

# River Confluences, Tributaries and the Fluvial Network

Editors  
Stephen P. Rice  
André G. Roy  
Bruce L. Rhoads

 WILEY

# **River Confluences, Tributaries and the Fluvial Network**

Edited by

**Stephen P. Rice, Loughborough University, UK**

**André G. Roy, Université de Montréal, Canada**

**Bruce L. Rhoads, University of Illinois, USA**



John Wiley & Sons, Ltd

Copyright © 2008 John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester,  
West Sussex PO19 8SQ, England  
Telephone (+44) 1243 779777

Chapters 9, 11 and 18 are the works of the US Government and are in the public domain in the United States of America.

Email (for orders and customer service enquiries): [cs-books@wiley.co.uk](mailto:cs-books@wiley.co.uk)  
Visit our Home Page on [www.wileyeurope.com](http://www.wileyeurope.com) or [www.wiley.com](http://www.wiley.com)

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except under the terms of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1T 4LP, UK, without the permission in writing of the Publisher. Requests to the Publisher should be addressed to the Permissions Department, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, or emailed to [permreq@wiley.co.uk](mailto:permreq@wiley.co.uk), or faxed to (+44) 1243 770620.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The Publisher is not associated with any product or vendor mentioned in this book.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the Publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

#### ***Other Wiley Editorial Offices***

John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA

Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 6045 Freemont Blvd, Mississauga, Ontario, L5R 4J3

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

#### ***Library of Congress Cataloging-in-Publication Data***

River confluences, tributaries, and the fluvial network / edited by Stephen P. Rice, André G. Roy, Bruce L. Rhoads.  
p. cm.

Includes bibliographical references and index.

ISBN 978-0-470-02672-4 (cloth)

1. Watersheds. 2. Geomorphology. 3. River engineering. I. Rice, Stephen P. II. Roy, André G.

III. Rhoads, Bruce L.

GB562.R58 2008

551.48'3—dc22

2008016826

#### ***British Library Cataloguing in Publication Data***

A catalogue record for this book is available from the British Library

ISBN 978-0-470-02672-4

Typeset in 10.5/13pt Minion by Aptara Inc., New Delhi, India

Printed and bound in Singapore by Markono Print Media Pte Ltd

This book is printed on acid-free paper

# **River Confluences, Tributaries and the Fluvial Network**

# 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**

# List of contributors

**Mario L. Amsler** (mamsler@fich1.unl.edu.ar) Facultad de Ingeniería y Ciencias Hídricas & Instituto Nacional de Limnología, Universidad Nacional de Litoral, Santa Fe 3000, Argentina

**Peter Ashmore** (pashmore@uwo.ca) Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada

**Douglas S. Bateman** (doug\_bateman@usgs.gov) Department of Forest Sciences, Oregon State University, Corvallis, OR 97331, USA

**Kenneth E. Bencala** (kbencala@usgs.gov) US Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, USA

**Lee Benda** (leebenda@earthsystems.net) Earth Systems Institute, 310 Mt Shasta Blvd, Mt Shasta, CA 96067, USA

**James L. Best** (jimbest@uiuc.edu) Departments of Geology and Geography and Ven Te Chow Hydrosystems Laboratory, University of Illinois at Urbana-Champaign, 1301 West Green Street, Urbana, IL 61801, USA

**Pascale M. Biron** (pascale.biron@concordia.ca) Department of Geography, Planning and Environment, Concordia University, 1455 de Maisonneuve Boulevard West, Montréal, Québec, H3G 1M8, Canada

**Rafael L. Bras** (rlbras@mit.edu) Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

**Kelly M. Burnett** (kmburnett@fs.fed.us) US Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, OR 97331, USA

**Robert A. Craddock** (craddockb@si.edu) Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 4th Street and Independence Avenue SW, WA 20013-7012, USA

**Robert Ettema** (rettema@uwyo.edu) Dean's Office, College of Engineering and Applied Science, University of Wyoming, 1000 E University Street, Laramie, WY 82071, USA

**Rob Ferguson** (r.i.ferguson@durham.ac.uk) Durham University, Department of Geography, Science Laboratories, South Road, Durham, DH1 3LE, UK

**Philippe Frey** (philippe.frey@cemagref.fr) Cemagref Groupement de Grenoble, Unité de Recherche ETNA (Erosion Torrentielle, Neige et Avalanches), Domaine universitaire, 2 rue de la Papeterie BP76, 38402 SAINT-MARTIN-D'HERES cedex, France

**J. Tobi Gardner** (jgardne7@uwo.ca) Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada

**Nicole M. Gasparini** (nicoleg@alum.mit.edu) School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-1404 USA

**Michael N. Gooseff** (mgooseff@engr.psu.edu) Department of Civil and Environmental Engineering, Pennsylvania State University, University Park, PA 16802, USA

