Water Resilience for Human Prosperity

Humanity has entered a new geological era, the Anthropocene, where the world's human population now constitutes the largest driving force of changes to the biosphere. Emerging water challenges require new system thinking and ideas for governance and management of water resources in the context of rapid global change.

This book presents a new resilience-based approach to water resources, addressing their role for global sustainability. Topics covered include the risks of unexpected change; human impacts and dependence on global water; the prospects for feeding the world's population by 2050; and a pathway for the future. The book's innovative and integrated approach links green and blue freshwater (the rainfed soil moisture supporting plant growth and the liquid water in rivers and aquifers) with terrestrial and aquatic ecosystem functions and use. It also links changes arising from land-use alteration with the impacts of those changes on social–ecological systems and ecosystem services.

Based on recent scientific advancements on integrated water resources research, global environmental changes and ecosystem services, the key focus is on building social–ecological resilience – the ability to persist, adapt and transform – in a future where we can expect more frequent water-related shocks and stresses. This is an important, state-of-the-art resource for academic researchers and water resource professionals, and also a key reference for graduate students studying water resource governance and management.

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CAMBRIDGE UNIVERSITY PRESS

Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment,
a department of the University of Cambridge.

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www.cambridge.org
Information on this title: www.cambridge.org/9781107024199

First published 2014

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

Library of Congress Cataloging-in-Publication data
Water resilience for human prosperity / Johan Rockström, Malin Falkenmark, Carl Foilke
pages cm
ISBN 978-1-107-02419-9 (Hardback)
1. Water–History. 2. Water supply–History. 3. Drinking water–History. I. Rockström, Johan.
GB659.6.W38 2014
333.91–dc23 2013028561

ISBN 978-1-107-02419-9 Hardback

Additional resources for this publication at www.cambridge.org/9781107024199

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Preface

Why yet another book on water? Partial thinking and sectoral approaches have dominated resource and environmental management for too long, and this is also true for freshwater. Perspectives are rapidly changing, however, expanding on the conventional perception of freshwater as 'blue water' – a natural resource to be extracted from rivers and groundwater for households, industry, irrigation and economic production. Integrated water resource management (IWRM), although still predominantly concerned with the blue water branch of the water cycle, has extended the focus to interacting sectors in catchments. More recently, water vapour or 'green water' has increased focus in the policy arena on issues such as rainfed agriculture. The role of freshwater in ecosystem services, both terrestrial and aquatic, is now on the agenda, as well as work on their water trade-offs or in relation to water-related tipping points in dynamic landscapes. New approaches are emerging, such as adaptive water governance of landscapes and catchments.

The biosphere – the sphere of life – is the living part of the outermost layer of our rocky planet – the part of the Earth's crust, oceans and atmosphere where life dwells. It is the global life-support system that integrates all living beings and their relationships. Life on Earth interacts in myriad ways with the chemistry of the atmosphere, the circulation of the oceans and the water cycle, including solid water in polar and permafrost regions, to form favourable conditions for life on Earth. People and societies are integrated parts of the biosphere, dependent on its functioning and life support.

Water plays a key role in the operation of the biosphere, from the level of the cell to the dynamics of the atmosphere. The water cycle functions as the bloodstream of the biosphere. Like any organism, humans have evolved with water, benefitting from its many functions and the mineral salts it carries. Water is required for soil formation and is critical to the production of the food we eat. Continents are connected by rainfall patterns, it provides climate-regulating services and plays a central role in extreme events such as floods, storms and droughts. On the blue planet, the water cycle is clearly essential to our existence and a precondition for our evolution.

It is now apparent that humanity has become a major force in the dynamics of the biosphere, shaping it not only locally and regionally but also globally, and leaving a significant imprint on the operation of the biosphere as a whole. Drivers of change such as rising human numbers, urbanisation, migration patterns, emerging markets, the diffusion of new technologies and social innovations can combine with sudden events such as floods, fires, pandemics, rapid shifts in fuel prices and volatile financial markets to trigger tipping points. The global social–ecological system is complex and dynamic, and subject to unexpected, often rapid, changes – not as exceptions but increasingly as the rule. Such changes play out in cascading fashion in a world where everyone is in everyone else's backyard. Thresholds and tipping points are now part of the furniture.

