River Restoration
Managing the Uncertainty in Restoring Physical Habitat

Editors
Stephen Darby
School of Geography, University of Southampton, UK

and

David Sear
School of Geography, University of Southampton, UK

John Wiley & Sons, Ltd

River Restoration

River Restoration

Managing the Uncertainty in Restoring Physical Habitat

Editors
Stephen Darby
School of Geography, University of Southampton, UK

and

David Sear
School of Geography, University of Southampton, UK

John Wiley & Sons, Ltd

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

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

The Publisher and the Author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of fitness for a particular purpose. The advice and strategies contained herein may not be suitable for every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the Publisher nor the Author shall be liable for any damages arising herefrom.

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, 42 McDougall Street, Milton, Queensland 4064, Australia

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

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

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

Darby, Stephen.
River restoration : managing the uncertainty in restoring physical habitat / Stephen Darby and David Sear.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-86706-8 (cloth)
1. Stream restoration. 2. Riparian restoration. I. Sear, David (David A.) II. Title.
TC409.D28 2008
627′.12–dc22
2007030210

British Library Cataloguing in Publication Data

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

ISBN-13 978-0-470-86706-8 (HB)

Typeset in 9/11 pt Times by SNP Best-set Typesetter Ltd., Hong Kong
Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire

Contents

Section I Introduction: The Nature and Significance of Uncertainty in River Restoration

Section II Planning and Designing Restoration Projects

Section III The Construction and Post-Construction Phases

Section IV Uncertainty and Sustainability: Restoration in the Long Term

Preface

For many years scientists and river practitioners have recognised the severity and extent to which aquatic ecosystems have been degraded by a variety of human disturbances and activities (Gregory and Park, 1974; Sear and Arnell, 2006). In turn, realisation of the widespread nature of the problem has more recently elicited a surge of interest in the possibility of undertaking corrective interventions, such as flow restoration and channel modifications, to restore or rehabilitate lost and/or damaged ecosystem functions (Brookes and Shields, 1996; Wissmar and Bisson, 2003). Indeed, there is now a substantial volume of literature on the broad topic of river restoration, much of which suggests that, to be sustainable, river restoration projects should be designed to recreate functional characteristics within a context of physical (i.e. geomorphic) stability. It is true that the emphasis on stable channel design may reflect the traditional disciplines of many of the river engineers who have now turned their attentions to restoration. Whatever the provenance and merits of this approach, a focus on stable channel design requires the application of geomorphic and engineering design tools (models) that are for the most part either entirely empirical or empirically calibrated. As a result, different results are obtained when different models are applied to the same problem. Furthermore, the data required to apply morphological models to restoration design are often absent, incomplete, or subject to measurement error. Finally, even when a restoration design is completed, it is usually not possible to predict the precise sequence of flood events. In the long term further variability is introduced by climatic or catchment changes (e.g. in land use), or unanticipated social or cultural changes, all of which might shift the basic premise(s) of the design. It is evident that the designers and managers of stream restoration projects are *inevitably* confronted with uncertainty.

Despite, or perhaps because of, this challenging situation the restoration literature, albeit with some notable exceptions (Wissmar and Bisson, 2003), has not yet devoted consideration to identifying associated uncertainties, let alone seeking to quantify, manage, or – where appropriate (see below) – constrain them. Rather, the discipline has instead tended to focus on management responses (e.g. post-project appraisal, adaptive management strategies) that only implicitly confront assumed sources of variability and uncertainty. Our concern is that a collective disciplinary failure to recognise, communicate and deal appropriately with uncertainties might, at some time in the future, undermine institutional and public confidence in river restoration. In a first attempt to address these issues, we (together with Dr Andrew Collison and Dr Sean Bennett) convened a special session on *Uncertainty in River Restoration* at the 2002 Fall Meeting of the American Geophysical Union (AGU) in San Francisco, California. While recognising that no single volume can ever cover all aspects of such a multi-faceted discipline as river restoration, the positive response to the topic at that AGU symposium prompted us to seek to explore it further in this volume. All the chapters for this book were, therefore, specially commissioned in an attempt to provide a coherent narrative structure that offers a rational theoretical analysis of the uncertain basis of restoration, while simultaneously providing practical guidance on managing the implications of that uncertainty.

The resulting book is structured into four main sections. Each offers a range of case studies in an attempt to ensure a wide geographic coverage. Likewise, the authorship is drawn from a range of countries and disciplines, in an attempt to bring a range of perspectives to the table. Section I comprises three chapters that review the nature and significance of uncertainty in river restoration, providing a context for the remainder of the book. In Chapter 1 Lemons and Victor focus on the specific nature of scientific uncertainty in restoration, while Graf (Chapter 2) expands on this theme, identifying a series of sources of uncertainty in theory, research and communication. In Chapter 3 Wheaton *et al.* synthesise and extend these analyses, presenting a classification that suggests uncertainty fundamentally arises either through limited knowledge or through natural system variability. This is an important distinction, not least because it helps to discriminate between those sources of uncertainty (limited knowledge) which should, where possible, be constrained (e.g. by scientific progress) from those sources (e.g. natural variability) that should be embraced to promote healthy system functioning. The management implications associated with each form of uncertainty are therefore distinct, but recognition that *embracing* certain types of uncertainty may be both necessary and desirable to assure sustainability is a theme that runs throughout many of the contributions herein.

The book is subsequently structured to address the discrete stages in the life span of a typical restoration project, covering the planning and design activities associated with the pre-construction phase (Section II), the construction phase itself (Section III) and the long term post-construction phase (Section IV). Section II (Chapters 4 to 8) presents contributions covering various aspects of planning and design associated with restoration projects. In Chapter 4 Kondolf and Yang's review reminds us that restoration is fundamentally a social and cultural process, with variability in cultural values acting as a significant contributor of uncertainty. Presenting an Australian case study, where the aim was to restore flows capable of flushing fine sediment from river gravels, Stewardson *et al.* (Chapter 5) identify the limits in our understanding of hydrological, hydraulic and geomorphic processes and how these constrain our ability to model river system dynamics. In terms of the uncertainty classification discussed in Chapter 3, their focus is essentially on quantifying the magnitude of uncertainty due to limited knowledge. Their results (that the magnitude of designed flushing flows is subject to uncertainty estimates approximately twice that of the flow itself) reinforce the earlier suggestion that restoration is indeed an uncertain discipline. Whether this really means that we should have 'unreasonable confidence' in restoration, as suggested by their provocative sub-title, is a theme that is continued throughout the book.

In contrast to the focus on uncertainty due to limited knowledge expounded in Chapter 5, Chapter 6 (Hughes *et al.*) reviews some of the difficulties associated with extending restoration into complex riparian and floodplain habitats, emphasising that in these systems uncertainty (in this case in the form of physical diversity and variability) is necessary to underpin the successful restoration of forest floodplain ecosystems. In Chapter 7, Clifford *et al.*'s comprehensive review of how the restoration of flow hydrology and hydraulics can be used to enhance aquatic habitats also recognises the importance of restoring natural variability, and provides recommendations on how such variability can be interpreted in modelling investigations. The theme of uncertainty associated with ecological targets is explored further in Chapter 8 (Perrow *et al.*), where the paradox that uncertainty is often viewed as a pejorative term is again highlighted, even if it is uncertainty (in the form of natural variability) that is the key mechanism for sustaining healthy ecosystems. How uncertainty due to the lack of understanding of a discipline (ecology) by river managers has led to a lack of using available science within restoration process is also highlighted.

Section III (Chapters 9 to 12) addresses the construction phase of a restoration project, which is defined in this book as extending up to one or two years after completion of the project. The contributions in this section are written primarily by river practitioners, who employ their collective experience to offer a range of perspectives on uncertainties encountered during this key stage of restoration. Mant *et al.* (Chapter 9) review the difficulties encountered during construction and note that strong teamwork skills are required to ensure that the design concepts provided by geomorphologists and ecologists are correctly translated into practice by those responsible for construction. A difficulty here is that restoration is seen as a relatively new facet of civil engineering, such that contractors may not always have the experience necessary to recognise that variability, rather than uniformity (their experience to date), is often necessary. To this end it is essential that designers inform the workforce of the specific requirements of the river restoration project, while project managers must also take responsibility for monitoring construction as it progresses. This points to the importance of ensuring that the constructed project does indeed conform to the design specifications, raising the issue of evaluating project outcomes.

This subject is the theme of the next three chapters. Skinner *et al.* (Chapter 10) review post-project appraisals with reference to both physical and ecological measures of success, whilst Rhoads *et al.* (Chapter 11) focus on methods for evaluating the geomorphological performance of restored rivers, providing examples from heavily urbanised catchments in Illinois in the USA. Both contributions emphasise the key need for both pre and post-project monitoring, even if only to a minimum standard. This is viewed as necessary to verify that projects are constructed according to their design, as well as an integral tool of adaptive management that can make project adjustments in the face of uncertainties introduced by variable post-project conditions. This theme is further explored by Brookes and

Dangerfield (Chapter 12), who propose that managers should adopt *continuous improvement* as an overall operational philosophy for restoring rivers. The term *continuous improvement* is widely documented in human resource, organisational management and environmental management literature, and is taken to be a philosophy of learning during the construction and post-construction phases (and making adaptations to a particular project as necessary) for the benefit of the continuing work and future practice. This appears to be a robust approach that has the potential, over time, to reduce uncertainties associated with limited knowledge while simultaneously providing a framework for adaptive response to uncertainties associated with natural variability.

