

Water Resources

An integrated approach

Edited by
Joseph Holden

Water Resources

An integrated approach

Edited by

Joseph Holden



First published 2014
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

© 2014 Editorial matter and selection: Joseph Holden; individual
chapters: the contributors

The right of the editor to be identified as the author of the editorial
material, and of the authors for their individual chapters, has been
asserted in accordance with sections 77 and 78 of the Copyright,
Designs and Patents Act 1988.

All rights reserved. No part of this book may be reprinted or
reproduced or utilised in any form or by any electronic, mechanical,
or other means, now known or hereafter invented, including
photocopying and recording, or in any information storage or retrieval
system, without permission in writing from the publishers.

Trademark notice: Product or corporate names may be trademarks
or registered trademarks, and are used only for identification and
explanation without intent to infringe.

British Library Cataloguing in Publication Data

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

Library of Congress Cataloging in Publication Data

Water resources/edited by Joseph Holden.

pages cm

Includes bibliographical references and index.

1. Water-supply. 2. Water resources development. 3. Water security.

I. Holden, Joseph, 1975– editor of compilation.

TD346.W28 2014

333.91—dc23

2013004283

ISBN: 978-0-415-60281-5 (hbk)

ISBN: 978-0-415-60282-2 (pbk)

ISBN: 978-0-203-48941-3 (ebk)

Typeset in Minion and Univers
by Florence Production Ltd, Stoodleigh, Devon, UK

Printed and bound in India by Replika Press Pvt. Ltd.

Water Resources

The world faces huge challenges for water as population continues to grow, as emerging economies develop and as climate change alters the global and local water cycles. There are major questions to be answered about how we supply water in a sustainable and safe manner to fulfil our needs, while at the same time protecting vulnerable ecosystems from disaster.

Water Resources: An Integrated Approach provides students with a comprehensive overview of both natural and socio-economic processes associated with water. The book contains chapters written by 20 specialist contributors, providing expert depth of coverage to topics. The text guides the reader through the topic of water, starting with its unique properties and moving through environmental processes and human impacts upon them, including the changing water cycle, water movement in river basins, water quality, groundwater and aquatic ecosystems. The book then covers management strategies for water resources, water treatment and reuse, and the role of water in human health before covering water economics and water conflict. The text concludes with a chapter that examines new concepts such as virtual water that help us understand current and future water resource use and availability across interconnected local and global scales.

This book provides a novel interdisciplinary approach to water in a changing world, from an environmental change perspective and interrelated social, political and economic dimensions. It includes global examples from both the developing and developed world. Each chapter is supplemented with boxed case studies, questions, project ideas and further reading, as well as a glossary of terms. The text is richly illustrated throughout with over 150 full-colour diagrams and photos.

Joseph Holden holds the Chair of Physical Geography at the University of Leeds. He is Head of water@leeds, the largest interdisciplinary water research centre in the UK, and he is also Director of Research for the School of Geography.

Contributors

Dr Anamika Barua, Department of Humanities and Social Sciences, Indian Institute of Technology, Guwahati, 781039, India; abarua@iitg.ernet.in

Dr Nesha C. Beharry-Borg, water@leeds, School of Earth and Environment, University of Leeds, LS2 9JT, UK; n.c.beharry-borg@leeds.ac.uk

Megan Beresford, water@leeds, School of Earth and Environment, University of Leeds, LS2 9JT, UK; megan.beresford@britishsugar.com

Dr Lee E. Brown, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; l.brown@leeds.ac.uk

Dr Pippa J. Chapman, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; p.j.chapman@leeds.ac.uk

Dr Frances Drake, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; f.drake@leeds.ac.uk

Dr Alison M. Dunn, water@leeds, Institute of Integrative and Comparative Biology, University of Leeds, Leeds, LS2 9JT, UK; a.dunn@leeds.ac.uk

Dr Dabo Guan, water@leeds, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT; d.guan@leeds.ac.uk

Professor Joseph Holden, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; j.holden@leeds.ac.uk

Dr Nigel J. Horan, water@leeds, School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK; n.j.horan@leeds.ac.uk

