Stream and Watershed Restoration
A Guide to Restoring Riverine Processes and Habitats
Edited by Philip Roni and Tim Beechie

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Our technical and engineering capacity increased tremendously in the last century, allowing us to manipulate rivers to meet demands for electricity, construction, navigation, and human safety. In this period of intense development, we strongly regulated rivers and damaged them. We were able to address a large number of human needs, thus improving human well-being. Other needs were compromised however, and river channel reactions to our actions have had more negative consequences than were ever anticipated.

We entered into a new period of ‘sustainable’ development in the mid-1990s, recognizing the value of river-scapes and the ecosystem services provided by rivers with little or no regulation. After decades of diking, some countries promote ‘more space’ or ‘room’ for rivers and diverse schemes of dike setback have been undertaken, both approaches aiming to protect populations. In urban and suburban areas, riverfronts and corridors are increasingly valued for their potential contribution to the quality of city life. In this context, new questions emerge around environmental ethics and justice, and public actions to mitigate, improve, enhance, restore, and repair the rivers are underway.

Repairing rivers is becoming a real challenge in different parts of the world, and varying strategies are proposed by decision makers to promote this new objective. In Europe, we must reach a good ecological status for our rivers by 2015. This effort is often associated with actions on the physical conditions: so-called hydromorphological measures.

River restoration is a newly emerging practical science based on the principles of engineering ecology. It is still a work in progress. We need to learn a lot, partly from our previous errors. We have passed the ‘we did it’ step, where the fact of doing was already an achievement in itself. Now we are climbing the ‘we did this and it was successful’ step. We are realizing more humbly that restoration is not so easy. We need to experiment, try, and innovate in a domain where uncertainty is high and patience is required; nature does not react obligingly to our requirements. After almost two decades of river restoration some scientists are now deeply involved in this new domain, becoming restoration specialists and providing feedback to the scientific community and practitioners. Good practice guidelines are therefore needed to allow us to move forward and improve decision-making procedures, techniques, and savoir faire.

What is the problem? Why is it degraded? These may seem basic questions, but their answers allow us to know whether we act on the disease or its symptoms. Rivers are not only water canals but also complex corridors with water and other features. Riparian vegetation is completely integrated within this environment, contributing to its good health. Flooding, erosion, and sediment deposition are the engines of this natural infrastructure. A good repair is based on a good diagnosis.

Where should we repair? When thinking about restoration, it is important to look at the big picture. The regional level is strategic here because it allows consideration of the different geographical contexts that control river functioning. Restoration measures can be valuable in a given regional context but not in another. Considering this level is therefore critical for improving the success of restoration. The regional level is also appropriate for policy making to plan and target actions. At this level we can prioritize where restoration would be most beneficial. Where is the most damage? Where would restoration most clearly satisfy needs?

What should we do when we repair? How can we design a restoration project? We need to consider geographical complexity; rivers have different sensitivities to change and can react differently to our actions. This can be helpful at times, but it may also have counter effects if we do not properly appreciate these properties. We also need to consider different timescales; sustainable solutions for very active and reactive rivers will be different from other cases, and self-restoration may take time to propagate its effect downstream. Process-based thinking provides a framework for preventing unexpected river responses. When we play with nature, there are rules we must know. Monitoring is also needed because we do not know enough: we must better define and characterize
what we call a restoration success. How should we do this? What can we learn from previous experiences? How can we capture this valuable feedback? All these are questions to be answered in the near future.

Restoration is a management action and a socio-economic challenge. It aims to provide benefits for society. Such action is therefore conducted in a collective framework and there is a need to reconsider why we are acting. Working not only with nature but also with society has become necessary. Public participation is important because these approaches are new, not always intuitive and sometimes contradictory to historical practices. Discussing conflicting aspects in order to understand different viewpoints opens ways to co-construct a river’s future.

Environmental education is equally a means for preparing society, especially younger generations, to develop with nature. Cost-effective pragmatic measures should be a goal shared by all participants.

All these questions are addressed in this very valuable contribution by a team of authors known internationally for their competence in the field of river restoration. Their motivation is to transfer their knowledge and help society answer this new challenge. Opportunistic restoration must give way to a more strategic framework for prioritizing, designing and implementing actions in an iterative way. The questions are complex. The authors’ response here is interdisciplinary, crossing examples and experiences from North America and Europe where pioneer experiences provide discussion material. This book is a very well-illustrated and exemplified update step. It comprehensively summarizes previous results, then moves on to promote principles, strategies, methods, and techniques to improve our practices and answer social demands for a better environment.

