# DAM REMOVAL RESEARCH

## Status and Prospects

William L. Graf, editor

THE HEINZ CENTER

THE H. JOHN HEINZ III CENTER FOR
SCIENCE, ECONOMICS AND THE ENVIRONMENT

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Proceedings of
The Heinz Center's Dam Removal
Research Workshop

October 23–24, 2002

THE
HEINZ
CENTER

THE H. JOHN HEINZ III CENTER FOR
SCIENCE, ECONOMICS AND THE ENVIRONMENT

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## About *Dam Removal Research: Status and Prospects*

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**Cover photo:** Rindge Dam on Malibu Creek in California. Photo by Sarah Baish.

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# PREFACE

IN LATE 1999 The H. John Heinz III Center for Science, Economics and the Environment undertook an ambitious project to identify the outcomes that could result from the removal of dams and to connect scientific research to the process of decision making for small dam removal. With financial support from The Heinz Center, the Federal Emergency Management Agency (FEMA), and the Electric Power Research Institute (EPRI), the Center convened a panel that included experts from academia, government, business, and nongovernmental environmental organizations to a two-year study of dam removal issues. The Center's report, *Dam Removal: Science and Decision Making*, published by the Heinz Center in 2002, outlines the results of the panel's work. It has become widely recognized as a summary of the outcomes of small dam removal and a guide to how to measure those outcomes and how to blend science into a decision-making process when dam removal becomes a realistic option for dam owners, administrators, and the public.

The original Heinz Center panel pointed out that although the science to support decisions for dam retention or removal was progressing, little cross-disciplinary communication is evident, and research priorities have not been established to guide researchers or funding efforts. The panel therefore recommended that sponsors support a technical conference or workshop to bring together a variety of researchers working on the scientific aspects of dam removal with the specific objectives of improving communication across disciplinary boundaries. This workshop was not intended to be a forum for debating whether dams should be removed; rather, it was to concentrate on science and the state of knowledge available for decision makers.

Acting on this recommendation, The Heinz Center organized the Dam Removal Research Workshop, held October 23–24, 2002, at the Airlie Conference Center in Warrenton, Virginia. Funding for the workshop was provided by The Heinz Center and FEMA. More than 30 invited specialists, ranging from physical scientists and social scientists to decision makers and managers, made formal presentations, conducted special panels, and discussed dam removal issues. The guiding questions for this workshop were: What do we not know? What sorts of scientific knowledge do we have to support management decisions, and what is our level of confidence in that knowledge? What do we know? What are the gaps in the scientific knowledge that researchers need to address to support wise decisions, and what are research crossovers between disciplines?

This proceedings is a record of the presentations and discussions at the workshop. It does not make recommendations on the future directions of dam removal, nor is it a consensus on these issues. The significance of the Workshop on Dam Removal Research is that it brought together researchers who are looking at a new issue in environmental management. Although other efforts have been made to bring together stakeholders for discussions about the political processes involved in river management related to dams (e.g., the Aspen Institute dialogues on dam removal), and although there is now an extensive literature on the effects of dam installation and operation, the exact environmental, economic, and social impacts of dam removal are not yet well known.

The workshop was specifically designed to avoid taking any particular positions on whether dams should be removed generally, and it did not address the advisability of removing any individual structures. Those questions, which are political in nature are the purview of local and regional communities. Indeed, the purpose of the workshop was to make these decisions better informed, not to steer the ultimate choice of a course of action. Many participants in the workshop had very definite opinions on these matters, but for these two days these positions were put aside as participants searched for a common knowledge base.

The summary of the papers and discussion at the workshop that follows highlights some commonalities among the presentations and discussions by identifying underlying disconnections in research as well as some overarching connecting themes.

William L. Graf
*Chair*
*Workshop Steering Committee*

# Summary and Perspective

William L. Graf
*Department of Geography, University of South Carolina*

Rivers have played a major role in the economic development of the United States and have served as cornerstones of the nation's natural environment. The dams placed on all of America's major rivers and on most of its minor ones have helped to suppress floods and have provided water for agricultural and urban uses, hydroelectric power, navigation, recreation, and wildlife management. By the end of the 20th century, there were more than 80,000 dams in the United States 6 feet or higher, according to the U.S. National Inventory of Dams (http://crunch.tec. army.mil/nid/webpages/nid.cfm), many of which were generating major social and economic benefits. But as many as 2 million dams may actually dot the United States (Graf, 1993).

In the late 20th century, unforeseen changes and costs associated with dams began to become apparent. They included the desiccation of river channels, loss of aquatic and riparian habitat, and significant reductions in native species, particularly of fish. More than half of all the animals and plants on the endangered species list owed their precarious positions to water control structures (Losos et al., 1995). Then, for the first time in American history, dam owners, public officials, and citizens began to consider seriously removing many dams because they were aging and required a serious investment to keep them in good repair. But, despite the availability of a well-developed knowledge base for building dams, policymakers knew little about the effects of their installation and even less about the effects of their removal.

## RESEARCH ON DAM REMOVAL: AN OVERVIEW

Almost all of the formal presentations made at this workshop appear in this book. This section describes briefly the subject of each contribution, and, taken as group, these reviews provide a broad overview of the entire workshop. Presenters were asked to examine specific issues raised during the development of the Heinz Center report on small dam removal, thereby helping to focus additional research and coordination.