This new situation – the Anthropocene – calls for a fundamental shift in perspectives and world views, reconnecting development and progress to the capacity of the biosphere and its water cycle to sustain society and prosperity. This reconnection is linked to the insight that humanity has been prospering from a stability that is exceptional in the history of the Earth. The past 10 000 years, the Holocene geological epoch, was an era during which agriculture and human civilisations emerged and flourished. Many take the favourable Holocene conditions for granted. In our view, a greater appreciation is needed of water as part of biosphere dynamics and resilience. Hence the call for a broader water perspective that connects the local with the global. Resilience, in the way we approach it, is about persistence in the face of change, having the capacity to continually adapt to complex dynamics,

and to develop in order to get out of traps and even transform and shift into new development pathways. The capacity of the biosphere and the water bloodstream sets the framework for such pathways – the planetary boundaries for prosperous societal development.

It is in this context that we have written this book – to take on the challenge of expanding mindsets towards water as the bloodstream of the biosphere of which people are an embedded part. In the globally interconnected world, humanity is critically dependent on the capacity of the biosphere to support our way of life, and the way we have organised societies, technologies and economies. The water bloodstream approach is not just an ethical stand. It is about prosperity and ultimately about survival. It is also about biosphere stewardship and innovation for sustainable development for humanity.

We have written this book in search of a deeper understanding of the new water dynamics in the globally integrated system of people and nature, to put forward new conceptual systems, perspectives, hypotheses and findings. We believe that science has a responsibility to search for a better understanding of the new challenges facing humanity, and to explore pathways for a sustainable world. We describe and analyse the role of water in the biosphere and how it relates to human actions and well-being from the global to the local levels, and we introduce new concepts such as water resilience and water stewardship in the new Anthropocene era. Striving for water stewardship and a resilient biosphere is not about preserving the status quo or circumventing change. It is about having the capacity to deal with change, turning crises into opportunities and shifting into sustainable pathways.

Resilience thinking encourages us to anticipate, experiment, adapt and transform. Water resilience and water stewardship are about strengthening the resilience of social–ecological systems to deal with changing conditions, and finding ways to live in prosperity in the Anthropocene era. This will require an appreciation of the critical role of water in the operation of the biosphere for human well-being. We hope this book will inspire people in this direction.

Carl Folke, Malin Falkenmark
and Johan Rockström

Introduction to the book

Scope of the book

This book aims at synthesising our current state of knowledge and probing the key area of how recent insights from social–ecological systems and resilience research influence our understanding of water resource governance and management in a world subject to rapid global environmental change. It advances a proposed new framework on 'water resilience' as an integral part of sustainable water resource management. We have a focus on ecosystem services in productive landscapes, especially food production (and bioresources), seen from the perspective of land, water, ecosystem interactions and resilience building. Focus is on water resources from local to global scale, exploring dynamic interactions between sectors, components of the Earth system and scales. The book will therefore only briefly address water quality issues. The water resource focus of the book includes water flows from the local water balance to the global hydrological cycle – i.e. the governance and management of precipitation, vapour flows, as well as surface and sub-surface runoff flows and resources. It is, furthermore, global in scope, even though a particular focus is set on the regions of the world facing the most challenging future in terms of water resource scarcity and water resilience challenges related to current and future global environmental change. This means that a particular focus is given to the semi-arid and dry sub-humid tropical savannah regions of the world.

The water and ecosystems focus of the book, places the emphasis on the relations between freshwater and the living systems in the biosphere. The book thus takes as a starting point the role of water resources in the generation of ecosystem functions and services from terrestrial and aquatic ecosystems, and how these define the resilience of ecosystems; how human interactions with water impact on ecosystem and resilience; and how innovative water governance and management principles can be applied to human challenges in an era of rapid global changes. In essence we attempt to advance a social–ecological systems approach to water resilience for human prosperity in the Anthropocene.

The book thereby does not focus on water in marine ecosystems, and does not explore the important role of water for resource use (e.g. in mining) nor for domestic and urban water supply and water for industrial purposes. This said, the book obviously takes an integrated perspective on the trade-offs between water use for living systems and other resource and social uses. Our special focus on water and food in a changing world is justified by the fact that no human sector consumes so much freshwater as bioresources for food, energy and biomass, which raises, apart from trade-offs between different water needs, the challenge of how to build water resilient *food production* in the world.