Hervé Piégay,
Research Director at the Centre National de la Recherche Scientifique, Lyon, France
Series Foreword

Advancing River Restoration and Management

The field of river restoration and management has evolved enormously in recent decades, driven largely by increased recognition of the ecological values, river functions, and ecosystem services. Many conventional river management techniques, emphasizing hard structural controls, have proven difficult to maintain over time, resulting in sometimes spectacular failures, and often degraded river environment. More sustainable results are likely from a holistic framework, which requires viewing the ‘problem’ at a larger catchment scale and involves the application of tools from diverse fields. Success often hinges on understanding the sometimes complex interactions among physical, ecological and social processes.

Thus, effective river restoration and management requires nurturing the interdisciplinary conversation, testing and refining our scientific theories, reducing uncertainties, designing future scenarios for evaluating the best options, and better understanding the divide between nature and culture that conditions human actions. It also implies that scientists better communicate with managers and practitioners, so that new insights from research can guide management, and so that results from implemented projects can in turn, inform research directions.

The series provides a forum for ‘integrative sciences’ to improve rivers. It highlights innovative approaches, from the underlying science, concepts, methodologies, new technologies, and new practices, to help managers and scientists alike improve our understanding of river processes, and to inform our efforts to better steward and restore our fluvial resources for more harmonious coexistence of humans with their fluvial environment.

G. Mathias Kondolf,
University of California, Berkeley

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University of Lyon, CNRS
Preface

This book was borne out of the clear need for a comprehensive resource for developing stream and watershed restoration programs at regional (provincial), watershed, reach, and project scales. Many restoration efforts have failed to meet their objectives because they have not adequately addressed the root cause of habitat degradation, or because they do not recognize the role that watershed and riverine processes play in determining the outcome of restoration actions. Over our many years of experience in watershed research, we have repeatedly seen the need for a systematic process-based approach to planning, prioritizing, designing, and evaluating habitat restoration programs and projects. In the chapters that follow, we strive to meet this need. This book is a synthesis of our previous efforts on restoration that have been published as manuscripts, books, and technical reports, as well as our experience teaching practitioners and students in workshops and university courses. We focus primarily on restoration of physical processes and habitat and draw heavily from our experiences in North America and Europe, the continents where considerable habitat restoration and research has occurred. However, the principles and methods covered in this volume are applicable to stream, river, and watershed restoration anywhere in the world and useful for programs that focus on improving degraded water quality and reducing contaminants.

This book is intended as a guide for practitioners, an instructional manual for educators and students, and a general reference for those interested or active in the field of aquatic and restoration ecology. It is organized in a stepwise fashion covering the key aspects of aquatic restoration including: assessing watershed and riverine processes and conditions; identifying restoration opportunities; choosing appropriate restoration techniques; prioritizing restoration actions; and monitoring and implementation. For the educator and student, it is set up so that each chapter can be covered as a section of a course on stream and watershed restoration. Ideally, an instructor will use our text along with data from a local watershed to create realistic and relevant assignments and exercises for the students. For those new to restoration, we recommend reading through most of the chapters in the order presented before embarking on a project. For the experienced restoration practitioner or those with a general interest in the topic, we recommend reading the introduction and watershed processes chapters (1 and 2) and then the remaining chapters in the order that most suits your needs and interests.

This book would not have been possible without the assistance of numerous individuals and organizations. First, our employer the Northwest Fisheries Science Center and current and former supervisors John Ferguson, Tracy Collier, and Doug Dey deserve special thanks for allowing us to pursue and work on this project. We would also like to thank all those who assisted us by reviewing chapters including: Peter Kiffney, John Klochak, Keith Hendry, Mason Bryant, Tom O’Brien, Matt Hudson, Jennifer Steger, Lauren Senkry, Erik Michelson, Martin O’Grady, Sarah Miller, Chris James, Robin Jenkinson, Pauliina Louhi, Ray White, Martin Janes, Jenny Mant, Mary Raines, and Dana Warren. Karrie Hanson, Ed Quimby, Bert Tarrant and JoAnne Butzerin provided much-needed assistance with technical editing. We thank Su Kim, Clemens Trautwein and Hiroo Imaki for assistance in developing figures and numerous individuals for providing photos of restoration used in one or more chapters. Finally, we would like to thank all those who have and continue to dedicate their lives to environmental restoration. We hope that this book will serve you well in your challenge to protect and restore streams, rivers, and watersheds.

