaries and the Fluvial Network

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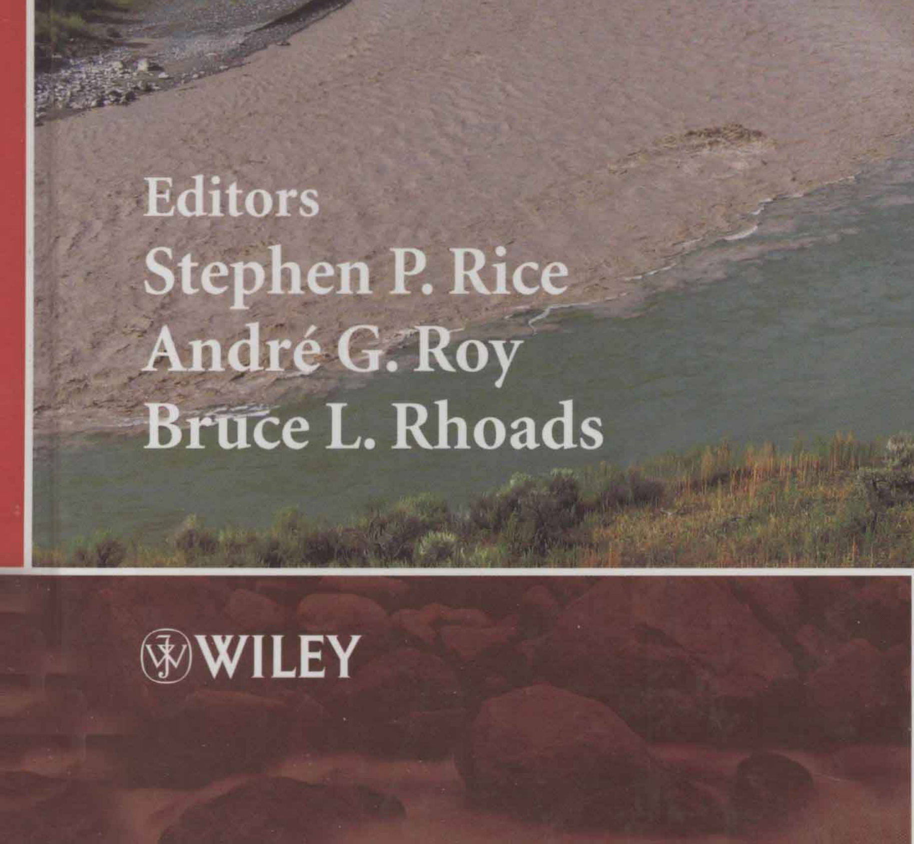

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Preface

When the book proposal that led to this publication was reviewed, we were flattered, but mainly daunted, by the suggestion from a particularly generous referee that we should write this book ourselves. While grateful for the referee's support of the project, we persevered with our original intention of compiling an edited volume. The resulting collection of chapters draws on the research of an international group of scholars and practitioners who work in universities, government agencies, private consultancies and research establishments. Their expertise is in academic and applied geomorphology, hydrology, sedimentology, ecology and engineering. Their methods include numerical modelling, laboratory experimentation and detailed field investigations. Looking at the chapters that they have produced, it is clear to us that we were right to favour the great variety and depth of their expertise and experience over our own, inevitably inferior, knowledge of their areas of specialization. We are therefore grateful to our authors for embracing our project, for sharing their understanding and for helping us to, in a sense, avoid having to write this book ourselves.

And it is a book that needed to be written (in one way or another). River confluences are ubiquitous and critical nodes in river networks, and the branching pattern of tributaries and sub-networks is one of the most characteristic features of river systems on Earth and elsewhere. We find it somewhat remarkable, then, that this will be the first book to focus attention explicitly on confluence dynamics, tributary impacts and the links between processes at these scales and river network functions. We believe that understanding confluence processes and interactions between the tributary and main stem are keystones for scaling-up our understanding of river processes to the drainage network scale: without an understanding of the nodes in the network and the interactions between connected links, the development of basin-scale models and tools is restricted. We subscribe to the view that such network-scale understanding is central to the successful integration of Earth, environmental and biological sciences within riverine landscapes and thence the sustainable management of our riverscapes. We therefore hope that this book will be a helpful stepping-stone for the pursuit of an integrated, cross-scale river science.