**General Views.** At the outset, William W. Stelle addressed the connection between scientists and decision makers, while injecting a healthy dose of reality based on his experiences in federal agencies (see Chapter 1). According to Stelle, scientists do not tell decision makers what they should do. Decision makers decide what they want to do, and scientific information may help to inform their choices. Scientists can be most effective when they have a clear understanding of the end uses of their work.

**Inventory of Removed Dams.** Molly Marie Pohl reviewed her experiences in trying to assemble a database that accounts for those dams already removed (see Chapter 2). The initial Heinz Center report, *Dam Removal: Science and Decision Making* (Heinz Center, 2002), recommended creation of a national inventory of removed dams as a mechanism for sharing information and experiences, and Pohl's work in this area illustrated the potential for success and barriers to creation of such a database. Her experience shows that such an accounting is possible; quality data are available for about 416 structures. However, because of incomplete recordkeeping, a complete inventory of removed structures might not be possible.

**Social Perspectives on Dam Removal.** Helen Sarakinos contributed observations about the social dimensions of dam removal, a subject identified in the original Heinz Center report as requiring additional immediate attention by the research community involved in dam removals (see Chapter 3). Dam owners naturally play an important role in the decision-making process, but 20–30 percent of dams in Wisconsin are orphans, without identifiable owners. Each owner operates in a self-defined social context that influences the decision about whether to repair aging structures. The public also is a major factor in the decision-making process, but the public is highly diverse and subject to an amazingly long list of misconceptions about rivers and dams. Sarakinos demonstrated that additional social science research is needed, particularly on how people make decisions, how common community values develop, and how information is disseminated throughout a community.

**Economic Aspects of Dam Removal.** The original Heinz Center report highlighted the absence of sound economic information on dam removal, and Brian Graber explored this issue further from his standpoint as a consultant in watershed restoration in Wisconsin (see Chapter 4). His data showed that removal of aging dams is often cheaper than repair, but that assessing costs and benefits is a wide-ranging exercise that is still not perfected. Decision makers need to better understand the long-term effects of dam removal on businesses, individuals, and communities and the effects of dam removal on property values for landowners near reservoirs and rivers. They also need to know more about the changes in property values associated with past dam removals.

**Ecological Effects of Dam Removal.** David D. Hart reviewed the effects that dam removal might have on various physical, chemical, and biological characteristics of stream and river ecosystems (see Chapter 5). He connected his review to two observations in the Heinz Center's initial report: (1) the need for measurable indicator parameters for decision makers, and (2) the need for follow-up monitoring after any dam removal. Using the removal of a low-head, run-of-river structure on Pennsylvania's Manatawny Creek, he illustrated the importance of measurable indicator parameters for monitoring ecosystem response to dam removal. For example, individuals of some fish species rapidly moved into the former impoundment after dam removal, whereas a short-term reduction in the abundance of some species occurred in the downstream reaches in an apparent response to increased sediment transport and channel aggradation. Hart also pointed out that although most of the dams undergoing removal are small, few researchers have looked at the ecological effects of existing small dams—a knowledge gap that hinders their ability to predict responses to small dam removal.

Timothy J. Randle reviewed ongoing investigations in Washington's Elwha River, where two dams are slated for removal (see Chapter 6). His report on the expected mobility and fate of sediments presently stored in reservoirs behind the dams revealed the complexity of sediment systems in large watersheds. The scientific experience with predicting the behavior of these stored sediments once the dams are removed is scarce, but reasonable estimates are possible through the application of fundamental engineering and geomorphic principles. Changes in the downstream river after dam removal may be far-reaching, and might include channel change, adjustments in flood regimes, and coastal deposition of sediments.

**Physical Effects of Dam Removal.** As outlined in the initial Heinz Center report, the most important physical effect of dam removal is changes in the mobility of sediment. Sara L. Rathburn and Ellen E. Wohl described their investigations of sediment dynamics in the North Fork Cache la Poudre River in Colorado in relation to Halligan Dam (see Chapter 7). The effects of releases of sediment into the system by Halligan Dam demonstrated that models based on cross sections of the stream have not yet evolved into coupled models (where the output of one model is used as input for another) that are informative at the landscape or geographic scale—the scale used in management decisions.

In his analysis of the removal of Good Hope Dam on Pennsylvania's Conodoguinet Creek, Jeffrey J. Chaplin also stressed the importance of monitoring (see Chapter 8). Measurements to date have shown little change in channel configuration after dam removal, and the water quality was not harmed by the release of previously stored sediments—an outcome that might have been different if the sediments had been contaminated.

**Policy Dimensions of Dam Removal.** The initial Heinz Center report reviewed the general federal policies influencing dam removal, and in her review Elizabeth Maclin enumerated the federal laws and regulations—that primarily the Clean Water Act and the Endangered Species Act, among many others—come into play when considering dam removal (see Chapter 9). Any dam removal effort must take into account state, county, and municipal regulations as well. Removal of state-owned or private dams may require complex permit processes, with the complexity varying widely from place to place. The fact that Pennsylvania has recently removed 60 dams while Massachusetts has removed only two probably reflects differences in bureaucratic and regulatory regimes more than anything else.

