1 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

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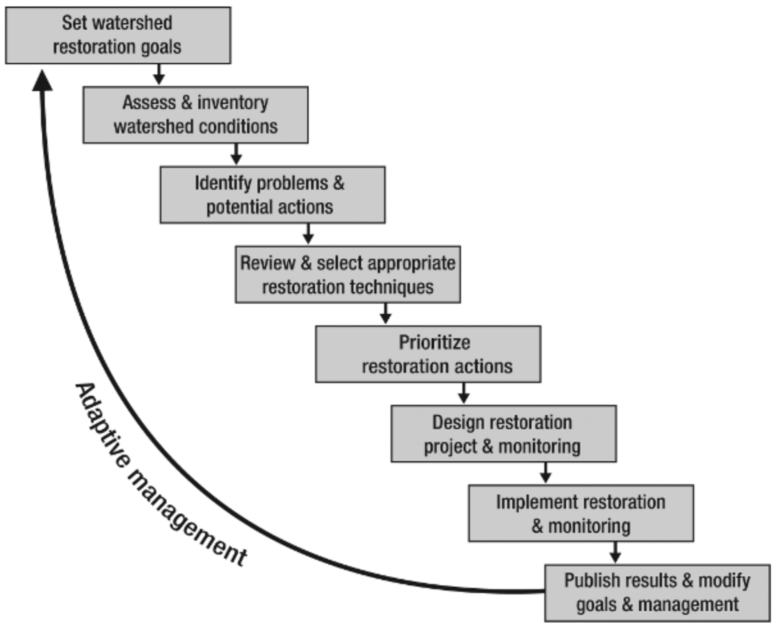

Figure 1.1 Major steps in the restoration process required to develop a comprehensive restoration program and well-designed restoration projects.

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 (Buijse *et al.* 2002; Omerod 2004; Young *et al.* 2005). The terms restoration, rehabilitation, enhancement, improvement, mitigation, reclamation, full and partial restoration, passive and active 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.

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).

Term	Definition
Protection	Creating laws or other mechanisms to safeguard and protect areas of intact habitat from degradation.
Restoration	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).
Rehabilitation	Restoring or improving some aspects or 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.
Improvement	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.
Reclamation	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.
Creation	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.
Mitigation	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).

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 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 & Allord 1999; Airoldi & Beck 2007). Estimates suggest that globally more than 75% of riverine habitats are degraded (Benke 1990; Dynesius & Nelsson 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.

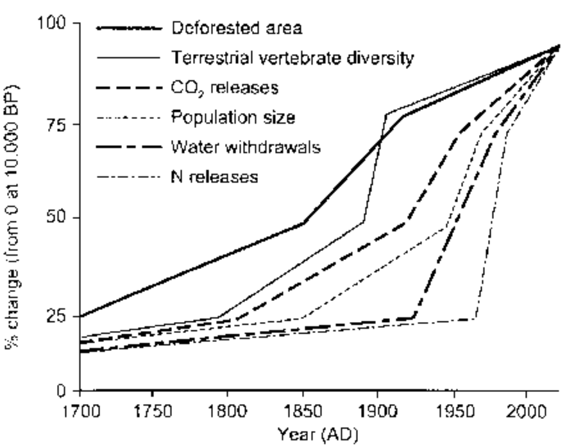

Figure 1.2 Increase in selected human impacts during the last 300 years (percent increased compared to 10,000 BP). From Goudie (2006). Reproduced by permission of John Wiley & Sons.

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). However, large-scale environmental movements did not start until the late 19th and early 20th century in the UK, Europe, the USA, Australia, New Zealand and elsewhere (Hutton & Connors 1999). 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 higher-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 remeandering 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 emphases 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; Roni *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.

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