Philip Roni and Tim Beechie
June 2012
Introduction to Restoration: Key Steps for Designing Effective Programs and Projects

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1.1 Introduction

The restoration of streams, rivers, and watersheds has become a growth industry in North America and Europe in the 21st century, with an estimated $1 billion spent annually in the United States alone (Bernhardt et al. 2005). This comes with a growing appreciation from the general public of the importance of water, watersheds, and natural places not only for their wildlife and fisheries, but also for social, cultural, economic, and spiritual reasons. With this increased emphasis on restoration has come the need for new techniques and guidance for assessing stream and watershed conditions, identifying factors degrading aquatic habitats, selecting appropriate restoration actions, and monitoring and evaluating restoration actions at appropriate scales. All these require detailed consideration of not only the latest scientific information but also regulations and socioeconomic constraints at local, regional, and national levels. Thus the challenges facing watershed restoration in the 21st century are multifaceted, including both technical and non-technical issues.

As interest in aquatic restoration has increased, several texts have been produced over the last few decades to assist with various aspects of river restoration. Most have focused on habitat improvement techniques specific to trout and salmon (e.g. Hunter 1991; Mills 1991; Hunt 1993; O’Grady 2006) or design considerations for specific techniques (e.g. Brookes & Shields 1996; Slaney & Zoldakis 1997; RRC 2002). A few have provided more comprehensive regional overviews of riverine restoration planning and techniques (Ward et al. 1994 in UK; Cowx & Welcomme 1998 in Europe; FISRWG 1998 in USA; CIRF 2006 in Italy). Still others have published overviews of key concepts and principles (e.g. Brierley & Fryirs 2008; Clewell & Aronson 2008). Collectively these publications cover many of the tools, techniques, and concepts needed for restoration planning, but no single book covers the full restoration process from initial assessment to monitoring of results and adaptive management. In this book, we strive to meet the need for a comprehensive guide and educational tool that covers the key steps in this process and provide a text that links watershed assessment and problem identification to identification of appropriate restoration measures, project selection, prioritization, project implementation, and effectiveness monitoring (Figure 1.1). Each of these steps is discussed in detail in subsequent chapters. In addition, we discuss the human dimension and how one can best work with citizens, government bodies, and private companies to develop restoration projects and goals. In this introductory
chapter we provide important background on the need for restoration, its relatively short history, and the major steps and considerations for planning and implementing restoration actions.

1.2 What is restoration?

Restoration ecology is a relatively young field with considerable confusion over its terminology (Buijs et al. 2002; Omerod 2004; Young et al. 2005). The terms restoration, rehabilitation, enhancement, improvement, mitigation, reclamation, full and partial restoration, and others have been used to describe various activities meant to restore ecological processes or improve aquatic habitats (Table 1.1). These represent a gradient of activities from creating new habitats, to mitigating for lost habitat, to full restoration of ecosystem processes and functions and even protection. In practice, the term restoration is used to refer to any of the above activities. To avoid further confusion over terminology, we therefore use the term in this sense throughout this text. Where appropriate, we distinguish between full restoration, partial restoration and habitat improvement or creation (Table 1.1).

We focus most of our discussion on ‘active restoration,’ which are restoration efforts that take on the ground action to restore or improve conditions. However, regulations, laws, land-use practices, and other forms of ‘passive restoration’ that eliminate or prevent human disturbance or impacts to allow recovery of the environment are equally important. For example, most of the improvements in water quality and habitat condition in the USA, Europe, and elsewhere would not have occurred without legislation and regulation. Similarly, habitat protection, while not typically included in definitions of restoration, is a critical watershed conservation and restoration strategy that should not be overlooked. Given the continued pressure on aquatic ecosystems, including a growing human population and climate change, habitat loss will continue and even outpace restoration efforts unless protection of high-quality functioning habitats is a high-priority component of restoration plans. In fact, habitat protection in many cases is a type of passive restoration that allows ecosystems to recover following disturbance. Ultimately, it is much more cost-effective to protect functioning habitats from degradation than it is to try to restore them once they have been damaged.
**1.3 Why is restoration needed?**