Dr Paul Kay, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; p.kay@leeds.ac.uk

Professor Adrian T. McDonald, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; a.t.mcdonald@leeds.ac.uk

Dr Gordon Mitchell, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; g.mitchell@leeds.ac.uk

Dr Noelle E. Odling, water@leeds, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK; n.e.odling@leeds.ac.uk

Dr Colin S. Pitts, water@leeds, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK; c.pitts@leeds.ac.uk

Professor Stephen Sitch, Geography, College of Life and Environmental Sciences, University of Exeter, EX4 4RJ, UK; s.a.sitch@exeter.ac.uk

Dr Rebecca J. Slack, water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK; r.j.slack@leeds.ac.uk

Dr Sonja S. Teelucksingh, Economics Department and Sir Arthur Lewis Institute for Social and Economic Studies, University of the West Indies, St. Augustine, Trinidad and Tobago; sonja.teelucksingh@sta.uwi.edu

Dr Martin R. Tillotson, water@leeds, School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK; m.r.tillotson@leeds.ac.uk

Kitriphar Tongper, water@leeds, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK; ktongper@gmail.com

Dr L. Jared West, water@leeds, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK; l.j.west@leeds.ac.uk

Preface

Water is of fundamental importance to life on Earth. It also has huge economic and cultural significance. This book examines water and water resources from scientific, economic and social perspectives. It is aimed at university students of all levels and water practitioners and policy makers who want to obtain a good grounding in the subject of water across the disciplines. The world faces grand challenges for water as population continues to grow, as emerging economies develop and as climate change alters the global and local water cycles. There are major questions to be answered about how we supply water in a sustainable and safe manner to fulfil our needs, while at the same time protecting vulnerable ecosystems from disaster. These grand challenges require an interdisciplinary approach to address them because there are scientific and technological issues to be addressed, there are economic and political issues to be addressed and there are social and cultural issues to be addressed and these all interconnect. Solving a technological problem on water supply may be futile if there is no political or social will, nor the economic means to utilise that technological advance.

The team of twenty authors who have contributed their knowledge and understanding to this book have compiled their experiences from around the world. This book begins by outlining the nature of water, some of its unique properties, the challenges for water resources and the role of water in society. It then moves in Chapter 2 to examine the global water cycle and the importance of water in moving energy around the planet and how climate change is affecting the water cycle through a series of feedback mechanisms. Chapter 3 covers the water cycle at a more local scale, looking at processes within river basins, including water movements through and over soils and in rivers. The pathways for water through river basins and the way we manage the landscape affect both water quality in rivers and lakes and such surface water quality issues are covered in Chapter 4. The discussion is supplemented by a detailed treatment of groundwater processes, water supply and groundwater quality in Chapter 5. Water bodies form an important part of ecosystems and also host a diverse community of organisms. Aquatic ecosystems and their modifications through human action are given attention in Chapter 6.

The demand for water needs to be managed and the supply of water to people, industry and agriculture needs to be planned for. Thus, Chapter 7 provides an overview of issues around water resource management. The quality and quantity of water both for drinking water supply and within the local environment has a fundamental role to play in human health. Droughts and periods of water scarcity can lead to famine and death. Too much water through flooding can kill not only by drowning but through the spread of disease, food shortages, loss of shelter and livelihood disruption. Infectious diseases associated with water and chemicals carried within water can have huge impacts on human health and therefore these topics are covered in Chapter 8. Techniques for providing clean water for consumption and for treating wastewater (and utilising the resources that wastewater provides) are described in Chapter 9.

Water is an economic good and is crucial for agriculture, industry and many other things from which we derive benefit. It is therefore essential, as described by Chapter 10, to examine the principles of economics and different types of valuation techniques which might be applied to water in order to understand some of our water problems and potential water solutions. Because water is so fundamental to life, is in such demand by humans and has economic value, it is also a cause of conflict around the world. Determining who has the rights to access, extract and use water, a substance that is fluid and mobile, is a complex issue with different traditions operating in different parts of the world. Chapter 11 looks at different types of water conflict and water rights issues from around the world and how these conflicts can be managed. Finally, in Chapter 12,

the book looks at new concepts that can help us to understand current and future water resource use and availability across interconnected local and global scales, including the water footprint and 'virtual' water flows.