**A Case Study.** In his presentation (not included in this volume), Ted Frink used the San Clemente Dam on California's Carmel River as an illustration of how many aspects of a general discussion of dam removal play themselves out in a specific place. The safety of San Clemente Dam, like many structures considered for removal, is questionable because of the threats posed by earthquakes or flood hazards. Managers considering removal must wrestle with thorny issues such as how to dispose of sediments behind the dam and how to evaluate the potential effects of retention or removal on endangered species.

## DISCONNECTIONS IN DAM REMOVAL RESEARCH

The presentations, panel interactions, and discussions at the workshop revealed the disconnections that hinder the application of science to decision making for dam removal.

**The General vs. the Particular.** Basic scientific and engineering research seeks generalizations that are widely applicable. Research related to dam removal also must seek these general concepts, yet decision makers require understanding and predictive capability that is tailored to the unique circumstances surrounding a particular dam site. Research on dam removal will therefore have to be general enough to apply to all locations, but flexible enough to accommodate a wide range of conditions resulting from the variability in dams and rivers.

**Deterministic vs. Probabilistic Concepts.** Deterministic mathematics underlies understanding of the behavior of rivers and their responses to human activities, and most of the models used to predict outcomes of decisions are deterministic. In applications, these models produce a single answer to a single question. Because of the complexity of river processes and the effects of dams, however, it is not possible to predict with certainty the course of future events (a problem deeply rooted in modern geomorphology for rivers—see Leopold et al., 1964). For this reason, probabilistic approaches are better for decision making—approaches in which predictions are made with an associated likelihood that the prediction will be borne out. The error envelopes around predicted conditions can help decision makers to understand the reliability of scientific and engineering predictions.

**Slow Science vs. Fast Decision Making.** Science proceeds slowly. It requires observations over periods of time that may reach several years for the processes related to dam removal, and the seasonality of river processes introduces variability that takes years to understand. Decision makers, however, must deal with relatively rapid bureaucratic processes. They are typically constrained by legally imposed time limits such as a 90-day comment period for a proposed course of action. Moreover, the election cycle of two to four years exerts considerable influence on public policymaking. Often, then, science cannot produce results fast enough to satisfy the needs of those who must decide on a course of action.

**Models vs. Data.** There are several computer-based models that can predict river processes after dam removal. Model effectiveness is directly dependent on empirical data, and at present few data are available to describe changes after dam removal. It is possible to simulate future events, but such predictions are most reliable if observational data from past events are on hand, and for dam removals this kind of data is notable by its absence.

**Small Dams vs. Large Dams.** All dams are not created equal. Almost every dam removed so far has been a small structure. Small, low-head, run-of-river structures have relatively simple operational characteristics, and their effects on river hydrology are easily defined, even though the effects of small dams on many physical, chemical, and biological characteristics are not (Figure S.1). Large, high-head, water storage dams have complicated operational characteristics and their effects on river hydrology are difficult to define. Therefore, what is learned from experience with dams of one size is not likely to be applicable to dams of a different size. Extensive research on a range of structural sizes is required to support decision making in the variety of cases described in the rest of this section.

**Small Rivers vs. Large Rivers.** Compared with large rivers, small streams have simpler hydrology and sediment systems, and their landforms and

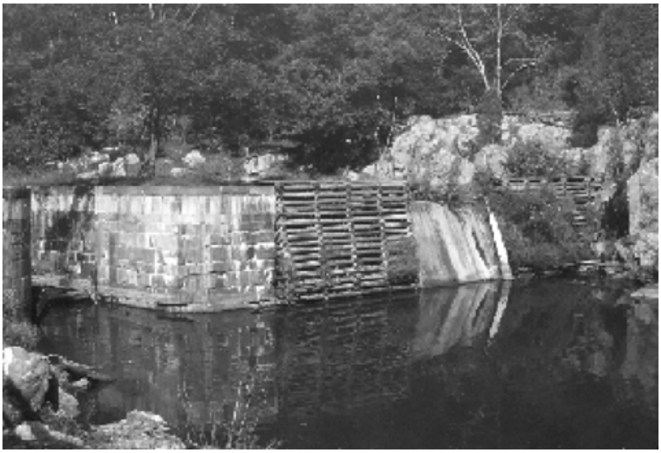

**Figure S.1** Small dam and lock associated with the C&O Canal, Washington, D.C. Courtesy of William L. Graf.

ecosystems are less complex. The larger the river, the more likely that sediment transport will be an important part of the river dynamics and the more likely that contaminants from the upstream watershed will be an issue for decision makers. Larger streams have larger watersheds and inevitably involve a greater number of stakeholders than smaller streams. For these reasons, knowledge gained about natural processes in small streams, human intervention in those processes, and the cultural and social dimensions of decision making related to them are not directly transferable to larger rivers.