It may seem obvious to people living in densely populated and developed areas why one might seek to restore streams or watersheds, but the level of human impact and the reasons for restoration vary widely among stream reaches, watersheds, regions, and countries. Human impacts to watersheds began well before recorded history. Archeological evidence indicates that localized deforestation and subsequent impacts to watersheds occurred in populated areas throughout the world even prior to 1000 BC (Williams 2001). For example, forest removal or conversion to agricultural lands occurred in the Mesolithic and Neolithic periods (c. 9000–3000 BC) in parts of Greece and Britain (van Andel et al. 1990; Brown 2002). Deforestation expanded during both the Bronze and Iron Age (c. 3000 BC to 500 AD) when metal tools replaced stone tools and made clearing of forests and plowing of lands easier. Extensive hillslope erosion and subsequent sedimentation and aggradation of river valleys in Greece and other areas in the eastern Mediterranean is attributed to deforestation and intensive agriculture during the Bronze Age (van Andel et al. 1990; Montgomery 2007). This was followed by diversion of rivers, draining wetlands, and harnessing waterpower in some areas of Europe and the Mediterranean with the rise of the Roman Empire (Cowx & Welcomme 1998). Deforestation, which often leads to increased silt loads, expanded rapidly during the Middle Ages not only in Europe but also in China and elsewhere, resulting in filling of coastal and low-lying areas and presumably other impacts to streams. During medieval times and through the Renaissance (c. 1000 to 1700 AD), extensive deforestation and conversion of lands to agriculture in Europe and the Mediterranean were common (Cowx & Welcomme 1998; Williams 2001). This occurred somewhat later in the New World and elsewhere following European colonization. More dramatic changes to rivers and watersheds occurred during the Industrial Revolution, as construction of dams and weirs to power industry and rapid industrialization caused the pollution of many waters. In parts of Europe, the mass production of drainage tiles and other technologies led to the drainage and conversion of vast wetlands to agricultural land (Vought & Lacoursière 2006). Increasing urban and agricultural activities resulted in some local

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**Table 1.1** Commonly used restoration terminology and general definitions. In this book and in practice, the term restoration is used to encompass all these activities with the exception of protection and mitigation. Where appropriate, we distinguish between restoration in its strictest sense (full restoration), rehabilitation (partial restoration), and habitat improvement or creation. Modified from Roni (2005), Roni et al. (2005), and Beechie et al. (2010).

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>Creating laws or other mechanisms to safeguard and protect areas of intact habitat from degradation.</td>
</tr>
<tr>
<td>Restoration</td>
<td>Returning an aquatic system or habitat to its original, undisturbed state. This is sometimes called ‘full restoration,’ and can be further divided into passive (removal of human disturbance to allow recovery) and active restoration (active manipulations to restore processes or conditions).</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>Restoring or improving some aspects of an ecosystem but not fully restoring all components. It is also called ‘partial restoration’ and may also be used as a general term for a variety of restoration and improvement activities.</td>
</tr>
<tr>
<td>Improvement</td>
<td>Improving the quality of a habitat through direct manipulation (e.g. placement of instream structures, addition of nutrients). Sometimes referred to as habitat enhancement and sometimes also considered as ‘partial restoration’ or rehabilitation.</td>
</tr>
<tr>
<td>Reclamation</td>
<td>Returning an area to its previous habitat type but not necessarily fully restoring all functions (e.g. removal of fill to expose historic estuary, removal of a levee to allow river to periodically inundate a historic wetland). Sometimes referred to as compensation.</td>
</tr>
<tr>
<td>Creation</td>
<td>Constructing a new habitat or ecosystem where it did not previously exist (e.g. creating new estuarine habitat, or excavating an off-channel pond). This is often part of mitigation activities.</td>
</tr>
<tr>
<td>Mitigation</td>
<td>Taking action to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (e.g. creating of new habitats to replace those lost by a land development).</td>
</tr>
</tbody>
</table>
channelization of rivers and streams. The combination of migration barriers (dams) and pollution due to industry and the rapidly growing human population led to the decline of several migratory fishes in Europe and eastern North America.

The most severe impacts to aquatic systems in North America, Europe and elsewhere arguably occurred in the late 19th and during the 20th century. Increasingly mechanized societies channelized and dredged rivers, drained wetlands, cut down entire forests, intensified agriculture, and built dams for power, irrigation, and flood control. In the UK, Ireland, Europe, the USA, and elsewhere, large river channelization and wetland drainage programs occurred from the early part of the 20th century up until the 1970s (Cowx & Welcomme 1998; O’Grady 2006). This history of land and water uses along with other human activities produced the degraded conditions we see on the landscape today. For example, it is estimated that worldwide over 50% of wetlands may have been lost (Goudie 2006). Coastal wetland loss in some US states and Europe countries exceed 80% (Dahl & Allard 1999; Airoldi & Beck 2007). Estimates suggest that globally more than 75% of riverine habitats are degraded (Benke 1990; Dynesius & Nilsson 1994; Muhar et al. 2000; Vörösmarty et al. 2010).