Section IV (Chapters 13 and 14) addresses the challenge of the need to assure the long term sustainability of restoration projects in the face of uncertain futures. There is a clear recognition that as the time scales over which project outcomes should be considered increase, there is a concomitant need to address increased spatial scales. Specifically, there is a need to consider how catchment-scale processes (which influence the fluxes of water and sediment supplied to restoration reaches) are to be sustained in the long term. Clearly, as spatial and temporal scales increase, then so do the uncertainties particularly, but not exclusively so, those associated with increases in spatial and temporal variability. In Chapter 13 Downs and Gregory bring a hydromorphological perspective to these issues, suggesting that the bounds of these uncertainties can be evaluated with reference to long term (palaeo)hydrological and geomorphological evidence of past catchment response – in effect advocating a more precise definition of the uncertainty due to natural variability.

The final chapter (Chapter 14; Newson & Clark) provides an apt conclusion. Recognising that uncertainty (in the form of natural variability) is both endemic and necessary, it is noted that there is a conflict between the precautionary principle – a cornerstone of sustainable thinking – and uncertainty. Newson and Clark recognise that all restorations have outcomes that are to some extent unpredictable, and the precautionary principle thus becomes a recipe for inaction. Uncertainty is therefore simultaneously necessary for, but also a barrier to, sustainability. They attempt to resolve this particular problem by identifying management and restoration opportunities that are sustainable despite being uncertain, noting that in practical terms it is to adaptive management that we most often turn for a way forward, reinforcing a series of conclusions from earlier chapters.

Do we have unreasonable confidence in restoration, based on the state of the art, or are we happy to boldly go with the uncertain ebb and flow of natural variability? Perhaps the way forward is through a clearer and more transparent approach to communicating uncertainty, such that all participants – and especially stakeholders – understand that while every effort can and should be made to identify, and where possible reduce, scientific and methodological uncertainties, uncertainty due to natural variability is both welcome and necessary to sustain healthy aquatic ecosystems. This implies a concerted approach on two fronts: scientists can continue to refine the knowledge base (and managers need to recognise the value of this research for their (adaptive) management practices), while managers must work harder to build and accommodate variability into projects. Uncertainty in river restoration is endemic but clearly offers opportunities, not just as a rationale for further research, but fundamentally for more sustainably managed restoration projects. Just as life goes on with little confidence or ability to predict the future, so restoration must continue to evolve and adopt an approach that is consistent with the uncertain functioning of riverine ecosystems.

In closing this preface, we would like to acknowledge those who have made significant contributions during the production of this book. Firstly, we would like to thank those numerous professionals who provided detailed peer reviews of each chapter, often working to tight deadlines. The anonymous nature of peer review means that we are unable to identify them here, but you know who you are! Finally, Tim Aspden and the staff of the Cartographic Unit at the School of Geography, University of Southampton, provided guidance on, and help with, the production of much of the artwork. A final acknowledgment must go to our families who have put up with longer hours than normal (or natural!) in the drive for completion.

Stephen Darby and David Sear
December 2007

REFERENCES

Brookes A, Shields FD. 1996. *River Channel Restoration: Guiding Principles for Sustainable Projects.* John Wiley & Sons Ltd: Chichester, UK.

Gregory KJ, Park CC. 1974. Adjustment of river channel capacity downstream from a reservoir. *Water Resources Research* **10**: 840–873.

Sear DA, Arnell NW. 2006. The application of palaeohydrology to river management. *Catena* **66**: 169–183.

Wissmar RC, Bisson PA (Eds). 2003c. *Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems*. American Fisheries Society: Bethesda, Maryland, USA.

List of Contributors

Jorge Abad, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA.

Dr Mike Acreman, Water Resources & Environment Division, Centre for Ecology & Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK (man@ceh.ac.uk).

Professor Fabian Bombadelli, Department of Civil and Environmental Engineering, University of California at Davis, Davis, California 95616, USA (fabombardelli@ucdavis.edu).

Dr Douglas Booker, National Institute of Water and Atmospheric Research, 10 Kyle St., Riccarton, Christchurch, 8011, New Zealand (d.booker@niwa.co.nz).

Dr Andrew Brookes, Jacobs (UK), School Green, Shinfield, Reading RG2 9HL, UK (andrew.brookes@jacobs.com).

Professor Mike Clark, School of Geography, University of Southampton, Highfield, Southampton SO17 1BJ, UK (M.J.Clark@soton.ac.uk).

Professor Nick Clifford, School of Geography, The University of Nottingham, University Park, Nottingham NG7 2RD, UK (Nick.Clifford@nottingham.ac.uk).

Dr Helen Dangerfield, Royal Haskoning, 4 Dean's Yard, London, SW19 3NL, UK (Helen.dangerfield@royalhaskoning.com).

Dr Melinda Daniels, Department of Geography, Kansas State University, USA (melinda.daniels@uconn.edu).

Dr Stephen Darby, School of Geography, University of Southampton, Highfield, Southampton SO17 1BJ, UK (S.E.Darby@soton.ac.uk).

Dr Peter Downs, Stillwater Sciences, 2855 Telegraph Avenue, #400, Berkeley, California 94705 USA (downs@stillwatersci.com).

Dr Judy England, Environment Agency, Apollo Court, 2 Bishop's Square, St. Albans Road West, Hatfield AL10 9EX, UK.

Professor Marcelo Garcia, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA (mhgarcia@uiuc.edu).

Professor William Graf, Department of Geography, University of South Carolina, Columbia, South Carolina 29208, USA (graf@sc.edu).

Professor Ken Gregory, School of Geography, University of Southampton, Highfield, Southampton SO17 1BJ, UK (Ken.Gregory@btinternet.com).

Dr Simon Harrison, Department of Zoology, Ecology and Plant Sciences, University College Cork, Lee Maltings, Prospect Row, Cork, Ireland (s.harrison@ucc.ie).

Dr Francine Hughes, Department of Life Sciences, Anglia Ruskin University, East Road, Cambridge CB1 1PT, UK (f.hughes@anglia.ac.uk).

Martin Janes, River Restoration Centre Manager, The River Restoration Centre, Building 53, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK (rrc@therrc.co.uk).

Professor Mat Kondolf, Department of Landscape Architecture and Environmental Planning, University of California, Berkeley, California 94720-2000, USA (kondolf@uclink.berkeley.edu).

David Leeming, Consultant Ecologist, Spindlewood, 45 West End, Ashwell, Hertfordshire SG7 5QY, UK.

Professor John Lemons, Department of Environmental Studies, University of New England,11 Hills Beach Road, Biddeford, Maine 04005, USA (jlemons@une.edu).

Dr Jenny Mant, The River Restoration Centre, Building 53, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK (rrc@therrc.co.uk).

Dr Tim Moss, Institute for Regional Development and Structural Planning (IRS), Flakenstrasse 28–31, 15537 Erkner, Germany. (MossT@irs-net.de).

Professor Malcolm Newson, Department of Geography, University of Newcastle-Upon-Tyne, Newcastle-Upon-Tyne NE1 7RU, UK (M.D.Newson@ncl.ac.uk).

Dr Martin Perrow, ECON, Ecological Consultancy, Norwich Research Park, Colney Lane, Norwich, Norfolk NR4 7UH, UK (m.perrow@econ-ecology.com).

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

Professor Keith Richards, Department of Geography, University of Cambridge, Downing Place, Cambridge CB2 3EN, UK (keith.richards@geog.cam.ac.uk).

Dr Roy Richardson, Scottish Environment Protection Agency, Burnbrae, Mossilee Road, Galashiels TD1 1NF, UK.

Dr Jose Rodriguez, Faculty of Engineering and Built Environment, University of Newcastle, Newcastle, New South Wales 2308, Australia (jose.rodriguez@newcastle.edu.au).

Dr Ian Rutherfurd, Geography Program, School of Resource Management, University of Melbourne, Melbourne, Victoria 3010 Australia (idruth@unimelb.edu.au).

Professor David Sear, School of Geography, University of Southampton, Highfield, Southampton SO17 1BJ, UK (D.Sear@soton.ac.uk).

Dr F. Doug Shields Jr, Water Quality and Ecology Research Unit, National Sedimentation Laboratory, USDA Agricultural Research Service, National Sedimentation Laboratory, PO Box 1157, Oxford, Mississippi, USA (dshields@ars.usda.gov).

Eleanor R. Skeate, ECON, Ecological Consultancy, Norwich Research Park, Colney Lane, Norwich, Norfolk NR4 7UH, UK (e.skeate@econ-ecology.com).

Dr Kevin Skinner, Principal Geomorphologist, Jacobs Babtie, School Green, Shinfield, Reading RG2 9HL UK (Kevin.skinner@jacobs.com).

Dr Michael Stewardson, Department of Civil and Environmental Engineering and eWater CRC, University of Melbourne, Melbourne, Victoria, 3010 Australia (mjstew@unimelb.edu.au).