**Humid Regions vs. Drylands.** The basic theory for explanation of river processes has mostly evolved from humid region examples, so that in the drylands of the western United States established concepts must be modified before they are used for predictive purposes. The channels and near-channel landforms are largely produced by event-driven hydrologic processes, with rapid change occurring over a short time span, followed by lengthy periods of relatively little change. These system-forming events occur more frequently in humid regions, and so are better understood there. Floods are important instigators of system change, but the range between average flows and flood flows is very different from one region to another. Rivers in the eastern humid region have 100-year floods that are about five times greater than the average yearly flood. In western dryland rivers, the 100-year flood may be 50 times greater than the average yearly flood. Dams therefore have different effects in each region, and the effects from flood suppression are much greater in the West.

**Private vs. Public Land.** Land ownership along the shores of reservoirs and stream banks establishes the interests of stakeholders in dam removal decisions, but this ownership differs from East to West in the United States. In the East, land ownership near rivers and lakes is mostly private, so that any changes in those water systems directly affect the personal interests of private citizens or corporations. In western areas, land ownership near rivers and lakes includes substantial public interests (usually federal), so that dam removals affect the interests of a regional or national constituency. The decision processes in private versus public ownership are therefore quite different and require different approaches.

**Who Benefits vs. Who Pays.** The costs of dam removals and of subsequent river restoration efforts are most often borne by private citizens, with substantial government support. The users of the final river resource may be widely defined, but could be almost exclusively local. Alternatively, dam removal may be favored by interest groups representing a geographically diverse population, but the costs of removal in the sense of disruption from deconstruction activities and changed landscapes are borne only locally. In both of these cases, there is a disconnection between those who benefit and those who pay—a disconnection that is sometimes difficult to bridge.

**What Science Learns vs. What the Public Believes.** The knowledge base of researchers is generally greater than the knowledge of the public, although sometimes local knowledge is better, particularly in the details. For example, the public in the area near a potential dam removal operation may believe that flooding will be more common downstream from a removed run-of-river structure, or that mudflats will persist in the floor area of the reservoir after dam removal. Even though abundant evidence indicates that neither of these outcomes is probable, without substantial public education by researchers, misconceptions will persist and make informed decisions difficult.

## WHAT WE KNOW AND WHAT WE DO NOT KNOW IN DAM REMOVAL RESEARCH

Participants in the Heinz Center Workshop on Dam Removal Research identified components of the existing science that are helpful in weighing dam removal, but some readily identifiable gaps also exist in the knowledge. The major things that are known follow.

- *Continuation of interest.* The concept of dam removal as a viable option in the management of dams by owners is a component of river restoration efforts. Dam removal is not a passing fancy. Decision makers continue to have an interest in the subject, and they recognize that the science is often inadequate. Although dam removal as a management option is probably practiced most often in the United States, interest in the general subject and in the Heinz Center's dam removal report is considerable from nations as diverse as the United Kingdom, Germany, Italy, Australia, Taiwan, Malaysia, and Japan.

- *Site-specific studies.* The body of data and scientifically based understanding of the outcomes of dam removal related to specific sites is growing. For example, dams on the Baraboo River (Wisconsin) and portions of the Susquehanna River system (Pennsylvania) have provided a foundation for site-specific knowledge that has yet to grow into generalizations.
- *Direction of expected changes.* The sciences of hydrology, geomorphology, and ecology offer a sound enough basis to predict the general direction of the changes that will result from the removal of dams, including those dams up to medium in size. For example, it is generally expected that after dam removal channel bed sediments downstream from the dam will become finer and those in the former reservoir will become coarser (at least temporarily) and that greater variability in flows will be evident if water storage structures are removed.
- *Models for points and cross sections.* Engineering-based models are generally available for predicting changes related to dam removal at particular points along streams or at cross sections. Models based on cross sections, such as the U.S. Army Corps of Engineers' HEC-RAS (http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html) and the U.S. Forest Service's XSPRO (ftp://ftpsite.westconsultants.com/Outgoing/WinXSPRO/), are in the public domain and available to anyone for application. The outputs of these models are accepted in legal, engineering, and scientific communities.
- *Removal of small dams.* Hundreds of dams have been removed in recent years, but this collective experience is related to small structures, generally less than 25 feet high and generally run-of-river.
- *Short-term species recovery.* The observations and data becoming available are shedding light on the changes in species occurrence and distribution that follow dam removal. Close monitoring of these changes is beginning to yield information in some detail for a limited number of sites. General results across several species and systems are not yet available. Because of the recent interest in species discovery, observations of a year or so are the most common.

The workshop also revealed some major gaps in the science of dam removal.

- *Social considerations.* Privately owned dams on publicly owned waterways are the recipe for a contentious debate. Because of the legal framework governing water and environmental affairs in the United States, citizens are certain to be participants in the decision process for the removal of many dams. Despite the importance of social processes, the creation and expression of opinions, and the collision between private property rights and public trust resources, relatively little social science research can be brought to bear on dam removal issues.
- *Economic considerations*. Because the data needed to construct economic models for predicting the outcome of dam removal or retention are not available, it is difficult to estimate the effects of either decision on economic activities indirectly related to the structure in question. The economic implications of dam removal are still poorly understood. Decision makers dealing with possible dam removals consistently overestimate the direct costs of removal and underestimate the costs of retention. Improved documentation of the financial aspects of previous dam removal projects would help decision makers and the public to better estimate the costs of various options. Finally, restoration costs need to be tied more closely to dam removal decisions. Restoration might occur with the dam removed or in place, but in either case the restoration costs are likely to a factor in any retention–removal decision and should be known.
- *Landscape-scale studies.* Although the present knowledge and models can be applied effectively to points or cross sections, and by extension to short reaches of river, researchers are poorly equipped to understand the effects of dam removal on a landscape scale of many miles along streams. Almost no studies have been conducted on the effects of dam removal on a watershed, an important consideration given the prevailing interests in issues such as fish passage and nonpoint source pollution, which are inherently watershed-related.
- *Magnitude of expected changes.* Researchers in dam removal can make reasonable guesses about the direction of expected changes in hydrologic, geomorphic, and biologic systems, but predicting the magnitude of these changes is usually beyond their capability. They might predict magnitudes of change in hydrology, espe-