The above factors, coupled with an increasing human population, have led to increased air pollution, highly modified and polluted rivers, and a rapid increase in number of threatened, endangered, or extinct species (Figure 1.2; Goudie 2006). The World Water Council estimates that more than half the world’s rivers are polluted or at risk of running dry, and less than 20% of the world’s freshwaters are considered pristine (World Water Council 2000; UN Water 2009). Moreover, 80% of human water supplies are threatened by watershed disturbance, pollution, water resource development or other factors (Vörösmarty et al. 2010). As recently as 2004, 44% of the stream miles in the USA were considered too polluted to support fishing or swimming (EPA 2009). Current species extinction rates are estimated to be more than 100–1000 times background (prehistoric) rates (Baillie et al. 2004), and some studies suggest that modern rates are more than 25,000 times background rates (Wilson 1992). Extinction rates for freshwater fauna are thought to be 4–5 times that of terrestrial species (Ricciardi & Rasmussen 1999), and habitat loss and degradation are believed to be the primary cause of extinctions (Baillie et al. 2004). A suite of human activities has led to degradation of streams and watersheds and impaired their use for biota (including humans), and therefore stream and watershed restoration has become critically important worldwide.

1.4 History of the environmental movement

The rapid modification of our natural environment was recognized centuries ago. Limited protection of forests for hunting and timber production occurred in the ancient times, middle ages (c. 500–1500 AD), and the early modern period (c. 1500–1800 AD). Ancient empires such as Assyria, Babylon, and Persia set aside hunting reserves and the Roman Empire set up a system of protected areas for wildlife (Brockington et al. 2008). The Emperor Hadrian set half of Mount Lebanon aside in the 2nd century AD to protect cedar forests (Brockington et al. 2008). As early as the 11th century in Scotland and 13th century in England, laws and fishing seasons were set to protect salmon (Montgomery 2003). The late 1800s saw the establishment of some of the first national parks such as Yellowstone National Park in the USA, Rocky Mountain National Park in Canada, and Royal National Park in Australia. During the same period, the Audubon Society, the Sierra Club, the Wilderness Society in America, and the Royal Society for Protection of Birds in the UK were formed and began pushing for greater protection of wild lands and wildlife.
The modern environmental movement began in the 1960s, initially focusing on water and air quality issues. In the USA, key publications on increasing environmental problems such as Rachel Carson’s Silent Spring (Carson 1962) and a series of environmental disasters led to a large environmental movement and a series of laws to protect the environment in the 1960s and 1970s. These laws included the Wilderness Act (1964), the National Environmental Policy Act (1969), the Clean Air Act (1970), the Water Pollution Control Act (1972), and the Endangered Species Act (1973). Similar legislation was passed in the 1970s, 1980s, and 1990s in other industrialized countries (e.g. German Federal Nature Conservation Act 1976, Swiss Environmental Protection Law 1983, Canadian Fisheries Act 1985, Canadian Water Act 1985, Japanese Act on Conservation of Endangered Species of Wild Fauna and Flora 1992, Australian Endangered Species Protection Act 1992). In 2000, the European Union (EU) passed the Water Framework Directive (WFD), arguably the most sweeping legislation for the protection and restoration of watersheds and aquatic biota. The WFD combined with other EU Directives for the conservation of nature and biodiversity such as the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC) provide a legal basis to implement comprehensive, interdisciplinary basin-wide restoration programs.

Another key environmental aspect is the importance and economic value of ecosystem goods and services. Until recently the value of ecosystems was only based on the goods they might produce (e.g. harvestable fish, food, timber), but in recent years the services or benefits we derive directly or indirectly from ecosystem functions have also been recognized. These other services include waste processing, carbon sequestering, regulation of atmospheric gases, water regulation, climate regulation, genetic resources, and many others (Costanza et al. 1997; Cunningham 2002). In fact, the economic value of ecosystem services globally has been estimated to be 2–3 times that of the total global gross domestic product from world economies (Costanza et al. 1997). This realization of the importance of functioning ecosystems for our economic prosperity and our very existence has led to further emphasis on protecting and restoring natural ecosystems globally.