Each chapter contains some boxed features, which are grouped into one of four themes: case studies, contemporary challenges, techniques or the future of water. These boxed features allow interested readers to study more detail on the selected topics, should they wish. As you read the book you will also notice some words that are typeset in bold within the text. These words are highlighted the first time they appear in each chapter and can be found in the glossary with an explanation of their meaning. Each chapter also contains reflective questions and some project ideas.

The book's interdisciplinary nature reflects my own personal role as head of water@leeds, which is the largest water research group in any UK university. water@leeds members work together as scientists, social scientists and humanities experts to tackle water challenges facing the world. Research is often in partnership with external bodies such as government bodies, NGOs, industry and practitioners to ensure that the research is applicable to societal needs. The water challenges we face are crucial to the survival of the human race, stability and peace around the world and to the sustainability of the Earth's ecosystems. It is therefore vital that around the world we improve understanding of water resource issues from an interdisciplinary perspective. This book is part of that mission and I hope that you will feel inspired to join us in trying to make a real difference to people's lives through sharing an understanding of water resource issues with others.

Acknowledgements

Alison Manson, University of Leeds, is thanked for her work in producing most of the drawings within the book. Additional figure and table source acknowledgements are provided where known. Kathryn Smith is thanked for helping to compile and check the references and glossary and obtaining figure permissions. Samantha Bowman and Rianne Dubois are thanked for permissions management and compiling the index. Thanks are also given to the editorial production team at Routledge for their support in producing this volume. Kitriphar Tongper and Dr Anamika

Barua are thanked for contributing some materials for Chapter 1. Dr Tanya A. Warnars, Centre for Ecology and Hydrology, Wallingford is thanked for support on Chapter 2 in providing the latest update on glaciers in South Asia and material on the EU WATCH project. Every effort has been made to contact copyright holders for their permission to reprint material in this book. The publishers would be grateful to hear from any copyright holder who is not here acknowledged and will undertake to rectify any errors or omissions in future editions of this book.



eFocus on the Environment

30 day
free trials
available!

Growing concerns about climate change, pollution and environmental degradation have put the environment at the top of the agenda in the early decades of the 21st Century. This collection includes books from 18 disciplines, offering the broadest possible understanding of environmental issues. Its coverage ranges from philosophical works exploring environmental values to works offering practical suggestions to immediate policy questions.

Key features:

- Global coverage with extensive treatment of both the developed and developing world
- Particular attention to the concept of sustainability, at both a micro and a macro level
- Includes several key reference works, such as: *Routledge Handbook of Climate Change and Society*, *Fifty Key Thinkers on the Environment*, *The Complete Guide to Climate Change*, and *The Environment Dictionary*
- Looks at the impact of tourism and other major industries.

eFocus on the Environment is available as a subscription package with 10 new eBooks added per year.



Recommend
this package
to your
librarian
today!

Order now for guaranteed capped price increase.

www.ebooksubscriptions.com

For a complete list of titles, visit:

www.ebooksubscriptions.com/eFocusEnvironment

For more information, pricing enquiries or to order a free trial, please contact your local online sales team:

UK and Rest of the World

Tel: +44 (0) 20 7017 6062

Email: online.sales@tandf.co.uk

United States, Canada and South America

Tel: 1-888-318-2367

Email: e-reference@taylorandfrancis.com



Taylor & Francis 
Taylor & Francis Group



Routledge

Routledge Paperbacks Direct

Bringing you the cream of our hardback publishing at paperback prices

This exciting new initiative makes the best of our hardback publishing available in paperback format for authors and individual customers.

Routledge Paperbacks Direct is an ever-evolving programme with new titles being added regularly.