Mark L. Tomlinson ECON, Ecological Consultancy, Norwich Research Park, Colney Lane, Norwich, Norfolk NR4 7UH, UK (m.tomlinson@econ-ecology.com).

Professor Reginald Victor, Centre for Environmental Studies and Research, c/o Department of Biology, Sultan Qaboos University, PO Box 36, Al-Khod, PC 123, Muscat Sultanate of Oman (rvictor@squ.edu.om).

Joseph M. Wheaton, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth SY23 3DB, UK (Joe.Wheaton@aber.ac.uk).

Dr Chia-Ning Yang, Department of Landscape Architecture, California State Polytechnic University, Pomona, California 91768, USA (cnyang@csupomona.edu).

SECTION I

Introduction: The Nature and Significance of Uncertainty in River Restoration

1

Uncertainty in River Restoration

John Lemons[1] and Reginald Victor[2]

[1] *Department of Environmental Studies, University of New England, USA*
[2] *Center for Environmental Studies and Research, Department of Biology, Sultan Qaboos University, Sultanate of Oman*

1.1 INTRODUCTION

As we are well aware, rivers fundamentally shape the planet and human life. Both ancient and modern societies have developed and flourished in the proximity of rivers and this trend has continued till modern times. Nienhuis and Leuven (2001) summarize how humans have spatially and temporally altered rivers over a 6000-year period by various anthropogenic activities. For example, intensive use of European rivers started over 500 years ago leading to the loss of their ecological integrity (Smits *et al*., 2000). Some rivers were altered for navigation, flood control, agriculture and reclamation of land for urban development, while most were used as chutes for waste disposal including sewage, thermal effluents and both nontoxic and toxic chemicals; some rivers were also routinely dredged to facilitate the transport and storage of timber, while others were heavily fished (Ward and Stanford, 1979; De Wall *et al*., 1995; Eiseltova and Biggs, 1995).

Large river systems (stream order >8) all over the world have been extensively dammed for hydroelectric power, recreation, flood control and to divert water to support agriculture. Impacts of large dams include the loss of fisheries and the ecological collapse of the entire river regime (Balon and Coche, 1974; Rzoska, 1976; Obeng, 1981). Extensive series of levees built along large rivers have caused major losses of ecosystem structure and function. Along the Mississippi River, the largest river in North America, levees threaten federal plans to protect endangered species (EPA, 2004). The effects of impounding small rivers (stream order 4–8) are even more drastic. In some West African small rivers entire fish communities had changed due to impoundment and the ecological perturbations extended for considerable distances downstream (Victor and Tetteh, 1988; Victor and Meye, 1994; Victor and Onomivbori, 1996). Gopal (2003) describes how rivers in arid and semi-arid regions in Asia are being degraded due to overexploitation of natural resources, salinization, pollution and introduction of exotic species.

Just as rivers have undergone alteration, so too have there been efforts to restore them in order to provide benefits to the environment and/or human health, as this book attests (see also MacMahon and Holl, 2001). Obviously, scientific research contributes to river restoration by: providing reliable and needed explanatory or heuristic knowledge and understanding of restoration problems; helping to identify and define new research needs and directions through the acquisition of factual information; and informing policy and decision making (Caldwell, 1996).

A major premise of this book is that to be sustainable, river restoration projects need to effectively recreate a rivers' functional characteristics taking into account the dynamic geomorphic characteristics. While many restoration projects have benefited environmental and/or human health, understudied sources of uncertainty limit confidence in predicting the outcomes of restoration activities and programs. Specific examples of uncertainty in river restoration discussed in this book include those inherent in: river management processes; the planning and design phases of restoration projects; hydraulic and hydrological aspects of restoration; water quantity issues; identifying appropriate ecological characteristics and predicting their

---

River Restoration: Managing the Uncertainty in Restoring Physical Habitat Edited by Stephen Darby and David Sear

responses in restoration designs; and the construction and post-construction phases of restoration projects. The sources of uncertainties include: lack of scientific and other information; limitations of analytical methods and tools; complexities of river systems; and needs to make value-laden judgments at all stages of river restoration problem identification, analysis and solution implementation.

Beginning in and since the early 1990s some philosophers, scientists and public policy experts concluded that the sources and implications of scientific and other uncertainty in environmental problem solving, including restoration, have been understudied and, as a consequence, not sufficiently taken into account by researchers, public policy makers and decision makers (Mayo and Hollander, 1991; Cranor, 1993; Shrader-Frechette and McCoy, 1993; Funtowicz and Ravetz, 1995; Lemons and Brown, 1995; Lemons, 1996; EEA, 2001; Kriebel *et al*., 2001; Tickner, 2002, 2003).

In agreeing with this conclusion, the objective in this chapter is therefore to first discuss various broad views about scientific uncertainty and indicate how and why these need to be taken into greater account by scientists, policy makers and decision makers. (Other chapters address uncertainty and analyze in more concrete detail how it interacts with the specific theories and practices of river restoration.). Discussion then focuses on what might constitute 'good' science when science is used to inform policy and decision making under conditions of scientific uncertainty. Value-laden sources and implications of uncertainty in river restoration are then discussed because they are both important but understudied. Discussion of the value-laden sources and implications of uncertainty is followed with: a brief discussion of some of the practical and policy implications of uncertainty in river restoration, and, finally, a brief case study of river restoration in order to communicate our views with a practical example. For reasons of brevity the case study communicates views about some, but not all, aspects of uncertainty in river restoration.

Parenthetically, here it is necessary to comment on definitions of 'restoration' when used in the context of river restoration. The field of restoration ecology suffers from a lack of conceptual clarity concerning its meaning, goals and objectives. Since about the mid-1980s, the field of river restoration has increasingly evolved in an attempt to better meet societies' needs to more effectively repair damage to rivers (e.g., Cairns and Heckman, 1996; Karr and Chu, 1999; Cairns, 2001). The Society of Wetlands Scientists (SWS, 2000) defined restoration as 'actions taken in a converted or degraded natural wetland that result in the re-establishment of ecological processes, function, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within its landscape.' In 2002, the Society for Ecological Restoration (SER, 2002) defined restoration as the '. . . process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.' Regardless of these definitions, the goals and objectives of river restoration are not clear.

Rolston (1988) believes that where possible ecosystems should be returned to their 'natural' or 'original' condition. Westra (1995) argues that restoration should focus on restoring ecosystems' abilities to continue their ongoing change and development unconstrained by human interruptions past or present. The United States National Research Council (NRC, 1999) defined restoration as 'the return of an ecosystem to a close approximation of its condition prior to disturbance.' This definition was expanded by Cairns (2001), who asserted that the goal of restoration should be devoted to 'returning damaged ecosystems to a condition that is structurally and functionally similar to the predisturbance state.'

Alternatively, others involved in the field of restoration ecology provide definitions for restoration that more explicitly focus on historical, social, cultural, political, aesthetic and moral aspects. For example, Sweeney (2000) argues that restoration should focus on the value-laden social and ethical perspectives regarding what constitutes a 'restored' ecosystem. Some others maintain that conservation and, by implication, restoration goals should take into account the views and practices of rural and indigenous people who depend on the ecosystems for their physical and cultural subsistence, and should also include scientific and nonscientific considerations (Gomez-Pompa and Kaus, 1992; Westra, 1995; Light and Higgs, 1996; Higgs, 1997; Chauhan, 2003). Regier (1995) proposes an abstract definition for restoration that is dependent on what people believe as fostering a state of 'well-being.'

Obviously, lack of conceptual clarity about restoration introduces an element of uncertainty into restoration problem solving. In this chapter, while being mindful of the unresolved problems of conceptual clarity regarding 'restoration' other sources and implications of uncertainty and their relevance to river restoration are focused upon.

1.2 BROAD PHILOSOPHICAL VIEWS ABOUT SCIENTIFIC UNCERTAINTY

During the 19th century there was a high degree of confidence in the methods and tools of science and technology to increase understanding of the natural world and enable robust predictions of its future states. This confidence in science contributed to beliefs that 'nature' could be controlled and rendered useful to humankind (Latour, 1988).

Contributing to these beliefs were philosophers and scientists (so-called 'logical positivists') who proposed that an important goal of science should focus on formulating hypotheses and conducting observations to test them, developing an understanding of processes and linkages among variables, and developing conclusions and predictions about which there is a high degree of confidence. More specifically, the logical positivistic view of science assumes that: knowledge is founded on experience; concepts and generalizations only represent the particulars from which they have been abstracted; meaning is grounded in observation; the sciences are unified according to the methodology of the natural sciences and the ideal pursued in knowledge is the form of mathematically formulated universal science deducible from the smallest number of possible axioms; and values are not facts grounded in observation and therefore cannot be included as a part of scientific knowledge. One the one hand, while logical positivism has influenced the thinking of modern scientists public policy makers, and decision makers, on the other it does not enjoy wide support from contemporary scientific philosophers (Hull, 1974).