**Correigh Greene** (Correigh.Greene@noaa.gov) NOAA NW Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA

**Robert E. Gresswell** (bgresswell@usgs.gov) US Geological Survey, Northern Rocky Mountain Science Center, 1648 S. 7th Avenue, Bozeman, MT 59717, USA

**Richard J. Hardy** (r.j.hardy@durham.ac.uk) Durham University, Department of Geography, Science Laboratories, South Road, Durham, DH1 3LE, UK

**Trevor Hoey** (thoey@ges.gla.ac.uk) Department of Geographical and Earth Sciences, East Quadrangle, University Avenue, University of Glasgow, Glasgow, G12 8QQ, UK

**Alan D. Howard** (alanh@virginia.edu) Department of Environmental Sciences, University of Virginia, 291 McCormick Rd, PO Box 400123, Charlottesville, VA 22904-4123, USA

**Rossman P. Irwin III** (IrwinR@si.edu) Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, MRC 315, 6th Street and Independence Avenue SW, WA 20013-7012, USA

**Peter Kiffney** (Peter.Kiffney@noaa.gov) NOAA NW Fisheries Science Center, Mukilteo Field Station, Building B, Mukilteo, WA 98275, USA

**Ray A. Kostaschuk** (rkostasc@uoguelph.ca) Department of Geography, University of Guelph, Ontario, N1G 2W1, Canada

**Praveen Kumar** (kumar1@uiuc.edu) Department of Civil and Environmental Engineering, University of Illinois, 205 North Mathews Avenue, Urbana, IL 61801, USA



**Norbert Landon** (norbert.landon@univ-lyon2.fr) Université Lumière, Lyon 2, Faculté GHHAT, Institut de Recherche en Géographie, 5 avenue Pierre Mendès CP11, 69676 BRON cedex, France

**Stuart N. Lane** (s.n.lane@durham.ac.uk) Durham University, Department of Geography, Science Laboratories, South Road, Durham, DH1 3LE, UK

**Frédéric Liébault** (frederic.liebault@cemagef.fr) Cemagref Groupement de Grenoble, Unité de Recherche ETNA (Erosion Torrentielle, Neige et Avalanches), Domaine universitaire, 2 rue de la Papeterie BP76, 38402 SAINT-MARTIN-D'HERES cedex, France

**Hua Lu** (hlu@bas.ac.uk) British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK

**Oscar Orfeo** (cecoal@arnet.com.ar) Centro de Ecología Aplicada del Litoral (CECOAL), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Corrientes City, Corrientes 3400, Argentina

**Daniel R. Parsons** (parsons@earth.leeds.ac.uk) School of Earth & Environment, University of Leeds, Leeds, LS2 9JT, UK

**George R. Pess** (george.pess@noaa.gov) NOAA – Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA

**Hervé Piégay** (herve.piegay@ens-lsh.fr) Université de Lyon, UMR 5600 CNRS, Site ENS-LSH, Plateforme ISIG, 15 Parvis René Descartes, BP7000, 69342 Lyon cedex 07, France

**Bruce L. Rhoads** (brhoads@uiuc.edu) Department of Geography, University of Illinois at Urbana-Champaign, Room 220 Davenport Hall, 607 South Mathews Avenue, Urbana, IL 61801-3671, USA

**Stephen P. Rice** (s.rice@lboro.ac.uk) Department of Geography, Loughborough University, Loughborough, LE11 3TU, UK

**Keith Richards** (ksr10@cam.ac.uk) Department of Geography, University of Cambridge, Downing Place, Cambridge, CB2 3EN, UK

**André Roy** (andre.roy@umontreal.ca) Département de Géographie, Université de Montréal, CP 6128, succursale Centre-Ville, Montréal, Québec, H3C 3J7, Canada

**Patricia M. Saco** (patricia.saco@newcastle.edu.au) Civil and Environmental Engineering, University of Newcastle, Callaghan, New South Wales 2308, Australia

**Ricardo N. Szupiany** (rszupian@fich1.unl.edu.ar) Facultad de Ingeniería y Ciencias Hídricas, Universidad Nacional de Litoral en Santa Fe, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Santa Fe 3000, Argentina