To take a look at the titles available, visit our website.

www.routledgepaperbacksdirect.com

 **Routledge**
Taylor & Francis Group

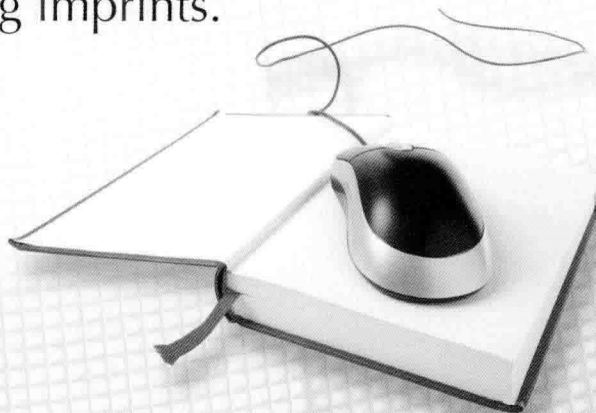
ROUTLEDGE PAPERBACKS DIRECT

Taylor & Francis

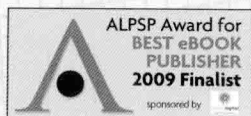
eBookstore

www.ebookstore.tandf.co.uk

Over 23,000 eBooks available for individual purchase in Humanities, Social Sciences, Behavioural Sciences and Law from some of the world's leading imprints.



***"An innovative way of approaching electronic books...Recommended."** – Choice*



Taylor & Francis eBooks
Taylor & Francis Group

A flexible and dynamic resource for teaching, learning and research.

Routledge International Handbooks is an outstanding, award-winning series that provides cutting-edge overviews of classic research, current research and future trends in Social Science, Humanities and STM.

Each Handbook:

- is introduced and contextualised by leading figures in the field
- features specially commissioned original essays
- draws upon an international team of expert contributors
- provides a comprehensive overview of a sub-discipline.

Routledge International Handbooks aim to address new developments in the sphere, while at the same time providing an authoritative guide to theory and method, the key sub-disciplines and the primary debates of today.

If you would like more information on our on-going *Handbooks* publishing programme, please contact us.

Tel: +44 (0)20 701 76566

Email: reference@routledge.com

www.routledge.com/reference



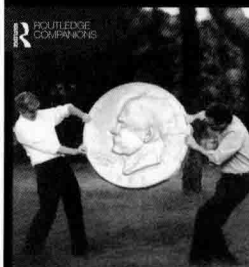
Biomechanics and Human Movement Science

Edited by Yvonne Hong and Roger Bartlett



The Routledge Companion to Nonprofit Marketing

Edited by Adrian Sargeant and Walter Wymmer



The Routledge Companion to Fair Value and Financial Reporting

Edited by Peter Walton



Globalization Studies

Edited by Bryan S. Turner



Sexuality, Health and Rights

Edited by Peter Aggleton and Richard Parker

Contents

<i>List of figures, tables and boxes</i>	vii
<i>List of contributors</i>	xv
<i>Preface</i>	xvii
<i>Acknowledgements</i>	xix
1 Water fundamentals	1
<i>Joseph Holden</i>	
2 The changing water cycle	19
<i>Stephen Sitch and Frances Drake</i>	
3 River basin hydrology	49
<i>Joseph Holden</i>	
4 Surface water quality	79
<i>Pippa J. Chapman, Paul Kay, Gordon Mitchell and Colin S. Pitts</i>	
5 Groundwater	123
<i>L. Jared West and Noelle E. Odling</i>	
6 Aquatic ecosystems	161
<i>Lee E. Brown, Colin S. Pitts and Alison M. Dunn</i>	

7	Water demand planning and management	203
	<i>Adrian T. McDonald and Gordon Mitchell</i>	
8	Water and health	223
	<i>Rebecca J. Slack</i>	
9	Potable water and wastewater treatment	265
	<i>Nigel J. Horan</i>	
10	Water economics	293
	<i>Sonja S. Teelucksingh, Nesha C. Beharry-Borg and Dabo Guan</i>	
11	Water conflict, law and governance	315
	<i>Kitriphar Tongper and Anamika Barua</i>	
12	The future of water: water footprints and virtual water	333
	<i>Martin R. Tillotson, Megan Beresford, Dabo Guan and Joseph Holden</i>	
	<i>Glossary</i>	351
	<i>Index</i>	365