Scientists typically are conservative insofar as they provisionally reject a null hypothesis only if the probability of making a type I error is five percent or less (Cranor, 1993; Lemons *et al*., 1997). This scientific conservatism is consistent with the logical positivist goal of developing conclusions about which there is a high degree of confidence. With respect to the use of science as a basis for public policy and decision making, there are those who hold that scientific methods and tools are capable of yielding information about which there is a high degree of scientific confidence and, therefore, it is this information and not more speculative information that should be used as the basis for policy and decision making (Peters, 1991; Sunstein, 2002). This latter view is a component of the field of environmental and human health risk assessment, which has developed to help inform public policy and decision makers about the risks from threats from both natural phenomena and human activities, including assessing whether to undertake some river restoration projects. Components of risk analysis include: identifying the sequence of events through which exposure to risk could occur; determining the number and kinds of people or environmental resources exposed to the risk; determining the adverse effects of exposure to the risks; and communicating risk assessment findings to decision makers and the public. Although risk assessors acknowledge scientific uncertainty, they often hold that scientific methods and tools can identify the risks and enable the calculation of the probabilities of their occurrence, including the bounding of the probabilities with confidence limits. For indepth discussions on the role of scientific information in policy and decision making, see Peters (1991), Shrader-Frechette, (1994), Caldwell (1996), Lemons (1996), and Kaiser and Storvik (2003).

Historically, logical positivism and its outgrowths also have influenced the thinking of some scientists and policy makers in other ways by inculcating the view that 'good' science is objective insofar as it is not biased by the values of the scientists. Accordingly, this view holds that the proper role of science in policy and decision making is to provide factual information to decision makers, and that any controversies about the factual information should be left to members of the scientific community competent in evaluating the scientific bases of the controversies (Shrader-Frechette, 1982). Consequently, the conclusions of scientific analyses do not become a part of broader public policy debates such as those that might pertain to such issues as what level of risk is acceptable. Practically speaking, proponents of this view believe that the scientific and technical problems of managing large scale and complex problems are enormous and that the public cannot be expected to grasp the many scientific and technical issues inherent in understanding and resolving the problems. Further, the fundamental differences people have about how problems should be handled generate endless debate and controversy. This implies that while people and local governmental representatives with different interests may review and comment on scientific and technical documents, they would not be brought into the actual decision- making process regarding the complex scientific dimensions of problems (Lemons *et al*., 1997).

Despite the high degree of confidence held by some people in scientific methods, confidence in the power of science to understand and predict natural phenomena has been undermined by general relativity theories, quantum theories and chaos theories (Brown, 1987). Rorty (1979) notes that there is no evidence that science develops better and more accurate 'mirrors' with which to view nature. In his classic work, Kuhn (1962) describes how on the one hand the level of confidence in models used by members of the scientific community increases with evidence that supports the underlying hypotheses of the models, and on the other the scientists' use of the models cannot be expected to produce consistently better and cumulatively more truthful descriptions of the way the world works. According to Kuhn, the reason is because predictive successes of scientific theories do not guarantee their metaphysical accuracy because 'paradigm shifts' subsequently change scientists' views of nature. Other critics have pointed out that so-called scientific truths of historical periods are social constructs influenced by the dominant cultural and political powers of those periods (Briggs and

Peat, 1982; Funtowizc and Ravetz, 1995). Some postmodern critics argue that Western science has been permeated by a variety of biases (e.g., 'free market' economics and industrialism, racism, religion, patriarchy) that while serving powerful interests have not led to the generation and use of more 'objective' or value-free scientific knowledge (Sirageldin, 2002).

More practically speaking, scientific institutions as well as individual scientists increasingly hold the view that scientific uncertainty regarding environment and human health problems is so pervasive and value laden that many conclusions about the problems cannot be made with a high degree of scientific confidence (Cranor, 1993; Shrader-Frechette and McCoy, 1993; Lemons and Brown, 1995; Lemons, 1996; EEA, 2001; Kriebel *et al*., 2001; Tickner, 2002, 2003). This view is based on empirical studies focusing on: exposure to radiation from nuclear facilities and nuclear waste; managing large-scale ecosystems such as the Florida Everglades, agricultural lands, marine and freshwater oil spills; biodiversity protection and management of biological reserves; ocean dumping of sewage sludge; sulfur dioxide and protection of human lungs to remote lake restoration; antifouling paints on ships (e.g. tributyltin); estuarine eutrophication; protection and management of marine fisheries; extrapolating from toxicological responses in laboratory systems to both human health and to the responses of natural systems; management of fresh water resources; benzene in occupational settings; the use and health impacts of asbestos; risks from polychlorinated biphenyls (PCBs); halocarbons and the ozone layer; diethylstilbestrol (DES) and long-term consequences of prenatal exposure; human health effects of lead in the environment; methyl tertiary-butyl ether (MBTE) in petrol as a substitute for lead; chemical contamination in the Great Lakes; hormones as growth promoters in animals used for food; and global climate change.

1.3 WHAT IS 'GOOD' SCIENCE UNDER CONDITIONS OF UNCERTAINTY?

Here, the question discussed is: What is 'good' science when science is used in trying to solve river restoration problems under conditions of scientific uncertainty?

A traditional and commonly accepted goal of science is that the probabilities of adding speculative information to the body of scientific knowledge should be minimal (Hull, 1974; Peters, 1991). For this reason, scientists typically are conservative insofar as they provisionally reject a null hypothesis if there is a five percent or less chance of rejecting it when it is true; this criterion is known as a normal standard of scientific proof or so-called 'ninety-five percent confidence rule.' With respect to the science used to inform certain types of river restoration policies and decisions, an example of a null hypothesis is that there is no effect on rivers or their resources from existing or proposed human activities. A type I error is to accept a false positive result, that is, to conclude that there is harm to rivers or their resources when in fact there is none. A type II error is to accept a false negative result, that is, to conclude there is no harm when in fact there is.

Many environmental laws and regulations place the burden of proof for demonstrating harm to the environment or human health on government regulatory agencies or others attempting to demonstrate harm from development activities and, often, the standard that is used to meet the burden of proof test is the normal standard of scientific proof (Brown, 1995). When this standard is adopted as a basis for environmental decisions the scientific uncertainty that pervades many environmental problems means that the burden of proof usually will not be met, despite the fact that some information or even the weight of evidence might indicate the existence of harm to the environment or human health. Consequently, in public policy and decision making if the data show that some factor or perturbation has had an effect on the environment or human health but, say, only at the 70–90% confidence level the null hypothesis that there is no effect from the factor or perturbation is accepted. In such cases there is a tendency by decision makers and others to assume not only that there was not enough evidence to reject the null hypothesis but that there was no effect when, in fact, the experimental design or test could have been too weak or the data too variable or too close for an effect to be demonstrated even if there had been one (a type II error).

Minimizing a type II error requires the statistical power of a research design or hypothesis test to be calculated. In contrast to confidence, which is designed to minimize type I error, power depends on the magnitude of the hypothesized change to be detected, the sample variance, the number of replicates and the significance value. The power of a test is the probability of rejecting a null hypothesis when it is in fact false and should be rejected. The larger the detected change, the larger is the power. In situations where the detected changes are relatively small, statistical power is increased by increased sampling size but this involves additional costs, research facilities and time. Analysis of variance in assessing threats to environmental and human health problems shows that the number of samples required to yield a power of 0.95 increases rapidly if changes smaller than 50% of the standard deviation are to be detected (Cranor, 1993). If the sample size stays the same the probability of a type I error is increased if the probability of a type II error is decreased. A practical problem in river restoration is that a desired emphasis on avoiding type II error must be balanced against other opportunities to use limited scientific resources to address other environmental and human health problems.

Decisions about water management in the Klamath Basin along the California and Oregon border in the United States show some of the types of consequences that can happen when the law or decision makers require the use of scientific information that meets the normal standard of scientific proof. In decades long disputes about water management in the basin, federal biologists have been trying to save three species of endangered fish by calling for diversions of water from irrigation into the basin to reduce the frequency of fish kills during low water periods (over 30 000 Chinook salmon died during a fish kill in 2002) (Service, 2003). As would be expected, a recommendation to reduce the amount of water available for irrigation met with strong opposition by ranchers and farmers in the basin. However, failure of the biologists to meet normal scientific standards of proof demonstrating that releasing more water into the basin would help the fish has been cited by the United States Department of Interior (DOI) in its recent refusal to restrict the amount of water farmers can remove from waterways in the basin (NRC, 2004). It is important to understand that the DOI was not criticizing the scientists for doing poor science; rather, it concluded that the normal standard of proof was not met. The DOI noted that factors such as nutrient runoff from natural sources as well as farms and ranches, algae blooms and dams that restrict access to fishes' spawning grounds complicate and in fact might preclude demonstrating the relation of water flow into the basin and the health of the fish populations with a higher degree of scientific confidence.

The question of how to protect endangered species in the Klamath Basin and manage water resources raises a fundamental dilemma that those involved in river restoration have to confront. On the one hand, traditional scientific norms call for making conclusions on information about which there is a high degree of confidence. In the Klamath Basin example, adhering to traditional scientific norms constrains decisions to protect endangered fish under conditions of uncertainty but, at the same time, in the absence of decisions to protect endangered fish the threats continue. In this type of situation, when science is used for public policy and decision making, scientists might wish to consider whether and to what extent they should be more comfortable with making conclusions based on the weight of evidence rather than based solely or primarily on high levels of confidence, especially since public policy decisions are not based simply upon probabilistic considerations but rather involve making discrete and explicit choices among specific alternatives, including those with political, economic and ethical ramifications (Bella *et al*., 1994; Lemons *et al*., 1997). Admittedly, this could create a tension between doing 'good' science as traditionally defined because scientists would be making more speculative conclusions; however, in their attempt to make science rigorous in the sense of not wanting to add speculation to the body of scientific knowledge as required by the scientific profession the regulatory questions for which the studies are done may be frustrated.