Target audience

The book is targeted at graduate/post-graduate students, water resource professionals and senior water planners, and is therefore a book targeting higher education, which can also inform key water professionals in different sectors from agriculture and environment to industry and river basin planning.

We allow ourselves to be relatively detailed and in-depth, and quite technical where needed, while trying to reach a broader professional audience. We want to explain and give examples related to complex issues ranging from vapour shift, water-induced regime shifts, moisture feedback, water resilience, etc. The text is interspersed with a set of *boxes*, authored by invited water scientists looking deeper into a number of issues discussed or referred to in the main text.

Book sections

The book is divided into four parts.

Part I. A new perspective

Chapter 1 is an overview and framing chapter on the emerging challenge of water resilience in the Anthropocene. It explains the crucial roles played by water in the life-support systems on Earth in an era of rapid global and regional change. It discusses different disturbance regimes and the emerging threats and dilemmas, and highlights potential thresholds of critical concern. It explains the core roles of water in sustaining a desired 'Holocene-like' state on Planet Earth, and the risk for human-induced water thresholds. It also explains three core roles of water for resilience. The chapter furthermore highlights the central role of water partitioning changes, motivating special focus on foreseeable future land-use alterations, in particular future human use of bioresources, especially implications of feeding a growing humanity.

Part II. Living in a human-dominated world

Chapter 2 offers an overview of past human alterations to the Earth system and the main drivers of change. It highlights climate change in particular, as it interacts profoundly with the planet's global water cycle. It demonstrates the socially driven connectivity between different global regions, and human-generated impacts on the Earth System. It stresses that humanity is now living in the new Anthropocene, a new geological epoch where humanity constitutes a quasi-geological force of planetary change, at risk of and approaching various water-related tipping points.

Chapter 3 analyses the options for safe global pathways towards sustainable water development and the dangers to be avoided in the form of water-related thresholds, rigidity and poverty traps. It addresses water's involvement in abrupt, unexpected regime shifts in social–ecological systems. Resilience is characterised by the existence of reinforcing processes and stabilising feedbacks. Water's many different roles in the life-support system mean that it is profoundly involved in the processes of and responses to regime shifts, as both a state variable and a control variable.

Chapter 4 examines human dependence on the global water system (GWS), and the role of water as the bloodstream of the biosphere. It highlights human-generated changes in the system, including a number of remote water-related connections between regions (so-called teleconnections) such as trade-related virtual water flows. Resilience-related changes are summarised including land-use change and its implications for green–blue water partitioning; climate change, noting that aridification can reduce resilience to droughts; growing water demands; and groundwater overexploitation. It stresses that basin closure represents a critical threshold beyond which new processes and interactions are triggered.

Part III. Food production globally: in hotspot regions and in the landscape

Chapter 5 analyses the challenge of feeding a growing humanity from a water perspective. It describes the growing food demand up to 2050, considering population increase, average per capita food supply levels, and changed composition of animal and vegetal source foods in food supply. Country-level assessments of food water requirements are given for different scenarios, including climate change, irrigation development, water productivity improvements, alternative dietary options and reduced food losses. The chapter highlights the need for large-scale virtual water transfer through expanded food trade. Food supply is examined from a dynamic perspective in terms of the ability to cope with shocks and change, and the adaptability and social–ecological resilience required.

Chapter 6 analyses the large and rising social–ecological challenge in the water-poor savannah zone with rapidly increasing populations and demands for water. What are the implications of food supply efforts, and the implementation difficulties in these regional hotspot regions? The chapter clarifies that, contrary to popular beliefs, this zone has a substantial (and untapped) agro-hydrological potential. Rather than facing absolute lack in water, the challenge is the huge fluctuations in rainfall and the large amount of water lost to the farming system through evaporation, runoff and drainage. Water resilience strategies involve practices for dry-spell mitigation, using, e.g. water harvesting systems.