Figures, tables and boxes

FIGURES

1.1	A schematic diagram showing water molecules and the covalent and weak hydrogen bonds	2
1.2	Pond skaters are invertebrates that move across the water surface	4
1.3	Water forms droplets on most solid materials it comes into contact with	4
1.4	Capillary action in two glass tubes	5
1.5	When dissolved in water, each of the sodium and chloride ions is hydrated	5
1.6	Categories of world water resources	10
1.7	Declining per capita water availability in India	13
1.8	Competing water uses for main income groups of countries	14
2.1	The global hydrological cycle, with estimated flows and storage	20
2.2	The Clausius–Clapeyron (CC) relation	22
2.3	Saturated pressure–temperature curves for water and ice	23
2.4	Land–atmosphere coupling strength in June, July and August	25
2.5	The static jet stream of summer 2010, which led to different extreme events across Europe and Asia	26
2.6	Summer 2007 rainfall amount as a percentage of the 1971–2000 average	27
2.7	Conditions in the Pacific during (a) normal periods and (b) El Niño	29
2.8	Winter weather anomalies during (a) El Niño and (b) La Niña over North America	29
2.9	Severe conditions during the 1930s Dust Bowl of North America	31
2.10	Temperature and precipitation anomalies for the Dust Bowl drought from the Climate Research Unit (CRU) climate model simulations	32
2.11	Precipitation difference from long-term average 1900–2011 in the Sahel region showing the prolonged dry period since the 1970s	34
2.12	Changes in glacial extent for selected glaciers around the world	36

2.13	Leaf stomata regulate the uptake of carbon dioxide for photosynthesis, and water loss through transpiration	38
2.14	Mechanisms connecting changes in leaf conductance to canopy evapotranspiration and soil moisture changes	38
2.15	Population exposed to severe water scarcity (red)	40
2.16	Schematic showing example feedbacks of enhanced water vapour in the atmosphere	42
2.17	Robust findings on regional climate change for mean and extreme precipitation, drought and snow	42
3.1	An example gentle rainfall event resulting in a reduction in the infiltration capacity of the soil over time and the subsequent production of infiltration-excess overland flow	51
3.2	Production of saturation-excess overland flow	51
3.3	Soil water energy status on a slope	53
3.4	Macropore flow is indicated by the staining white dye solution where fingers of dye extend downward from the main body of dye in a soil profile	54
3.5	A large soil pipe with some flowing water emerging from the pipe which is at the head of a gully	54
3.6	A rain gauge flush with the ground surface surrounded by a metal mesh to reduce errors from turbulence and splash	55
3.7	Storm hydrographs (a) where infiltration-excess overland flow dominates, and (b) where throughflow dominates	57
3.8	Two example annual river flow records showing regimes of each river	58
3.9	The endorheic river basins of the Earth	59
3.10	A worked velocity-area calculation for river discharge	60
3.11	Predicted river storm flow discharge using the unit hydrograph model	62
3.12	New housing development in Calgary with a sustainable urban drainage system with a storm water storage lake	64
3.13	Mean monthly total discharge change (%) in the Pinios River for a 24-year modelling period	65
3.14	A river basin showing what happens to the main channel flood hydrograph after forestry plantation within a tributary basin due to flood wave synchronisation	67
3.15	The main types of drainage network pattern	68
3.16	Examples of river channel forms: (a) braided river; (b) meandering river, and (c) a straight river	69
3.17	Helicoidal flow through a meandering channel	70
3.18	River meanders tend to become more exaggerated until eventually the meander is cut through by the river, leaving behind an oxbow lake	71
3.19	Temporal variation of water and sediment discharge in the main channel of the Indus River below Kotri	73
3.20	Re-meandering on the River Kissimmee	74
4.1	The different hydrological pathways that precipitation may take to reach surface waters and their effect on solute concentrations	80
4.2	Eh-pH diagram for the simple ions and hydroxides of iron at atmospheric pressure and 25°C	82