1.4 VALUE-LADEN DIMENSIONS OF SCIENCE AND UNCERTAINTY

In addition to the policy and management problems that arise from the use of traditional scientific norms for making conclusions in river restoration, other value-laden dimensions of science and policy both contribute to uncertainty and raise complicated questions about how it should be handled in public policy.

Westra and Lemons (1995) and Lemons (1996) contain papers analyzing both philosophical and scientific concepts used to inform ecological restoration science and practice. The concepts are diverse and include basing restoration on: ecosystems' abilities to function successfully in a way deemed satisfactory by society; ecosystems' abilities to maintain a balanced, integrated, adaptive community of organisms having species composition, diversity and functional organization comparable to that of 'natural' habits of the region; ecosystems' abilities to regenerate themselves and withstand anthropogenic stress; and ecosystems' abilities to approach optimum capacity for ecological succession development options. One problem with all these definitions is that they are incomplete, general and qualitative insofar as they fail to provide precise principles that would make them operational.

In his analysis of value-laden issues in restoration for ecological as opposed to primarily or exclusively economic development goals, Cairns (2003) focuses on several types of problems. Firstly, some restoration projects are carried out on habitats different in kind from those altered or destroyed. For example, an upland forest may be destroyed in order to partially restore river systems and wetlands that once occupied a particular lowland area. Despite the fact that restoration of rivers and/or wetlands has ecological value, sacrificing a relatively undamaged habitat to restore another kind may cause unanticipated ecological change or harm. Secondly, with few exceptions most river and other ecological restoration projects are done to support the anthropocentric commodity or utilitarian values they offer humans and this poses conflicts with restoration goals for nonanthropcentric reasons. Thirdly, river restoration has uncertain outcomes because of unpredictable events like floods or droughts, and because of the limitations of the methods and tools of science to predict long-term outcomes. Fourthly, restoration efforts focusing on single species or ecosystem attributes might eliminate those species that had initially colonized disturbed areas and were at the same time able to tolerate anthropocentric stress. However, restoration projects might result in the displacement of species tolerant to human activities with those less tolerant, at least in the short term. Fifthly, ecological restoration often takes place with species that tolerate anthropocentric stress and the ultimate succession processes and states will be human dominated or dependent. Most likely, a return to indigenous species would require continual intervention by researchers and environmental decision makers on behalf of their re-establishment. While science is not determinative to how the issues are resolved, robust scientific information is needed to help inform satisfactory policy judgments.

Mayo and Hollander (1991), Cranor (1993), Shrader-Frechette and McCoy (1993) and Lemons and Brown (1995) analyzed how and why numerous value-laden judgments, evaluations, assumptions and inferences are embedded in scientific methods pertaining to the study and management of ecosystems, including geohydrological and other water resources. For example, people have to decide the ecosystem parameters that are more important to base judgments on, often with little or no empirical information available. Assumptions have to be made, often without direct empirical evidence, whether ecosystem parameters should be considered independently or synergistically, and whether threshold values for environmental or health impacts exist and, if so, what such values should be. In addition, a lack of empirical data cannot be separated entirely from practical limitations imposed on environmental scientists. Decision makers require information in a relatively short period and at reasonable cost. These factors constrain the focus of most restoration studies to the short term, relatively small spatial areas and measurement of a relatively small number of samples and parameters. Further, the above commentators conclude that many of the value-laden dimensions of scientific methodology and information not only are not fully recognized by scientists, policy and decision makers, but that the failure to sufficiently recognize the value-laden dimensions of science casts serious doubts about even the best and most thorough scientific and technical studies used to inform decisions about problems such as river restoration. In other words, unless the value-laden dimensions of scientific studies are disclosed the positions of decision makers will appear to be justified on value-neutral scientific reasoning and will appear to be more certain than warranted when, in fact, the positions will be based, in part, on often controversial and conflicting values of scientists and decision makers (see also Fleck, 1979).

One of the most common ways in which value issues are hidden in public policy concerning issues such as river restoration develops out of the expectation that technical analysts can isolate and apply the facts under dispute in a manner consistent with policy directives or legislative mandates. This separation of facts and values is highly problematic. For example, consider the use of safety factors in river water quality regulations as a means of extra protection for human or environmental health. Implicit in the choice of safety factors is an asymmetric cost function with health costs rising more steeply than costs for over-treatment. Implicit in the magnitude of a safety factor are significant uncertainties in health impacts and a steeper cost function for health effects from under-treatment than for over-treatment. When these issues remain implicit in the use of safety factors (as they typically are) the real issues of knowledge and uncertainty are obscured for decision makers and the public. Often, these issues remain implicit or hidden because safety factors and cost factors are described in quantitative terms pertaining to risks or cost–benefit calculations. This increases the likelihood of the misuse of conclusions by decision makers who do not understand the basis for deriving safety factors (Brown, 1987).

1.5 PRACTICAL AND POLICY ASPECTS OF UNCERTAINTY

Cairns (2001) analyzed how most complex environmental problems transcend the capabilities of any single discipline but at the same time and all too often research teams are not sufficiently interdisciplinary to deal adequately with the problems. In addition, problem solving often does not provide a balanced mix of academicians, public policy and decision makers, representatives from private industry or business and nongovernmental organizations. As a result, the framing of problems and their solution is too often fragmented and ineffectual and biased towards one or a few disciplinary approaches or stakeholder groups (Nienhuis and Leuven, 2001; Benyamine, 2002).

Some scientists and policy makers involved in environmental problem solving have argued for synthesizing analyses and alternatives to solutions of environmental resource problems (Lubchenco *et al*., 1991; Bella *et al*., 1994; Lemons and Brown, 1995; Caldwell, 1996). In practice, at least three levels of synthesis may be identified. The first is conceptual synthesis and occurs when the diverse and often disparate elements of a problem situation are pulled together intuitively, then tested and integrated to form a coherent research design. Following analysis of the problem and identification of its causes and consequences, a second level of synthesis involves delineation of the findings of the scientific research. A third level of synthesis can occur when research findings are evaluated and consolidated in deciding a course of action by decision makers.

Despite the need for greater synthesis of research methods and information, synthesis itself introduces additional value-laden dimensions and uncertainties into environmental problem solving. Caldwell (1996) and Brown (1995) discuss how decision makers must synthesize a policy (in part) from the scientific information available even when the information often is incomplete. When science is used to inform policy decisions such decisions also include economic, legal, administrative and cultural parameters and, therefore, are based on human values and judgments. Benyamine (2002) discusses how disagreements about scientific theories that are used as a basis for informing public policy and decision making become entangled with economic, legal and ideological issues. Sometimes, the disagreements remain largely confined to the scientific community, while at other times the public knows about them. When scientists and/or decision makers know the underlying theoretical bases for disagreements, this knowledge can influence the scientific arguments about the disagreements. However, some conflicting arguments and their underlying theoretical support can be under recognized or little understood by the non-scientific communities as well as by scientists whose specialized fields are outside the discipline where debates about theories are taking place. When this happens, conflicting scientific arguments will not have much influence on the disagreements.

There is debate within the scientific and public policy communities regarding approaches to deal with uncertainties (Bradshaw and Borchers, 2000). For example, one approach might be to attempt to increase scientific confidence by increasing scientific confirmation of hypotheses. In this way, scientists can decrease uncertainty sufficiently to allow more precise estimates of risk for policy and decision makers. A second approach might be to increase the knowledge of sources of uncertainty by enhancing education and communication between scientists, policy and decision makers and the general public. A benefit of this approach is that when scientists and decision makers are involved with the public there is greater opportunity for consensus building and less risk of legal challenges from disaffected stakeholders. A third approach might be to foster the view that scientific uncertainty should be regarded in public policy and decision making as it is within the scientific community, namely, as information for hypothesis building and testing. Consequently, calls for faster and more ‘certain’ scientific conclusions to inform public policy and decision making would be tempered with a better understanding of the limitations and capabilities of science to provide information about which there is a high degree of confidence.

Still another approach might be for society to require procedural rules for making decisions under conditions of scientific uncertainty to take into account conflicting points of view, possible consequences to welfare, as well as various ethical and legal obligations such as those involving free informed consent and due process (Shrader-Frechette, 1996). This approach could include greater use of the precautionary principle by helping to ensure that when there is substantial scientific uncertainty about the risks and benefits of a proposed activity, policy decisions should be made in a way that errs on the side of caution with respect to the environment and the health of the public (Kriebel *et al*., 2001; Tickner, 2003).