Chapter 7 focuses on basin-level challenges and the meso-scale perspective, which is where land-use changes can aggregate and affect ecosystem services, and consequently livelihood and development opportunities, and ecosystem sustainability. Agriculture, which is itself an ecosystem service provider, is

primarily a way to manage particular benefits from ecosystems, but other ecosystem services may be affected. Three landscapes are analysed in terms of landscape multifunctionality, exemplifying common development trends and emerging upstream–downstream conflicts of interest.

Part IV. Governance and pathways

Chapter 8 addresses the challenge of water governance of landscapes and basins for resilience, sustainability and human well-being. Integrated governance of land and water resources for the generation of ecosystem services, safeguarding development and avoiding crossing critical thresholds, is at the heart of this analysis, integrating global dynamics, the necessity of water governance that 'safeguards rainfall and wetness in landscapes'. We focus on the blue–green water partitioning, the blue–green trade-off between upstream and downstream activities and strategies for stabilising moisture feedbacks (the source of future rainfall). The chapter highlights governance challenges and transformations needed.

Chapter 9 concludes by addressing insights and pathways for a world transition towards sustainability by adopting a social–ecological systems approach to IWRM. It describes the evolution of water governance and management from a largely blue water focused paradigm from the early 1970s until the early 1990s, which has served humanity quite well in a world of relative water abundance, but which, now, under pressures of growing human demands, water use and the recognition of shifts in water supply and risks of thresholds due to global environmental change, necessitates a new integrated green–blue water paradigm. It summarises the new insights in terms of what we have learnt on water and resilience, and highlights the grand global challenge of feeding a world population within a safe operating space of planetary boundaries. It also notes that the current water governance paradigm of managing for a stable and predictable supply of water is ill-prepared to deal with the new reality of having to adapt to unavoidable changes.

The four-step resilience chain

As is noted in the Preface, we have written this book in search of a deeper understanding of the new water dynamics in the globally integrated system of people and nature, and to put forward new conceptual systems, perspectives, hypotheses and findings. We believe that science has a responsibility to search for a better understanding of the new challenges facing humanity, and to explore pathways for a sustainable world. All the different chapters analyse the role of water in the biosphere, and how it relates human actions and well-being to the global to local levels. New concepts are introduced, such as water resilience and water stewardship.

Striving for sustainable water stewardship and a resilient biosphere is not about preserving the status quo or circumventing change. It is about having the capacity to deal with change, turning crises into opportunities and shifting on to sustainable pathways. Special emphasis is put on the world's most water-dependent sector – agriculture.

Governing and managing water for resilience encompasses a range of actions from mitigation to resilience building, adaptation and transformation. The figure below shows these actions in a schematic way, indicating the interconnected challenges facing global water resource management. The range of actions along this 'change continuum' includes mitigation to reduce human pressures on the Earth System, building the resilience of Earth System components, adaptation to materialised responses and transformation after regime shifts in social–ecological systems.

Every chapter opens with a short *resilience-oriented ingress*, clarifying how it relates to the above sequence of stages in resilience thinking. The reader

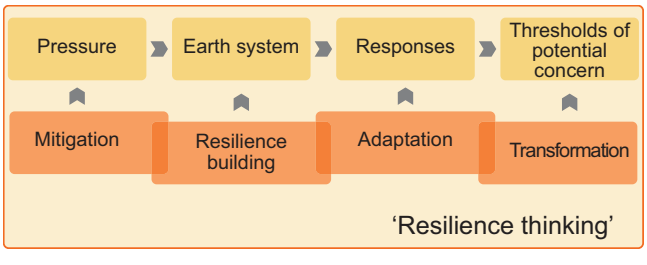

Figure I.1 The challenges facing the world in the Anthropocene, from a range of pressures to impacts on the Earth System, influence responses from societies and the possibilities of passing thresholds that change social–ecological systems. The chain of actions to build resilience for global sustainability includes mitigation, local resilience building, adaptation and transformation.

will find key components of the different steps in the resilience chain exemplified in the different chapters.