# Contents

<b>Preface</b>	<b>xi</b>
<b>List of contributors</b>	<b>xiii</b>
<b>1 Introduction: river confluences, tributaries and the fluvial network</b>	<b>1</b>
<i>Stephen P. Rice, Bruce L. Rhoads and André G. Roy</i>	
Introduction	1
Key aims of the book	4
Sections of the book	4
References	5
<b>I RIVER CHANNEL CONFLUENCES</b>	<b>11</b>
<b>2 Introduction to Part I: river channel confluences</b>	<b>13</b>
<i>André G. Roy</i>	
Introduction	13
Individual chapters	15
Reference	16
<b>3 Modelling hydraulics and sediment transport at river confluences</b>	<b>17</b>
<i>Pascale M. Biron and Stuart N. Lane</i>	
Introduction	17
Hydraulics	18
Bedload, suspended and solute transport	29
Conclusion	37
Acknowledgments	38
References	38
<b>4 Sediment transport, bed morphology and the sedimentology of river channel confluences</b>	<b>45</b>
<i>James L. Best and Bruce L. Rhoads</i>	
Context	45
Bed morphology	46

Sediment transport	56
Sedimentology	60
Conclusions	66
Acknowledgements	67
References	68
<b>5 Large river channel confluences</b>	<b>73</b>
<i>Daniel R. Parsons, James L. Best, Stuart N. Lane, Ray A. Kostachuk, Richard J. Hardy, Oscar Orfeo, Mario L. Amsler and Ricardo N. Szupiany</i>	
Introduction	73
Bed morphology	75
Flow structure at large river channel confluences	80
Flow mixing at large river confluences	85
Conclusions	87
Acknowledgements	88
References	88
<b>6 Management of confluences</b>	<b>93</b>
<i>Robert Ettema</i>	
Introduction	93
Unruly confluences	95
Management approaches	103
Managing confluences for sediment transport	104
Managing confluences for ice passage	111
Summary	116
References	116
<b>7 Unconfined confluences in braided rivers</b>	<b>119</b>
<i>Peter Ashmore and J. Tobi Gardner</i>	
Introduction	119
General characteristics and significance of confluences in braided channels	121
Confluence scour depth	125
Confluence kinetics and bar formation	128
Confluence spacing and the length-scale of braided morphology	130
Sediment transport and sediment budgets	132
Sediment sorting and alluvial deposits	135
Prospect	139
Acknowledgements	142
References	143
<b>II TRIBUTARY–MAIN-STEM INTERACTIONS</b>	<b>149</b>
<b>8 Introduction to Part II: tributary–main-stem interactions</b>	<b>151</b>
<i>Stephen P. Rice</i>	
Introduction	151
Individual chapters	153
References	155

<b>9</b>	<b>Spatial identification of tributary impacts in river networks</b>	<b>159</b>
	<i>Christian E. Torgersen, Robert E. Gresswell, Douglas S. Bateman and Kelly M. Burnett</i>	
	Introduction	159
	Data and measurement	160
	Analytical tools	167
	Future developments and challenges	175
	Acknowledgements	176
	References	176
<b>10</b>	<b>Effects of tributaries on main-channel geomorphology</b>	<b>183</b>
	<i>Rob Ferguson and Trevor Hoey</i>	
	Introduction	183
	Conceptual considerations	185
	Empirical evidence	187
	Theoretical models: (1) Regime analysis of confluences	191
	Theoretical models: (2) Numerical experiments with adjustable grain-size distributions	198
	Discussion	201
	Acknowledgments	206
	References	206
<b>11</b>	<b>The ecological importance of tributaries and confluences</b>	<b>209</b>
	<i>Stephen P. Rice, Peter Kiffney, Correigh Greene and George R. Pess</i>	
	Introduction	209
	Tributaries, confluences and river ecology	210
	Tributaries, ecosystem functions and river management	215
	Constraints on understanding and progress	217
	A case study	218
	Conclusion	235
	Acknowledgments	237
	References	237
<b>12</b>	<b>Tributaries and the management of main-stem geomorphology</b>	<b>243</b>
	<i>Frédéric Liébault, Hervé Piégay, Philippe Frey and Norbert Landon</i>	
	Introduction	243
	Conceptual framework for assessing the geomorphological impact of tributaries	245
	Managing the geomorphological impact of tributaries	251
	Conclusion	266
	Acknowledgments	267
	References	267
<b>13</b>	<b>Confluence environments at the scale of river networks</b>	<b>271</b>
	<i>Lee Benda</i>	
	Introduction	271
	River network structure and confluence environments	272