1.6 CASE STUDY OF SCIENTIFIC UNCERTAINTY IN RIVER RESTORATION

The example discussed here is based on ecological studies conducted from 1980–1989 in a small (4th order), black water West African river, the River Ikpoba flowing through Benin City, Southern Nigeria (Victor and Dickson, 1985; Victor and Ogbeibu, 1985, 1986, 1991; Victor and Tetteh, 1988; Ogbeibu and Victor, 1989; Victor and Brown, 1990; Victor and Meye, 1994; Victor and Onomivbori, 1996; Victor, 1998). The stretch of river studied was affected by a variety of urban perturbations such as damming, water extraction, point and nonpoint source pollution, sand dredging and agriculture. As a result of government policies and directives mandating river clean-up activities, there was a rare opportunity to study river restoration by recovery processes. Scientific results of this study were published in the series of publications listed above and provide one of the bases of our focus on uncertainties associated with the restoration process.

The first logical step was to investigate recovery processes. Geomorphologic changes of the river channel and the entire riparian corridor influenced by urban development could not be reversed (e.g. the presence of a dam, water extraction for human consumption) and therefore complete restoration would not be possible. Removal of human influences where possible would permit recovery, but the rates limiting recovery in different sections would not only depend on the type of influence (e.g. sand extraction, car washing), but would also be complicated by natural events such as floods. Thus the optimum threshold for the recovery process in this study at various sections of the river continuum was unpredictable and uncertain. Other significant uncertainties were: the role of early recolonizing species affecting the trajectory of recovery; the successional sequence of species re-establishing; and the establishment of appropriate abiotic conditions and the establishment of previously non-existing non-native species like the water hyacinth.

The next group of uncertainties was related to the analysis and synthesis of data. Removal of a particular human influence (e.g. discharge of untreated sewage) in one section significantly increased the presence of a parameter, say i ($P < 0.05$), showing that this parameter was a good indicator of recovery. But the same parameter did not increase significantly in an adjacent section with a similar problem ($P > 0.05$) showing its uncertain predictive status. Graphical examination of associations between specific human influences (e.g. removal of detergent contamination) and biological parameters like taxa richness and abundance showed positive relationships, but statistically these relationships as evaluated by Pearson's r or Spearman's r_s were not significant ($P > 0.05$). Thus, correlation matrices generated for evaluating relationships between the removal of perturbation influences and the recovery of both biotic and abiotic parameters were difficult to interpret. Interpretation using traditional statistical norms and acceptable levels of significance were ecologically and rationally highly problematic.

Further uncertainties arose while considering the temporal and spatial scale of the recovery process. The recovery process was happening in an urban setting with a new land use matrix, far different from pristine or semipristine natural conditions that previously existed. Therefore, comparison of the restored river sections to that of 'undisturbed' sections upstream was not valid and new baseline standards had to be established for future monitoring. Even these were extremely site specific with very limited potential for use in other sections of the study stretch. Because of the uncertainties involved, the scale needed for managing temporal and spatial variability in restoration was not apparent. 'Rules of thumb' based on value judgments had to be made to evaluate recovery in specific sections of the river stretch with specific types of perturbations. The magnitude of uncertainties involved render the combination of tools used here (e.g. sampling duration, sampling frequencies, choice of methods, size of samples, analytical models) inadequate to evaluate recovery processes in other rivers of similar stream order, larger rivers with higher stream order and even the same river 100 km downstream where its stream order is >8.

Implementation and analysis of monitoring were also wrought with uncertainties. For example, five different sections of the river stretch were monitored for restoration by recovery. Each section was characterized by its own set of physical and biological parameters that were good indicators of recovery at the time of the study. Due to limitations of funding, personnel and the required cost effectiveness of the monitoring program, proposals had to identify common parameters that would monitor the overall health of the study stretch in the long term. As discussed earlier, uncertainties associated with the analysis and synthesis of data did not permit the ready identification of common parameters. Even if there was an agreement on using different sets of parameters for different sections of the stretch, there was no certainty that these parameters (e.g. BOD, nitrate–N, fish diversity) will continue to serve as good indicators of recovery in the long term. It was also possible that a parameter considered trivial and not included in the monitoring program (e.g. dissolved organic matter, haptobenthos) may become important in the long term, which in itself cannot be defined clearly. 'Long term' in this case at least did not refer to an indefinite period and envisaged monitoring programs were not relatively open-ended, as often is the case in countries with limited resources. Policy and decision makers considered what seemed to be a comprehensive proposal for monitoring in the view of scientists as not being practical.

Policy questions concerning river restoration in the geopolitical context were plagued with more uncertainties than scientific questions. The political climate of the study area at that time was unstable and government changed hands frequently. For example, one government downgraded the priority given to environmental issues, such as river restoration, by the previous government if personal interests and political expediency demanded it. Assuming no change in policies with change in governments, there were uncertainties concerning funding tools that would ensure the long term success of restoration, design of legislation to accommodate river restoration without compromising sustainable development and coordination of policies and legislation to devise strategies for river restoration in a broader context of the administrative region (e.g. district, state, country). The management of restored or recovered river as a water resource for domestic use, agriculture, fisheries and recreation was not considered intentionally. For scientific uncertainty concerning water resources management, see Canter (1996).

1.7 CONCLUSION

Scientific and other uncertainty is pervasive in environmental problem solving, and river restoration is no exception. When the traditional scientific standard of proof is used as a basis for river restoration decisions, the scientific uncertainty that pervades many restoration problems means that the standard usually will not be met, despite the fact that some information or even the weight of evidence might indicate the existence of harm and therefore the need for restoration. A high degree of confidence in river restoration science, as in other sciences, unfortunately seems to hinge on conventional statistical decision rules such as when, for example, river monitoring during restoration strives to detect human-influenced factors that caused deviations from baseline conditions. The major concern here will be ecological change and not how large or small the P-values are (Yoccoz, 1991; Stewart-Oaten, 1996). Most statistical decision rules are too simplistic and misleading insofar as their assumptions that lack of statistical significance means lack of environmental significance (Karr and Chu, 1999). According to Yoccoz (1991), Kriebel *et al*. (2001), and Lemons *et al*. (1997) ecologists tend to over-use tests of significance and restoration ecologists are no exception to this rule. Karr and Chu (1999) suggest that it would be wiser to decide what is ecologically relevant first and then use hypothesis testing to detect ecologically relevant effects; the use of other statistical tools such as power analysis and decision theory also is recommended (Hilborn, 1997).

Cairns and Heckman (1996) state that restoration ecology in general 'is a bridge between the social and natural sciences.' In this chapter it has been shown that it is impossible to separate scientific and policy questions in restoration ecology and this, in and of itself, introduces uncertainty into what otherwise might be viewed as value–neutral or 'objective' scientific conclusions.

As discussed more generally in this chapter and shown more specifically in the case study section, scientific research is both value-laden and is used to support politically-driven river restoration policies and decision making (see also Shrader-Frechette, 1994). For example, historical or descriptive research is intended to reveal or explain the dynamics of a given policy and to explore its origin and evolution. Prescriptive or advocacy research defends a conclusion or possibly even a preconceived policy, and also is characterized by publicized disputes among, e.g., scientists. Decision-informing or predictive research typically is financed by grants or contracts leading to conclusions supportive of a predetermined policy preference, sponsor bias, or predilections within a research peer group. Consequently, the focus of this research does not attempt to analyze all feasible alternative policy choices and the probable consequences. Because the focus of this research is on applicability for a particular policy its findings are presented in the form of propositions upon which decisions can be made. The efficacy of the policy towards which the research is focused depends on the validity, reliability and persuasiveness of the research and the extent of political public receptivity.

It is important to clearly distinguish between the use of methods and tools of science to understand the phenomena of nature and the acquisition of scientific information about a restoration issue and the setting of policy; but in practice, there is not always an unambiguous demarcation. Policy makers set agendas that determine the questions that are asked of scientists; scientists formulate hypotheses in ways limited by their tools and their imaginations and disciplinary conventions. Consequently, the information they provide to the policy makers is limited and socially determined to a degree and therefore there is a complicated feedback relation between the discoveries of science and the setting of policy. While attempting to be objective and focus on understanding river restoration phenomena, scientists and other researchers should be aware of the policy uses of their work and of their social responsibility to carryout science that protects the environment and human health (Kriebel *et al*., 2001). In trying to fulfill this responsibility, scientific and other uncertainty needs to be taken into greater account.

The discussion of some of the value-laden decisions and judgments scientists and other researchers make is not a criticism. Rather, the issue is discussed because a failure to recognize the existence of the value-laden dimensions of science casts serious doubt about even the best and most thorough of scientific and technical studies used to inform decisions about river restoration. In other words, unless the value-laden dimensions of scientific and technical studies used to derive information are disclosed, the positions of policy makers and decision makers will appear to be justified on objective or value–neutral scientific reasoning when, in fact, they will be based in part on often controversial or conflicting values of scientists themselves.

REFERENCES

Balon EK, Coche AG. 1974. Lake Kariba, *A Man-Made Tropical Ecosystem in Central Africa*. DW Junk Publishers: The Hague, The Netherlands.

Bella DA, Jacobs R, Hiram L. 1994. Ecological indicators of global climate change: A research framework. *Environmental Management* **18**: 489–500.

Benyamine M. 2002. *Theoretical Disputes and Practical Environmental Dilemmas*. Orebro Studies in Environmental Science 3. Orebro University: Orebro.