To date, work in this area has been communicated almost exclusively via academic journals in geomorphology, ecology, geology and engineering. By bringing together the expertise represented here in one place, our aim is to provide a single benchmark reference that defines the current state of understanding as well as the leading edge of contemporary research. Each chapter is built around two central pillars: a critical review of work in the author's area of expertise and unpublished research that highlights the cutting edge of research in that area. In this way, the book is at once intended to fulfil the needs of students (of whatever age and standing) who require sound, thoughtful reviews of particular topics and also those who are actively involved in conducting and applying research on confluences, tributaries and networks. We therefore hope that the book will be useful both as a standard reference and as a source of new research questions and hypotheses.

To close, some thanks. First to the authors of these chapters for their time and effort: we are grateful and hope that the exercise has been rewarding. Each chapter was fully reviewed and we must thank the large number of colleagues who acted as independent referees; their input was consistently constructive and has substantially improved the quality of the end product. Natasha Todd-Burley's editorial assistance was invaluable during the final stages of production. Finally, the book has been a number of years in the making and we therefore want to thank family and friends for their continued support. In particular, SPR would like to thank Georgina for her support and encouragement throughout this process and dedicate his contribution to his brother Mike, who beat him to a publication with tributary associations. BLR thanks Kathy, Jamie and Steven for helping him to keep life in proper perspective at all times. AGR thanks his co-editors for their enthusiasm for this project, his research team for their constant support and Catherine for being there.

Stephen Rice, Bruce Rhoads, André Roy
October 2007

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Contents

1

Introduction: river confluences, tributaries and the fluvial network

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Introduction

That river systems are networks consisting of links and nodes is one of their most obvious characteristics. Despite the ubiquity of confluences and tributary networks, the first century of modern fluvial geomorphology paid little consistent attention to river junctions and the interactions between tributaries and the main stem (Kennedy, 1984). Important exceptions include classic contributions from Playfair (1802), Lyell (1830) and Sternberg (1875), works on tributary–main-stem interactions (e.g. Krumbein, 1942; Miller, 1958), considerations of junction hydraulics and mixing (e.g. Taylor, 1944; Mackay, 1970) and the seminal works on river network structure (e.g. Horton, 1945; Shreve, 1967). However, the 1980s marked the beginning of a period in which confluence, tributary and network studies developed rapidly. Key contributions were concerned with: confluence morphology, hydraulics and sedimentology (Mosley, 1976; Best, 1986, 1988; Roy *et al.*, 1988), tributary-induced changes in channel form (Richards, 1980; Roy

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and Woldenberg, 1986; Rhoads, 1987) and bed sediments (Church and Kellerhals, 1978; Knighton, 1980), the ecological role of tributaries along unregulated (Bruns *et al.*, 1984) and regulated rivers (Petts, 1984; Petts and Greenwood, 1985), tributaries as repositories of paleoflood information (Kochel and Baker, 1982) and tributary network structure (Abrahams and Campbell, 1976; Flint, 1980; Abrahams and Updegraph, 1987).

Figure 1.1 indicates the rapid increase in the volume of published work on tributaries and confluences in the period since 1980 and illustrates how the initial impetus of the 1980s was consolidated in the 1990s. Ecological interest has lagged behind geomorphology and hydraulics, but it is clear that ecological interest is now growing at the fastest rate. This body of work has demonstrated that river confluences are critical nodes in river systems where tributary fluxes of water and sediment can elicit adjustments in the geomorphology, hydraulics, sedimentology and ecology of the recipient channel. At