Pressure	Chapters 2, 4, 5, 6: drivers of change, land-use change, feeding humanity, water supply, energy supply, industrial production, urbanisation, technological development and international trade
Earth system	Chapters 2 and 4: land productivity, Holocene equilibrium, GWS, ecosystem functions, biodiversity
Responses	Chapters 2, 5, 6: land degradation, CO_2-enrichment, water stress, aquifer overexploitation, virtual water flows, megafires, traps, migration, famine
Thresholds/ tipping points	Chapters 1, 3, 4, 9: desertification, savannisation, salinisation, monsoon weakening, basin closure, aquifer depletion, thresholds of potential concern
Regime shifts	Chapters 1 and 3: Anthropocene dynamics, ecosystem shifts, unproductive land, biodiversity loss, poverty traps, rigidity traps
Resilience building	Chapters 1, 3, 6, 7, 8, 9: land stewardship, moisture feedback, balanced water uses, secured partitioning, environmental flow, planetary boundaries, vital ecosystem functions and services, upstream–downstream trade-offs

Authorship

This book is a result of a joint collaborative effort among all authors. The book was written by synthesising recent research, advancing new insights through a series of author workshops and a distributed responsibility for different chapters among co-authors. The lead authorship responsibility was shared as follows: Chapter 1, lead author Johan Rockström; Chapter 2, lead author Holger Hoff; Chapter 3, lead author Line Gordon; Chapter 4, lead author Holger Hoff; Chapter 5, co-lead authors Mats Lannerstad and Malin Falkenmark, data modelling and analysis Jens Heinke; Chapter 6, lead author Elin Enfors; Chapter 7, lead author Jennie Barron; Chapter 8, co-lead authors Carl Folke and Claudia Pahl-Wostl; Chapter 9, lead author Johan Rockström. Johan Rockström and Carl Folke led the effort together with Malin Falkenmark in distilling key messages and structuring the line of argument on water-related resilience thinking throughout the book.

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Acknowledgements

We wish to thank colleagues at the Stockholm Resilience Centre (SRC), Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences, the Potsdam Institute for Climate Impact Research and the Stockholm Environment Institute (SEI) for the stimulating discussions during the advancement of this book.

We are grateful to several donors and projects, without which this book could not have been written. Core funding was provided by Mistra, through its support to the Stockholm Resilience Centre, and from the Swedish Research Council Formas, through its Centre of Excellence grant to SRC and SEI. We also appreciate the support from the Kjell and Märta Beijer Foundation, which enabled the engagement of Beijer Institute colleagues, the Ebba och Sven Schwartz Stiftelse and the Swedish International Development Cooperation Agency (SIDA).

The authors greatly appreciate the contributions made by colleagues in the form of the informative boxes on particular issues found throughout this volume: Göran Berndes, Petra Döll, Ellen M. Douglas, Ruud van der Ent, Lance Gunderson, Elke Herrfahrdt-Pähle, Eloise Kendy, Yuanhong Li, Michael E. McClain, Denis Mpairwe, Jay O'Keeffe, Donald Peden, Marcela Quintero, Wilhelm Ripl, Hubert Savenije, Bridget Scanlon, Maja Schlüter, Jan Sendzimir, Will Steffen, Alain Vidal, Brian Walker and Qiang Zhu.

Many research colleagues have contributed significantly to our thinking in this book. We thank you all collectively, but would like to particularly mention Patrick Keys who assisted in development of several figures and the conceptual thinking; Howard Cambridge, SEI, ran the Nariale water balances in SWAT; Kausal Garg, ICRISAT, kindly developed additional maps for the Kothapally case study, and Philippe Cecchi, IRD UMR G-eau, has provided invaluable understanding of the Nariale catchment development, including providing land-use data over time. Charles Batchelor, independent consultant, kindly shared the case data from Rajasthan, India. Thanks to Dieter Gerten, the leading scientist at the Potsdam Institute on the LPJ model (used for all global estimates of green–blue water flows), and to several water scientists for dialogues stimulating and triggering the writing of this book (in particular, Hubert Savenije, Sandra Postel, Tony Allan, Charles Vörösmarty, Joseph Alcamo, Gretchen Daily, Suhas Wani, Theib Oweis, David Molden and Vladimir Smakhtin).

We greatly appreciate the enthusiasm and deep commitment to the realisation of this book shown by all these contributors.

Special thanks to Hugo Ahlenius for preparing all the figures and tables and leading the final stretch in organising the manuscript for submission, Mats Lannerstad for the management of this highly interactive book project, and to the language editor Andrew Mash, for your invaluable contributions. Without your tireless efforts we would not have been able to finalise this book.