Bradshaw GA, Borchers JG. 2000. Uncertainty as information: Narrowing the Science – Policy gap. *Conservation Ecology* **4**: 7. [online] URL: http://www.consecol.org/vol4/iss1/art7/) (accessed 23 March 2004)

Briggs J, Peat F. 1982. *Looking Glass Universe*. Simon and Schuster: New York.

Brown D. 1987. Ethics, science, and environmental regulation. *Environmental Ethics* **9**: 331–350.

Brown D. 1995. The role of ethics in sustainable development and environmental protection decisionmaking. In *Sustainable Development: Science, Ethics, and Public Policy*, Lemons J, Brown D (Eds). Kluwer Academic Publisher: Dordrecht, The Netherlands; 39–51.

Cairns (Jr) J. 2001. Rationale for restoration. In *Handbook of Ecological Restoration, Vol. 1: Principles and Restoration*, Davy AJ, Perry, J (Eds). Cambridge University Press: Cambridge; 10–23.

Cairns (Jr) J. 2003. Ethical issues in ecological restoration. *Ethics in Science and Environmental Politics* **3**: 50–61.

Cairns J (Jr), Heckman JR. 1996. Restoration ecology: The state of an emerging field. *Annual Review of Energy and Environment* **21**: 167–187.

Caldwell LK. 1996. In *Scientific Uncertainty and Environmental Problem Solving,* Lemons J (Ed). Blackwell Science, Cambridge; 394–422.

Canter LW. 1996. Scientific uncertainty and water resources management. In *Scientific Uncertainty and Environmental Problem Solving*, Lemons J (Ed). Blackwell Science Inc.: Cambridge; 264–297.

Chauhan M. 2003. Conserving biodiversity in arid regions: Experiences with protected areas in India. In *Conserving Biodiversity in Arid Regions*. Lemons J, Victor R, Schaffer D (Eds). Kluwer Academic Publishers: Boston.

Cranor C. 1993. *Regulating Toxic Substances: A Philosophy of Science and Law*. Oxford University Press, New York.

De Wall LC, Large ARG, Gippel CJ, Wade PM. 1995. River and floodplain rehabilitation in Western Europe: Opportunities and constraints. *Archives Hydrobiologia Supplement 101 – Large Rivers* **9**: 679–693.

Eiseltova M, Biggs J. 1995. Restoration of stream ecosystems: An integrated approach. *International Waterfowl and Wetlands Research Bureau Publication* **37**: 1–170.

(EEA) European Environment Agency. 2001. *Late Lessons From Early Warnings: The Precautionary Principle 1896–2000, Environmental Issue Report No. 22*. European Environment Agency: Luxembourg.

(EPA) U.S. Environmental Protection Agency. 2004. Lower Mississippi Valley Ecosystem Restoration Initiative. [online] URL: http://www.epa.gov/region4/programs/cbep/lowmiss.html (accessed 25 March 2004).

Fleck L. 1979. *Genesis and Development of a Scientific Fact*. University of Chicago Press: Chicago.

Funtowicz SO, Ravetz JR. 1995. Science for the post normal age. In *Perspectives on Ecological Integrity*, Westra L, Lemons J (eds). Kluwer Academic Publishers: Dordrecht, The Netherlands, 146–161.

Gomez-Pompa A, Kaus A. 1992. Taming the wilderness myth. *BioScience* **42**: 271–279.

Gopal B. 2003. Aquatic biodiversity in arid and semi-arid zones of Asia and water management. In *Conserving Biodiversity in Arid Regions*, Lemons J, Victor R, Schaffer D (Eds). Kluwer Academic Publishers: Norwell; 199–216.

Higgs ES. 1997. What is good ecological restoration? *Conservation Biology* **11**: 338–348.

Hilborn R. 1997. Statistical hypothesis testing and decision theory in fisheries science. *Fisheries* **22**: 19–20.

Hull D. 1974. *Philosophy of Biological Science*. Prentice–Hall: Englewood Cliffs.

Kaiser M, Storvik H (Eds). 2003. The Precautionary Principle: Between Research and Politics. The National Research Ethical Committee for Natural Science and Technology: Oslo, Norway.

Karr JR, Chu EW. 1999. *Restoring Life in Running Waters. Better Biological Monitoring*. Island Press: Washington, DC.

Kriebel D *et al*. 2001. The precautionary principle in environmental science. *Environmental Health Perspectives* **109**: 871–876.

Kuhn T. 1962. *The Theory of Scientific Revolutions*. University of Chicago Press: Chicago.

Latour B. 1988. The politics of explanation: An alternative. In *Knowledge and Reflexivity: New Frontiers in the Sociology of Knowledge*, Woolgar S (Ed). Sage Publications: London; 155–176.

Lemons J (Ed). 1996. *Scientific Uncertainty and Environmental Problem Solving*. Blackwell Science: Cambridge.

Lemons J, Brown D (Eds). 1995. *Sustainable Development: Science, Ethics, and Public Policy*. Kluwer Academic Publishers: Dordrecht, The Netherlands.

Lemons J, Shrader-Frechette KS, Cranor C. 1997. The precautionary principle: Scientific uncertainty and type I and type II errors. *Foundations of Science* **2**: 207–236.

Light A, Higgs ES. 1996. The politics of ecological restoration. *Environmental Ethics* **18**: 227–247.

Lubchenco J *et al*. 1991. The sustainable biosphere initiative: An ecological research agenda. *Ecology* **72**: 371–412.

MacMahon JA, Holl KD. 2001. Ecological restoration. A key to conservation biology's future. In *Conservation Biology. Research Priorities for the Next Decade*, Soule ME, Orians GH (Eds). Island Press: Washington, DC; 245–269.

Mayo DG, Hollander RD (Eds). 1991. *Acceptable Evidence*. Oxford University Press: Oxford.

(NRC) National Research Council. 1999. *New Strategies for America's Watersheds*. National Academy Press, Washington, DC.

(NRC) National Research Council. 2004. *Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies for Recovery*. Committee on Endangered and Threatened Species in the Klamath River Basin, Washington, DC.

Nienhuis PH, Leuven RSEW. 2001. River restoration and flood protection: Controversy or synergism? *Hydrobiologia* **444**: 85–99.

Obeng LE. 1981. Man's Impact on Tropical Rivers. In *Perspectives in Running Water Ecology*, Lock MA, Williams DD (Eds). Plenum Press: New York; 265–288.

Ogbeibu AE, Victor R. 1989. The effects of road and bridge construction on the bank–root macrobenthic invertebrates of a southern Nigerian stream. *Environmental Pollution* **56**: 85–100.

Peters RH. 1991. *A Critique for Ecology*. Cambridge University Press: Cambridge.

Regier HA. 1995. Ecosystem integrity in a context of ecostudies as related to the Great Lakes Region. In *Perspectives on Ecological Integrity*, Westra L, Lemons J (Eds). Kluwer Academic Publishers: Dordrecht, The Netherlands, 88–101.

Rolston H (III). 1988. *Environmental Ethics, Duties to and Values in the Natural World*. Temple University Press: Philadelphia.

Rorty R. 1979. *Philosophy and the Mirror of Nature*. Princeton University Press: New Jersey.

Rzoska J. 1976. *The Nile: Biology of an Ancient River*. DW Junk Publishers: The Hague, The Netherlands.

(SER) Society for Ecological Restoration Science and Policy Working Group. 2002. The SER Primer on Ecological Restoration. [online] URL: www.ser.org (accessed 25 August 2004).

Service RF. 2003. NRC backs ecosystem-wide changes to save Klamath fish. *Science* 302: 765.

Shrader-Frechette KS. 1982. Environmental impact assessment and the fallacy of unfinished business. *Environmental Ethics* **4**: 37–48.

Shrader-Frechette KS. 1994. *Ethics of Scientific Research*. Rowan & Littlefield Publisher, Inc.: Lanham.

Shrader-Frechette KS. 1996. Methodological rules for four classes of scientific uncertainty. In *Scientific Uncertainty and Environmental Problem Solving*, Lemons J (Ed). Blackwell Science: Cambridge; 12–39.

Shrader-Frechette KS, McCoy E. 1993. *Method in Ecology*. Cambridge University Press: Cambridge.

Sirageldin I. 2002. Human prospects in an age of uncertainty and decline of rationality. *Newsletter of the Economic Research Forum for the Arab Countries, Iran and Turkey* **2**: 9–11.

Smits AJ, Niehuis PH, Leuven RSEW. 2000. *New Approaches to River Management*. Backhuys Publishers: Leiden, The Netherlands.

Stewart-Oaten A. 1996. Goals in environmental monitoring. In *Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats*, Schmitt RJ, Osenbert CW (Eds). Academic Press: San Diego; 17–28.

Sunstein C. 2002. *Risk and Reason*. Cambridge University Press. Cambridge.

Sweeney S. 2000. Different means, shared ends: Environmental restoration and restoration ecology. *Biologica* **38**: 129–139.

(SWS) Society of Wetland Scientists position paper on the definitions of wetlands restoration. 2000. *Ecological Applications* **6**: 84–93.