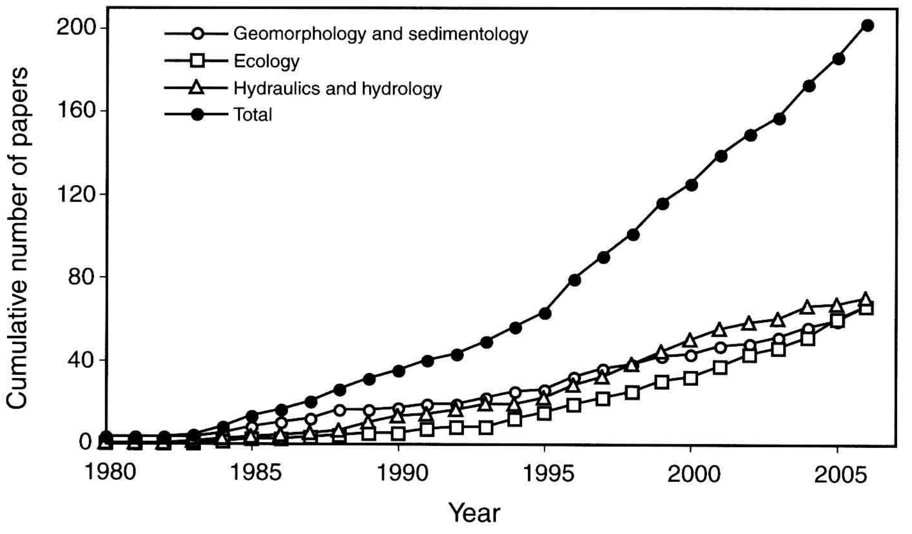

Figure 1.1 The growth in research publications that deal with confluences and tributaries. Network research is not included. Because of the cross-disciplinary nature of many papers, the classification into sub-disciplines is imperfect. Searches were made for the period 1980–2007 using the ISI Web of Science, Science Citation Index – Expanded (http://portal.isiknowledge.com/). A primary search was made of titles, abstracts and keywords using the Boolean expression '(confluence* OR tributar*) AND (river* OR channel*)'and subsequent searches explored other likely terms. Results from these searches were then scrutinized and only those papers where tributaries or confluences were the primary subject matter or where they were used explicitly to explain observed phenomena were retained. Large numbers of papers that studied a particular river system including one or more of its tributaries or confluences but which did not focus on the properties or processes of confluences or tributaries were excluded. Because many papers on water chemistry across drainage basins fall into this category, the 'hydraulics and hydrology' classification does not include any water quality papers.

the smallest scales, research at river confluences examined the distinctive flows, morphologies, sedimentary assemblages and habitats that make confluence sites important local features. Most attention has been directed towards understanding flow mixing at junctions (Gaudet and Roy, 1995; Best and Ashworth, 1997; Biron *et al.*, 2004; Rhoads and Sukhodolov, 2004; Ding and Wang, 2006) and relations between sediment transport, morphology and stratigraphy (Biron *et al.*, 1993; Kenworthy and Rhoads, 1995; Ashworth, 1996; Leclair and Roy, 1997; Paola, 1997; Roy and Sinha, 2005; Boyer *et al.*, 2006). The biological attributes of confluences have received some attention (Cellot, 1996; Kupferberg, 1996; Franks *et al.*, 2002; Fernandes *et al.*, 2004; Kreb and Budiono, 2005; Kiffney *et al.*, 2006), as have the dynamics of ice jams at confluences (Prowse, 1986; Ettema *et al.*, 1997; Shen *et al.*, 2000; Ettema and Muste, 2001). At this scale, improved understanding informed, and was informed by, studies of confluences in braided rivers (Ashmore, 1991; Ashworth *et al.*, 1992; Best and Ashworth, 1997), which, arguably, has laid the foundation for recent investigations of the dynamics of river bifurcations (Dargahi, 2004; Federici and Paola, 2003; Khan *et al.*, 2000; Parsons *et al.*, 2007).

At a slightly larger scale, the confluence zone has been recognized as an important site of storage and staging for clastic and organic materials in fans and terraces (Albertson and Patrick, 1996; Brierley and Fryirs, 1999; Florsheim *et al.*, 2001; May and Gresswell, 2004; Gomez-Villar *et al.*, 2006). Ecological research at this scale suggests that tributary channels in the vicinity of confluences can provide important biological resources including, for example, refugia from high water temperatures (Bramblett *et al.*, 2002; Cairns *et al.*, 2005) and main-stem predators (e.g. Fraser *et al.*, 1995). It has been proposed that such factors, along with enhanced morphological heterogeneity in this confluence zone, may create hotspots of elevated biodiversity (Benda *et al.*, 2004a). At the larger, reach scale, main-stem adjustments to tributary fluxes of water, sediment and organic materials have been shown to structure the longitudinal operation of various abiotic and biotic processes leading to step-changes or gradient shifts in, for example, bed material grain size (Dawson, 1988; Rice and Church, 1998), longitudinal profile (Rice and Church, 2001; Hanks and Webb, 2006) and macroinvertebrate ecology (Perry and Schaeffer, 1987; Rice *et al.*, 2001). Earlier work on tributary influences has been extended to investigate what controls the magnitude of tributary impacts (Rice, 1998; Benda *et al.*, 2004b; Ferguson *et al.*, 2006; Rice *et al.*, 2006).

Understanding confluence dynamics and tributary impacts at these various scales is crucial for scaling-up knowledge of river processes to the drainage network scale: understanding the operation of the nodes in a network is necessary in order to develop network-scale models and tools. Indeed, there is increasing awareness that river system science requires a better integration of process knowledge across a range of spatial scales and particular emphasis is being placed on understanding network-scale functions (e.g. Paola *et al.*, 2006). Building on early work that focused on the topological properties of river networks (see Abrahams, 1984, for a review), a large body of research over the past 30 years has focused on the fractal properties and scaling relations of networks