1.5 History of stream and watershed restoration

Similar to the environmental movement, the earliest stream restoration efforts were largely undertaken by hunters and fishermen. While efforts to minimize erosion and protect water supplies and agricultural land date back thousands of years (Riley 1998), the first substantial efforts to restore streams are thought to have been made in the late 1800s by local fishing clubs in the USA and river keepers on British estates interested in improving salmon or trout fishing (Thompson & Stull 2002; White 2002). As early as 1885, Van Cleef called for the restoration and protection of trout streams in the Eastern USA (Van Cleef 1885). There is also evidence of early restoration efforts in Germany and Norway (Walter 1912; Thompson & Stull 2002). These early efforts often included stocking of fish and killing of predatory birds, fish and mammals, actions that today would be frowned upon (White 2002).

More formalized efforts to restore streams were undertaken in the USA in the early part of the 20th century (Thompson & Stull 2002). The Civilian Conservation Corps and some smaller state-sponsored stream and land restoration programs began implementing restoration projects on miles of small streams in the Midwest, Rocky Mountains and elsewhere during the Great Depression, partly to combat soil and bank erosion. These efforts tended to focus on planting trees, fencing out livestock, bank protection and stabilization, installing small log structures or weirs to create pools, and even excavation of pools. The latter three techniques were largely engineering approaches attempting to create pool habitat or a static stream channel, and often treated symptoms (lack of pools) rather than underlying problems (e.g. excess sediment, lack of riparian vegetation and woody debris) (White 1996; Riley 1998). It is however important to remember that, during this period, streams were highly degraded from decades of severe overgrazing and removal of streamside vegetation and it was not yet fully understood how quickly riparian banks and vegetation might recover once they were protected (White 2002). The 1940s and 1950s witnessed an increased emphasis on planting of vegetation to stabilize banks; however, these efforts were often not viewed as favorably as instream structures and hardening of banks, which were seen as quicker and more permanent (White 1996). Both before and after World War II in Europe there were efforts to stabilize banks using plantings and bioengineering approaches, but again these were largely to create static channels and prevent streams from moving.

Expansion of state and federal stream restoration programs in the USA continued from the 1950s through the 1980s. Following years of overgrazing and other human activities, riparian vegetation began to recover along
numerous streams in the USA and Canada (White 2002). During this period, there was also an increased focus on placement of log and boulder cover structures, based largely on promising results from trout stream restoration in Wisconsin and Michigan. However, these structural techniques were largely pioneered in low-energy Eastern and Midwestern streams and met with mixed results when applied elsewhere, particularly in high-gradient higher-energy streams of the mountainous western North America. Several of these techniques were subsequently applied in European streams in the 1980s and 1990s with varying degrees of success. Despite the emphasis on structural treatments, the key stream restoration manual (White & Brynildson 1967) recommended protecting riparian vegetation before installing instream structures. Unfortunately, this sage advice was largely ignored until recently when the importance of watershed processes became more widely accepted (Chovanec et al. 2000; Hillman & Brierely 2005; Beechie et al. 2010). Fortunately, as early as the 1960s some states were acquiring land along streams to let riparian vegetation and streams recover naturally. There was also an increasing understanding of riverine processes – partly based on Leopold et al. (1964) – which biologists were attempting to incorporate into stream restoration projects.

The late 1980s and early 1990s saw rising awareness in the importance of riparian areas, the physical and ecological importance of large wood, and a better understanding of physical and biological processes and how land use and human activities impact those processes and fish habitat (White 2002). This was initially based on extensive studies on forested streams in the Pacific Northwest of North America, but was later based on studies in a range of land uses and ecoregions. The results of these studies led to recommendations for a watershed or ecosystem approach to management and a growing call for looking beyond an individual stream reach when planning restoration (Beechie & Bolton 1999; Roni et al. 2002; Hillman & Brierely 2005). From the 1990s until today, restoration efforts have slowly been changing from a focus on localized habitat improvement actions at a site or reach scale (which often overlooked the root causes of habitat degradation) to a more holistic watershed or ecosystem approach which tries to treat the underlying problem that has led to the habitat degradation (to be discussed in great detail in the following chapters). This is not to say that certain habitat improvement techniques are not widely used or are ineffective, but rather that greater emphasis has been placed on restoring whole watersheds through improving land use, reducing sediment sources, protecting riparian areas, and other restoration efforts focused on restoring the processes that create and maintain stream habitats and health.