Symmetry ratios and confluence environments	273
Basin shape, network patterns and confluence environments	280
Local network geometry	284
Drainage and confluence density	284
River network scaling properties of confluence environments	285
The law of stream sizes and the spatial scale of morphological diversity related to confluences	289
Longitudinal extent and size of confluence environments	290
Stochastic watershed processes	291
The role of hierarchical branching networks	292
Discussion	295
River networks, resource management and river restoration	296
Acknowledgements	297
References	297
<b>III CHANNEL NETWORKS</b>	<b>301</b>
<b>14 Introduction to Part III: channel networks</b>	<b>303</b>
<i>Bruce L. Rhoads</i>	
Introduction	303
Individual chapters	304
References	305
<b>15 Hydrologic dispersion in fluvial networks</b>	<b>307</b>
<i>Patricia M. Saco and Praveen Kumar</i>	
Hydrologic dispersion effects on runoff response	307
Runoff response as travel-time distributions: the GIUH	309
Geomorphologic dispersion in stream networks	314
Non-linear effects and the use of hydraulic geometry relations	316
Kinematic dispersion in stream networks	318
The effect of scale and rainfall intensity on the dispersive mechanisms	320
Hillslope Dispersive effects	324
Kinematic dispersion effects using the meta-channel approach	329
Summary and future research directions	331
Acknowledgments	333
References	333
<b>16 Sediment delivery: new approaches to modelling an old problem</b>	<b>337</b>
<i>Hua Lu and Keith Richards</i>	
Introduction	337
The concept of sediment delivery	340
Difficulties in measuring and estimating sediment yield and SDR	341
Links between hydrology and sediment production and yield	347
Physical inferences of sediment delivery based on a simple lumped model	352
Practical large-scale application using a distributed model	358
Conclusions	361

Acknowledgements	362
References	362
<b>17 Numerical predictions of the sensitivity of grain size and channel slope to an increase in precipitation</b>	<b>367</b>
<i>Nicole M. Gasparini, Rafael L. Bras and Gregory E. Tucker</i>	
Introduction	367
Landscape-evolution models	370
Example simulation of network evolution	376
Discussion	386
Conclusions	388
Acknowledgements	389
References	389
<b>18 Solute transport along stream and river networks</b>	<b>395</b>
<i>Michael N. Gooseff, Kenneth E. Bencala and Steven M. Wondzell</i>	
Introduction	395
Review of current knowledge	396
Linking transport processes with the fluvial geomorphic template	404
Forward-looking perspective	410
Acknowledgements	413
References	413
<b>19 Fluvial valley networks on Mars</b>	<b>419</b>
<i>Rossman P. Irwin III, Alan D. Howard and Robert A. Craddock</i>	
Introduction	419
Early observations	421
Distribution, age, origin and morphology of valley networks	422
Morphometry	432
Alluvial deposits	436
Hydrology	438
Summary	442
Acknowledgements	442
References	442
<b>Subject Index</b>	<b>453</b>
<b>Place Index</b>	<b>457</b>

# 1

## Introduction: river confluences, tributaries and the fluvial network

**Stephen P. Rice<sup>1</sup>, Bruce L. Rhoads<sup>2</sup> and André G. Roy<sup>3</sup>**

<sup>1</sup>*Department of Geography, Loughborough University, UK*

<sup>2</sup>*Department of Geography, University of Illinois, USA*

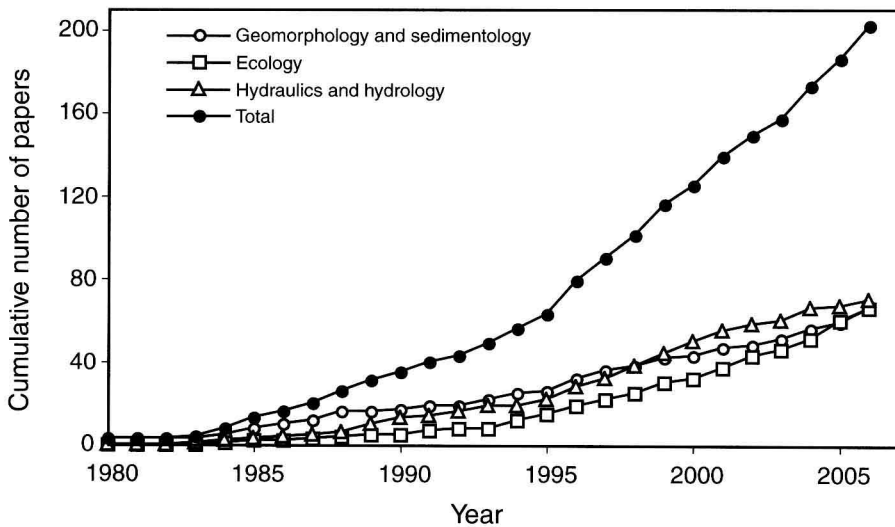
<sup>3</sup>*Canada Research Chair in Fluvial Dynamics, Département de Géographie, Université de Montréal, Canada*

### 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

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; Krebs 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