cially where the changes are likely to be very small (for run-of-river structures), or where basin hydrology for storage reservoirs is well known. Magnitudes of adjustment for channel forms and for biological populations are likely to be easiest for the smallest structures and progressively more difficult for the larger ones.

- *Integrated, broad-scale models.* The available hydraulic and hydrologic models such as HEC-RAS and XSPRO are valuable, but by not extending broadly enough into geomorphology and not linking directly to biology they do not completely meet the needs of decision makers. Model development is needed to serve extended spatial scales such as watersheds, and couplings are needed to model expected changes in important postremoval parameters such as channel characteristics and wildlife populations.
- *Removal of medium-size and larger dams.* No well-documented, scientifically analyzed project related to the removal of medium-size or large dams has been undertaken. If carried out, the removal of Matilija Dam in California and the Elwha River dams and Condit Dam (Figure S.2) in Washington are likely to generate a flow of scientific information and understanding that will be essential in considering the effects of removing dams that exceed the size of typical run-of-river structures and mill dams.

**Figure S.2** Condit Dam on the White Salmon River in Washington State, a medium-size structure shown here under construction in 1913. Courtesy of Bonneville Power Authority.

- *Long-term trends in wildlife populations.* Short-term population trends cannot be interpreted without a long-term context. Many wildlife populations fluctuate under entirely natural circumstances, so that sorting out the effects of human activities, including dam installation or removal, can be difficult, even over long periods. It is often impossible over short periods.

## SPECIAL TOPICS IN DAM REMOVAL RESEARCH

At the Dam Removal Research Workshop, three panel discussions were devoted to specific issues related to dam removal. The following sections summarize the comments by panel members and workshop participants on the Endangered Species Act, invasive species, and support for dam removal research.

### DAM REMOVAL AND THE ENDANGERED SPECIES ACT

The Endangered Species Act is important in considering dam removal and its effects because many species are dependent on aquatic or riparian ecosystems that are strongly influenced by dams. The following points emerged from the panel discussions.*

**A Watershed Scale.** From the perspective of species management, the appropriate scale for decision making and planning is the watershed, yet decisions about which dams to remove are often taken without regard for this larger perspective. This situation develops because the decision to remove a structure is the responsibility of the owner of the dam, and the owner has limited perspectives on the large-scale concerns related to endangered species. Thus far, the thinking is scarce on basin-wide approaches to dam removal that might benefit endangered species.

**Process Reversal and Dam Removal.** The installation of dams and other water control structures has adversely affected at least half of the

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* Members of the Panel on Dam Removal and the Endangered Species Act were David Wegner (leader and moderator), Tom Busiahn, Jim MacBroom, Elizabeth Maclin, David Policansky, and William W. Stelle.

entries on the national endangered species list through processes that have degraded habitat and prevented access to habitat (obstructions to passage). Loss of in-stream flows, deactivation of floodplains, and loss of ecological niches such as slack water areas, bars, and islands are examples. It is not obvious, however, that removal of dams and other water control structures will result in a reversal of these adverse processes. Although researchers have speculated that some processes are reversible and others are not (Graf, 2001), the present state of the science for regulated rivers is inadequate for identifying which processes are reversible in specific locations or for specific dams, with the exception of recognizing that fish passage can be restored by dam removal.

**Humans, Endangered Species, and Habitat.** Most plans to restore endangered species focus on managing the habitat required for species survival rather than dealing with individual animals or plants. For this reason, consideration of dam removal and its potential benefits must be based on understanding the geography of the important habitat and its relationship to dams and people, plants, and wildlife that might be affected. For endangered species, once the decision is made to remove a dam, the spatial implications of the decision become important: how far downstream and upstream will the effects be evident, and where do the effects overlap with important habitat for endangered species and humans?

**The Trump Card.** Sometimes in river management the Endangered Species Act has the potential to become the trump card, the issue that transcends all others and drives final decisions. However, no dam has been removed in the United States because of a mandate through the Endangered Species Act. Dams may increase biodiversity locally by creating new habitat at the dam and reservoir site, but usually native species decline. Because of the importance of rivers to diversity of native species, the act will continue to drive scientific investigations of the interactions among dams, water, sediment, and habitat.