European river restoration efforts largely began in the 1980s and increased dramatically during the 1990s (Cowx & Welcomme 1998), focusing mostly on rehabilitation of channelized, straightened and engineered channels and floodplains. In fact, the science of floodplain restoration and remanering of rivers was largely developed in Europe, and much of the literature on this topic comes from European case studies (e.g. Brookes 1992, 1996; Iversen et al. 1993). With the exception of some early erosion reduction efforts to reduce declining production of agricultural lands in the 1970s, restoration efforts in Australia and New Zealand and other developed countries also began in the 1980s and 1990s (Gippel & Collier 1998).

The number and scale of watershed restoration efforts, along with spending on restoration, has increased rapidly in the last few decades in North America, Europe, Australia, and elsewhere. This has been partly driven by increasing environmental awareness, stronger environmental regulations, and declines in species of fish and aquatic organisms that are of high socioeconomic and cultural value. As discussed in the Section 1.4, legal mechanisms have been developed to restore water quality, individual species, and riverine ecosystems in developed countries. Perhaps the most commonly recognized legal mandates are those requiring protection or restoration of specific species under national laws such as the Endangered Species Act in the USA, the Canadian Species at Risk Act, or the European Red List. These legislative actions are generally reactive and drive attempts to restore habitats for listed species. While the legislation behind these lists generally calls for conservation and restoration of the ecosystems upon which these species depend, restoration actions are commonly focused on restoring specific habitats deemed important for one species or another. In the USA and Canada, for example, massive efforts to restore watersheds in the Pacific Northwest of North America are almost exclusively focused on recovering threatened and endangered salmon and trout populations (Katz et al. 2007), although restoration actions such as sediment reduction and riparian restoration also benefit other species. Beyond endangered species concerns, many nations have also passed legislation aimed at more holistic attempts to restore riverine ecosystems (e.g. the Clean Water Act in the USA or the Water Framework Directive in the EU) which seek to improve more broadly defined hydromorphological, chemical, and biological conditions of rivers.
In conjunction with changing drivers of restoration and an increasingly holistic approach to restoring watersheds, the expertise needed to plan and implement projects has also evolved. Early restoration efforts were often initiated by outdoorsmen or fisheries biologists and later by engineers, and focused on structural treatments or bank stabilization. The greater emphasis on watershed processes in the USA and Europe has also led to improved design of more traditional habitat improvement techniques and greater emphasis on addressing root causes of degradation. Given that streams integrate both terrestrial and aquatic processes at multiple scales, the practice of restoring processes or improving habitats of an aquatic ecosystem requires an interdisciplinary approach to be successful. This often requires the collaboration of those with expertise in fish and aquatic biology, riparian and stream ecology, geology, hydrology and water management, geomorphology, landscape architecture, and even public policy, economics, and other social sciences. That is not to say that all projects will require expertise in all these fields, but most will benefit from an interdisciplinary team; this will certainly be essential for large or comprehensive restoration projects or programs to achieve their goals. Another aim of this book is therefore to provide a common basis and level of knowledge for individuals from various backgrounds to work together on developing and implementing successful restoration programs.

1.6 Key steps for planning and implementing restoration

Despite large financial investments in what has recently been called the ‘restoration economy’ (Cunningham 2002) and increasing literature on restoration planning, numerous watershed councils, river trusts, agencies, and other restoration practitioners do not follow a systematic approach for planning restoration projects throughout a watershed or basin. As a result, a number of restoration efforts fail or fall short of their objectives. Some of the most common problems or reasons for failure of a restoration program or project include:

- not addressing the root cause of habitat or water quality degradation;
- not recognizing upstream processes or downstream barriers to connectivity;
- inappropriate uses of common techniques (one size fits all);
- an inconsistent (or complete lack of an) approach for sequencing or prioritizing projects;
- poor or improper project design;
- failure to get adequate support from public and private organizations; and
- inadequate monitoring to determine project effectiveness.

These challenges and problems can be overcome by systematically following several logical steps that are critical to developing a successful restoration program or project (Figure 1.1). This book is designed to cover these steps in detail to assist with improving the design and evaluation of stream and watershed restoration plans and projects. We begin with a discussion of watershed processes and process-based restoration (Chapter 2), as these basic concepts underlie the restoration steps in subsequent chapters. The following chapters then explain the key steps, including: assessing watershed conditions and identifying restoration needs (Chapter 3); selecting appropriate restoration actions to address restoration needs (Chapter 5); identifying a prioritization strategy for prioritizing actions (Chapter 6); planning and implementing projects (Chapter 7); and developing a monitoring and evaluation program (Chapter 8). Goals and objectives need to be set at multiple stages of the restoration process, and there are multiple steps within each stage which we will discuss within each chapter. In addition, the human and socioeconomic aspects need to be considered throughout the planning and design process (Chapter 4). We close with a discussion of how to synthesize all these pieces to develop restoration plans and proposals (Chapter 9).