Tickner J. (Ed). 2002. *Environmental Science and Preventive Public Policy*. Island Press: Washington DC.

Tickner JA. 2003. *Precaution: Environmental Science and Preventive Public Policy*. Island Press: Washington, DC.

Victor R. 1998. Fish community changes associated with a small African reservoir. *International Review of Hydrobiologia* **83**: 603–610.

Victor R, Brown CA. 1990. The food and feeding habits of two species of characid fish in a perturbed West Africa river. *Journal of African Zoology* **104**: 97–108.

Victor R, Dickson DT. 1985. Macrobenthic invertebrates of a perturbed stream in Southern Nigeria. *Environmental Pollution Series A* **38**: 99–107.

Victor R, Meye J. 1994. Further studies on the fish communities of a perturbed stream in Southern Nigeria. *Journal of Tropical Ecology* **10**: 627–632.

Victor R, Ogbeibu AE. 1985. Macrobenthic invertebrates of a stream flowing through farmlands in Southern Nigeria. *Environmental Pollution Series A* **39**: 337–349.

Victor R., Ogbeibu AE. 1986. Reconlonization of macrobenthic invertebrates in a Nigerian stream after pesticide treatment and associated disruption. *Environmental Pollution Series A* **41**: 125–137.

Victor R, Ogbeibu AE. 1991. Macrobenthic invertebrates in the erosional biotope of a Nigerian river. *Tropical Zoology* **4**: 1–12.

Victor R. Onomivbori O. 1996. The effects of urban perturbations on the benthic macroinvertebrates of a southern Nigerian stream. In *Perspectives in Tropical Limnology*, Schiemer F, Boland T (Eds). SPB Academic Publishing: Amsterdam, The Netherlands; 233–238.

Victor R, Tetteh JO. 1988. Fish communities of a perturbed stream in Southern Nigeria. *Nigeria Journal Tropical Ecology* **4**: 49–59.

Ward JV, Stanford JA. 1979. *The Ecology of Regulated Streams*. Plenum Press: New York.

Westra L. 1995. Ecosystem integrity and sustainability: The foundational value of the wild. In *Perspectives on Ecological Integrity*, Westra L, Lemons J (Eds). Kluwer Academic Publishers: Dordrecht, The Netherlands; 12–33.

Westra L, Lemons J (Eds). 1995. *Perspectives on Ecological Integrity*. Kluwer Academic Publishers: Dordrecht, The Netherlands.

Yoccoz NG. 1991. Use, overuse and misuse of significance tests in evolutionary biology and ecology. *Bulletin Ecological Society America* **71**: 106–111.

2

Sources of Uncertainty in River Restoration Research

William L. Graf

Department of Geography, University of South Carolina, USA

2.1 INTRODUCTION: GENERAL SOURCES OF UNCERTAINTY

The practice of science in support of river restoration is subject to four primary sources of uncertainty (see Chapters 1 and 3 for additional/alternative views) so significant that they may prevent the restoration from achieving its goals. Firstly, the underlying theory applied by investigators to particular problem cases is imperfect and contains substantial gaps in explanatory and predictive capability. Secondly, the research process itself is subject to a variety of operational problems that introduce uncertainty to the use of science. Thirdly, the communication of scientific results to decision makers is often fraught with ambiguity derived from the scientific sender as well as the policy receiver. Fourthly, the scientists themselves are subject to bias that generates doubt in the outcome of generating scientific products and applying them. In the following sections the issues for each of these sources of uncertainty is outlined.

2.2 UNCERTAINTY IN THEORY

All science in support of river restoration begins with theory, because it is theory that allows the investigator to identify what to measure and how to construct a conceptual model that connects the measurements together. Investigators perceive only those aspects of the river and its operations that theory allows them to see. Practitioners of fluvial geomorphology tend to revere existing theory as a sacrosanct starting point but, like all sciences, geomorphology is in a state of constant change and revision. The change is sometimes gradual, as with the development and application of fundamental hydraulics to explain river behavior that evolved over a period of several decades (Chang, 1998; Simons and Sentürk, 1992). Sometimes the change is abrupt, as was the case with the introduction of the concepts surrounding hydraulic geometry that burst upon the fluvial geomorphology scene, became widely accepted in less than a decade and continued in common use for several decades (Leopold, 1994). The result of this constantly changing theory is that the geomorphologist working in 2007 may perceive a very different system than one working just a few years before or later, even though the physical system in all cases would be the same. Uncertainty, therefore, is included in the application of science in its broadest sense.

Another source of ambiguity in theory for river restoration is the regional specificity that is built into much of fluvial theory. Much of what we theorize about single-thread meandering rivers comes from research experience in northwest Europe and eastern North America (Knighton, 1998), yet the global applicability of this work is largely untested. Most of the streams of northwest Europe and eastern North America that have been intensively investigated are relatively small on a world-wide basis, and though some generalities certainly must apply in many locales, the details may differ. Until the late 1990s, much of the theory for dryland rivers came from experiences in the American Southwest (Graf, 1988), but more recent investigations in Australia by Gerald Nanson, Steven Tooth and others, for example, have shown that the American experience is not applicable in all drylands (Nanson and Knighton, 1996).

River Restoration: Managing the Uncertainty in Restoring Physical Habitat Edited by Stephen Darby and David Sear

If it is true that we must theorize based on what we know best, it must also be true that we are still limited in the range of our collective experience. As a result, when we apply existing theory in new geographic settings, there is reasonable doubt about the applicability of that theory, at least in its totality. Geomorphologists commonly recognize that it is unwise to extend statistical models beyond the numerical ranges of the data. It is equally risky to extend geomorphological models beyond the geographic ranges of their origin. The extension of theory also forces us to consider how much of the geomorphology and hydrology of a particular river is unique, regardless of its geographic location. Each reach (a few kilometers long) of a stream is likely to be unique but the overall operation and form of a river (hundreds of kilometers long) is likely to have many similarities with other systems of similar magnitude. At the more extensive end of this range of magnitudes, generalizations are possible, while at the local end of the range of magnitudes, uniqueness becomes more apparent.

The incompleteness of most fluvial geomorphologic theory is also a source of uncertainty. This incompleteness is in part purely a function of the natural river system, for which investigators have nine fundamental operating variables, but for which there are only a very few connective mathematical functions (Leopold, Wolman, and Miller, 1964). But an equally important limitation of existing theory is its lack of recognition of human effects. Throughout much of the twentieth century (with a few exceptions), geomorphology as a science pursued explanation for 'natural' rivers and many investigators made a conscious effort to avoid the confounding influence of technological influences. It has only been in the last twenty years that those human influences, pervasive and significant in many rivers of the world, have themselves become the objects of study (Costa *et al.*, 1995; Graf, 2001). By definition, rivers subject to restoration have undergone changes resulting from human management and technology, but existing theory is remarkably weak with respect to these issues.

The Colorado River in the Grand Canyon in the USA provides an example of the issues related to uncertainty in theory. Glen Canyon Dam, several kilometers upstream from the Grand Canyon controls the flow of the river, and especially reduces annual flood peaks to less than half of their former magnitude. The dam also reduces the sediment supply to the downstream canyon by more than 80%. As a result, the river has eroded sandy beaches and bars that once were common in the canyon (National Research Council, 1996). River restoration for the canyon included reintroduction of moderate floods to move the available sediment from the channel floor to elevated positions, restoring these ecological niches. Despite considerable research, there were no established theories to predict the response of the river to the artificial floods and although there have been several flood-simulating releases from the dam, the restoration results are not yet apparent.

2.3 UNCERTAINTY IN RESEARCH

Research using admittedly limited theory in support of restoration is subject to uncertainty in the specification of variables, assumptions, sampling, measurements and testing of hypotheses. The specification or definition of variables, for example, is much entangled in the vagaries of science, law and personal perception of the researcher. Channel width provides an example. Most geomorphologists would agree that channel width is the distance across the active channel from one bank to the other, but the application of this seemingly simple proposition is devilishly difficult in many rivers. How should semi-permanent islands be taken into account? What about ephemeral bars? How should width be determined in the common circumstance where multiple sets of banks have resulted from episodic incision or simply variable flows, which is often the case in arid, semi-arid, arctic or alpine regions. Many legal systems also define the channel as being 'between the banks,' but do not specify which banks to use for the description (Graf, 1988).

All geomorphological research includes assumptions which form another source of uncertainty. The geographic and ecological complexity of rivers and their environments imply that when conducting investigations it is essential to focus on a few components and assume away the importance of variability in other factors that go unmeasured. In geomorphology, hydrology and engineering studies that support restoration, investigators often assume stationarity of the hydro–climatic processes ruling the river. Stationarity means investigators assume that the underlying statistical distributions describing climatic variables important to river processes are unchanging. Standard magnitude/frequency analysis includes this assumption so that the researcher can address other variables of interest to planners, including the return intervals for various magnitudes of discharge. However, climate is anything but stationary, and its variation is highly likely to influence the statistical distributions upon which return interval concepts depend. This variation is also likely to be significant to the fluvial system over time scales as short as decades, scales that encompass the likely project life of most restoration efforts. Predictions for the near-term future of a few decades are therefore uncertain because the effects of expected climatic changes are not part of the analysis (see Chapter 13).