## DAM REMOVAL AND INVASIVE SPECIES

*Alien species* are organisms not native to a particular ecosystem; *invasive alien species* harm the environment, economy, or human health. In the United States, examples of invasive alien species are animals such as sea

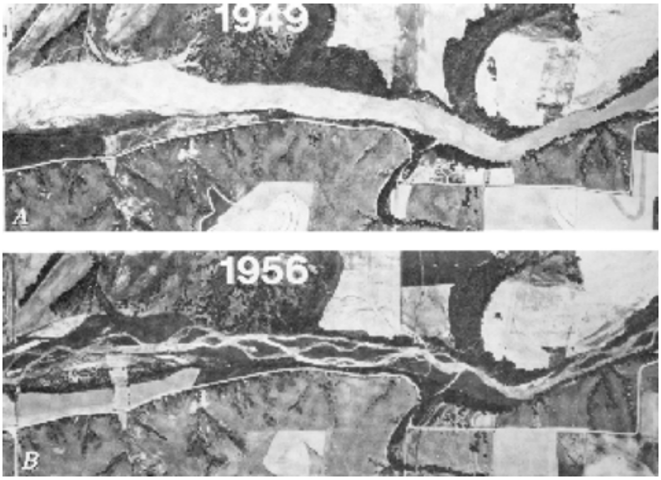

**Figure S.3** **The Republican River downstream from Harlan County Dam, Nebraska shown in 1949 and in 1956, after closure of the dam in 1952. The 1949 photograph shows the braided stream before dam installation; the 1956 photograph of the same area shows channels narrowed by invasive vegetation, including tamarisk.** Courtesy of U.S. Geological Survey and originally published in Williams and Wolman (1984).

lampreys and zebra mussels in the Great Lakes region, plants such as tamarisk and arrundo in the southwestern states, and the pathogens that cause malaria and West Nile virus. The following points emerged from the discussions of the Panel on Dam Removal and Invasive Species.*

**Dams as Facilitators and Supporters of Species Invasions.** Dams sometimes facilitate the process of biological invasion by creating habitat attractive for recreational activities that can result in the purposeful (e.g., stocking) or accidental (e.g., an organism "hitchhiking" on boats) introduction of non-native species. Dams also can change the general environment in such a way that it becomes more hospitable to certain types of invasive alien species. And they can alter the timing of flows downstream, particularly changing the timing of high flows (and thus altering the time-dependent growth and reproductive pattern of native flora),

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* Members of the panel were Jamie Reaser (leader and moderator), Mike Fritz, Kerry Griffin, Richard Marzolf, and Emily Stanley.

making invasive growth more competitive. Changing channel dimensions creates more space for colonization (Figure S.3). The release of cold waters from deep reservoir intakes also can change aquatic environments downstream to conditions that might favor certain types of alien species over native species. Along the southwestern rivers, dams may have created habitat conditions more favorable to tamarisk than the original undammed conditions. Dam removal might restore conditions more favorable to native species, but it also might increase disturbance regimes, which can often favor invasive alien species because they are typically rapid and strong colonizers.

**Intentional Introductions.** Often, the introduction of alien species is intentional, but the harmful conditions that result are not. For example, the introduction of some species of sport fish into rivers downstream from dams may result in fewer native species, which are also desired. Dam removal in these instances is problematic because public support for the maintenance of one species type or another may be considerable and because removal could benefit the favored or desired species as much as or more than the natives. Because of the possibility of both upstream and downstream effects in dam removals, consensus among stakeholders is often difficult to achieve in weighing dam removals, especially when one species has been introduced into the reservoir and another into the river downstream.

**Using Dams to Impede the Spread of Invasions.** Although dams are barriers to the passage of native populations, they also can serve as barriers to certain alien species. Dam removal therefore might have the undesired effect of providing greater range for invasive alien species. In the Great Lakes regions, dams on streams entering the lakes have prevented the upstream migration of sea lampreys and thus have restricted their ability to prey on native fishes.

**Public Perception vs. Scientific Understanding.** Stakeholders sometimes value alien species (often because they provide income), but scientific understanding may indicate that the species will produce significant harm. The introduction of striped bass into reservoirs, for example, may be viewed by the sporting public as an entirely positive decision, but fisheries researchers may argue that such introduction will result in the loss of other equally desired species, with implications for the entire aquatic ecosystem.

**Data Needs.** Invasive alien species must be considered in any analysis undertaken to assess the potential environmental and socioeconomic consequences of dam removal. The removal of some dams might reduce the effects of biological invasion, but the removal of others might facilitate the process of invasion and ultimately result in environmental and economic harm. Unfortunately, quite often decision makers are challenged with a paucity of data on the abundance and distribution of both native and alien species, as well as the physical elements with which they interact. Baseline biophysical surveys and long-term monitoring programs should be established to increase decision-making capacities by taking advantage of the few generalizations available. New software technologies that enable mapping and modeling of the distributions of invasive alien species and their relationships to other factors in the system can contribute significantly to better-informed decisions even where the data on invasive alien species are limited.

## SUPPORT FOR DAM REMOVAL RESEARCH

The initial report on dam removal by The Heinz Center argued that the best decisions are those that are best informed (Heinz Center, 2002). Science does not provide the answers for problems that managers face, but it can provide estimates for the outcomes of the range of decisions that might be contemplated. The Panel on Support for Dam Removal Research considered potential support for research that could refine the predictive science for dam removal.*

**Basic Theory and Empirical Science.** Theories about how rivers and riverine ecosystems behave are available but not well calibrated. More empirical studies are needed to fill out understanding of the implications of dam removal. Of particular importance are analyses of the sediment dynamics in dam removal situations. Monitoring conditions before and after removal could produce useful input for question-driven research.