Throughout this book we emphasize the concept of process-based restoration (Chapter 2), which aims to address root causes of habitat and ecosystem degradation (Sear 1994; Roní et al. 2002; Beechie et al. 2010). Our purpose in doing so is to help guide river and watershed restoration efforts toward actions that will have long-lasting positive effects on riverine ecosystems and to ensure that, when habitat improvement is undertaken, the site potential and watershed processes are considered. We also emphasize the importance of recognizing socioeconomic and political considerations such as involving landowners and other stakeholders, permit and land-use issues, and education and outreach to the general public to build continued support for restoration (Chapter 4). Failure to consider these factors and involve stakeholders early on can prevent even the most worthwhile and feasible projects from being implemented. The following chapters go into detail on each of the steps for planning...
and implementing successful stream and watershed restoration programs and projects.

### 1.7 References


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Watershed Processes, Human Impacts, and Process-based Restoration

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2.1 Introduction

Effective planning, design, and implementation of river restoration efforts each require an understanding of how watershed processes drive the structure and functions of riverine ecosystems, as well as how those processes support a wide variety of ecosystem services. In this book, the term ‘watershed process’ generally refers to movements of landscape or ecosystem components into and through river systems, which are typically measured as rates (Beechie & Bolton 1999). For example, erosion is a process that moves sediment from hillslopes to river channels, while sediment transport processes move sediment through stream and river channels to deltas and estuaries. Erosion is measured in units of mass/area/time, whereas sediment transport is commonly measured in units of mass/time. We do not restrict the term ‘processes’ to geomorphological or hydrological processes, but instead refer to a wide range of processes including erosion and sediment transport, storage and routing of water, plant growth and successional processes, delivery of nutrients and organic matter, inputs of thermal energy, trophic interactions, species interactions, and population dynamics. Understanding these processes and relationships between them is critical to the success of river restoration programs.

These driving processes influence states and dynamics of biological communities through a sequence of cause–effect linkages that connect watershed processes to habitat conditions, and habitat conditions to biota (Figure 2.1). ‘Habitat conditions’ here refers to physical, chemical, and thermal features of the river environment and ‘biota’ refers to ecological systems and functions that respond to habitat features. Humans alter watershed processes in many ways, leading to changes in habitat conditions, food webs, and biological communities (Allan 2004). Process-based restoration focuses on correcting anthropogenic disruptions to driving processes, thereby leading to recovery of habitats and biota (Sear 1994; Beechie & Bolton 1999). Restoration of critical processes also confers added resilience to river–floodplain ecosystems, as functioning processes allow the system to respond to future disturbances through natural physical and biological adjustments (Brierley et al. 2002; Beechie et al. 2010). While restoration of processes and habitats is critical to ecosystem recovery, correcting ecosystem degradation that results from lack of key species, introduction of non-native species, or poor water quality is also critical to ecosystem recovery (Karr 2006). Because these factors...
must also often be addressed to achieve restoration goals, we briefly address restoration of other ecosystem alterations and describe a comprehensive set of both processes and ecosystem features that may be important in restoring river ecosystems.

In this chapter we first describe the hierarchical suite of processes that drive riverine ecosystems. We identify and describe the main processes driving riverine habitat dynamics and biota, focusing on processes that are commonly targeted by stream and watershed restoration activities. We also describe how watershed and reach-scale processes drive the expression and dynamics of habitat types in each reach of a river network, and illustrate how habitat conditions control expression and dynamics of biological communities. Throughout, our main purpose is to illustrate how these processes are hierarchically nested, and to show that higher-level controls set limits on the expression of habitat features or ecosystem attributes as influenced by lower-level controls (e.g. Beechie et al. 2010). We then describe the landscape setting, and proceed to watershed-scale processes, reach-scale processes, habitat dynamics, and instream biological processes. We also briefly describe ways in which watershed processes may be altered, thereby affecting the productivity, resilience, and functions of river ecosystems. Alterations to processes are further discussed in the chapter on watershed assessments (Chapter 3), and restoration actions that restore processes are discussed in Chapter 5. Finally, we describe process-based restoration (which is a central theme of river and watershed restoration in this book) and we present four process-based principles to help guide restoration planning and implementation.