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* Members of the panel were Scott Carney (leader and moderator), James Colby, Mike Fritz, Carla Fleming, Gordon Grant, Kerry Griffin, L. Douglas James, Richard Marzolf, and Tim Randle.

**Some Geographic Unknowns.** Although the distribution and location of dams are known, no useful context exists for that knowledge. Anyone considering dam removal must be aware of the location of the dam in relationship to the entire watershed and other features such as mines, cities, agricultural areas, invasive species, drinking water supplies, important habitats for endangered species, and pollution sources. With the advent of geographic information systems, researchers are able to define the distribution of these features, but an analysis that incorporates understanding of the implications of the distributions has yet to be developed.

**Some Ecological Unknowns.** Decision makers are often forced to make choices without adequate science, especially in areas related to endangered species. Because for many species researchers are still unable to define how much habitat is required for species survival, it is not possible to manage river landscapes with definitive areas for the benefit of species.

**Agency-Based Research.** Some agency-based research has informative implications for decision makers dealing with dam removal. The Academy of Natural Sciences and American Rivers, Inc., exemplify nongovernmental organizations engaged in such work. State agencies are mostly oriented toward regulatory tasks, but some, such as the Pennsylvania Fish and Boat Commission, conduct research. At the federal level, the missions of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service include regulatory aspects, but those agencies also collect data and conduct scientific research. Box S.1 describes an example of research related to dam removal supported by the National Science Foundation.

**Correlation and Causality.** The discovery of an association between two variables, such as number of salmon and number of dams, is not scientific proof; explanation and causality also are required. Connections through causality are difficult to establish in many research questions related to rivers and dams because the latter represent complex systems with many potential candidates as causes. For this reason, scientific research in support of decision makers who are trying to assess the potential outcomes of dam removal is often not able to provide unambiguous predictions.

**Value Judgments.** Science has no inherent mechanism for making value judgments. Scientists have opinions, but their job is to provide

**Box S.1** NSF-Sponsored Research

The National Science Foundation (NSF) sponsors basic research into physical, chemical, and biological processes potentially related to dam removal. NSF seeks to support basic research with broad implications rather than single-issue, single-place investigations. The agency is directly interested in research that defines fundamental environmental relationships derived from repeatable measurements, sound theory, and rigorous testing. Most, but not all, NSF grants go to academic researchers who often work in tandem with researchers in other agencies. The significance of this approach is that for NSF there is no "science of dam removal," but rather general scientific principles that are applicable to issues in dam removal.

Although many NSF programs have bearing on research related to dam removal, three areas of research sponsorship most obviously intersect with dam removal: watershed investigations, sediment transport research, and systems analysis. As indicated earlier in this chapter, dam removal decisions are often made from a highly localized perspective, yet dams are situated within the natural matrix of a watershed. Successfully assessing the outcomes of dam removal depends on taking into account water, sediment, nutrient, and biologically related processes operating on a watershed scale. Basic research into watershed-scale hydrologic processes has received support from NSF for many years, with the results forming a basic understanding of how watershed hydrology works and how society affects these processes.

The Heinz Center report *Dam Removal: Science and Decision Making* indicated the exceptional importance of sediment forms and processes when predicting the outcomes of dam removal (Heinz Center, 2002). The ultimate fate of sediment and the contaminants it contains is a critical planning issue that depends on the ability of planners to predict transport processes and ultimate deposition locations for sediments released when dams are removed. Understanding and predicting these sediment transport processes require the application of basic physical principles in the complex hydraulic environment of open channel flow. NSF sponsors investigations into these basic processes with the ultimate objective of creating predictive tools likely to be useful in assessment of the effects of dam removal. Dams, like other engineering work, have definable life cycles; they are complex systems that are partly natural and partly artificial. Understanding the systematic functions of dams from construction to eventual removal, as well as determining the role of dams in functional hydrologic, geomorphic, and biologic systems, require multidisciplinary teams of advanced researchers. NSF recently committed to a decade-long effort to aggressively support research into these complex environmental systems. The initial Heinz Center report on dam removal is mentioned in the NSF policy document on complex environmental systems in the context of investigation into rivers, dams, and their interactions (Pfirman and AC-ERE, 2003).

answers to questions about the likely outcomes of dam removal. The choice of which outcomes are better or more desirable than others is a political process driven by social and cultural values. Government agencies and the public must decide which values to attach to these outcomes.

## CONCLUSIONS: ADAPTIVE SCIENCE

Decision makers attempting to assess the outcomes of dam removal frequently observe that "every dam is unique." Each dam has its own engineering and physical characteristics, own site, and own social or cultural context. These unique qualities, however, should not deter the search for the generalizations that link the many experiences with dam removal. Part of the reason that uniqueness seems dominant to researchers and decision makers is that the number of dams removed is still relatively small. As the number of experiences with dam removal increases, the generalizations are likely to become more apparent. Every river has unique water, sediment, and biological characteristics, but this uniqueness has not prevented the formulation of useful generalizations that allow scientists and engineers to model and predict their behavior, albeit with some local modifications. River scientists and engineers do not always get the prediction right, but they are often generally successful.

To play an effective role in dam removal, science and its practitioners must be flexible. In applying of adaptive management, decision makers choose a course of action and design it so that information is collected, results are monitored, and then adjustments are made accordingly to ultimately reach specific collective goals. *Adaptive science* must identify significant questions, seek to answer them, and then, in light of that experience, redefine the questions in consultation with managers. Ultimately, such a flexible process produces better predictions. Adaptive management and science are not open invitations to endless research. Adaptive applications reflect the expansion of the state of intellectual development of river management and restoration at the present time. Researchers simply do not know enough about outcomes to confidently use "off the shelf" predictions for major decisions about dam removal. For small, run-of-river dams, they have enough experience to make good judgment calls, but for medium-size or larger dams, or any dams in important habitat areas, they are still learning.

Adaptive science for dam removal requires a close association between basic theoretical science and applied science for problem solving. Traditionally, basic science has been thought of as curiosity-driven, as the source of new theoretical constructs, and as something that does not necessarily have immediate applications. Applied science draws on widely accepted theoretical approaches to solving specific problems in specific places. River restoration through dam removal and the prediction of the outcomes of dam removal require development of some new theory, particularly in geomorphology. Over the past several decades, geomorphologists have sought to construct theories about how natural rivers work, but they have paid little attention to the effects that humans have on these processes. Adaptive management should incorporate the effects of structures installed by a society and account for the effects of dams and their removal. At the same time, problems faced by decision makers and ecosystem researchers seeking prediction in specific cases can inform the directions and emphasis for theory building.

In many areas, the decision making on dam removal is proceeding more rapidly than the supporting science. But because of safety and liability considerations, dams are likely to be removed whether adequate science is or is not in place to predict the outcomes. Informed decisions are those most likely to be successful, but it is unlikely that all the social, economic, and environmental outcomes of dam removal will ever be known with certainty. Community opinion on dam removal also may be difficult to capture. However, long-term social impact studies related to dam removals should help to inform research and yield benefits to decision makers.

Finally, it is tempting for decision makers and researchers to become consumed by the problems of the moment, the issues surrounding individual cases, and the specific conflicts that arise here and there. If it is true that the best decisions are those that are as informed as possible, it is also true that those best decisions are likely to emerge from a larger vision of how Americans, their economic infrastructure (including dams), and their environmental systems are integrated and work with each other. The Clean Water Act spells out that larger vision, which still guides the application of science to dam removal: the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters.

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# 1

# KEYNOTE ADDRESS: MYTHS AND CHALLENGES IN NATURAL RESOURCE DECISION MAKING

WILLIAM W. STELLE
*Preston Gates and Ellis*

> The proper role of science is to light candles in dark corners.
> —*Bruce Babbitt*

THE HISTORY OF DAMS in the United States provides a wonderful vantage point from which to view the cultural, economic, and social development of modern-day America. Dams have served over the last century as powerful engines of economic and social development across the American landscape. They are a part of our history and our culture. This rich history fuels the present-day debates over the rightful future role that dams should play in our tomorrow amid the changing social and cultural values of the 21st century.

Decision making in the United States about the management of the land and natural resources is extensively delegated across multiple federal, state, and local authorities. This dispersion of authorities and

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Editor's note: The keynote address by William Stelle set the stage for the dam removal workshop. His comments and observations, based on his extensive government service dealing with the connection between science and policy, provide useful background for the other chapters in this volume.

responsibilities affects directly future decision making about whether and how to remove dams that arguably no longer serve compelling public purposes. It also promises to ensure that proper management of the governance of decision making will be as vital to good decision making as the quality of the empirical information that purportedly informs that decision making.

The Heinz Center Panel on Economic, Environmental, and Social Outcomes of Dam Removal has done good work in outlining a solid framework for analyzing the choices of maintaining or removing the many small dams whose substantial age, poor condition, or lack of current utility will rightfully generate a legitimate discussion of retention versus removal. It also properly assumes that numerous scientific disciplines may bring helpful tools to bear on those choices.

In my remarks today I seek not to add my two cents to the helpful discussions that will ensue over the next several days on the capacity of science to shed light on those choices. Rather, I choose to step back from those grainy details and offer you a clutter of random observations about the role of science in natural resource decision making based on my experience in the wonderful rough-and-tumble of natural resource policy and politics in Washington, D.C., and in the Pacific Northwest.

Decision making in the natural resource arena—as in many other arenas—is complex, hard to fathom, and characterized by the interplay of numerous factors, some of which are apparent, others of which are invisible. Scientific information is, obviously, one major set of factors at play, but it is only one of many. Understanding the role of science and its limits is important to increasing its relevance. My remarks are designed to touch on those limits in the hopes that you, as scientists, can therefore fashion your scientific inquiries and the information they generate in a more effective and influential manner.

Many myths surround the role of science in decision making. Some of those myths are part of the culture of the scientific community, while others find their place in our broader culture and affect how science is received and used. Identifying those myths and dispelling them when necessary will affect the use of science in decision making. I will therefore sketch some of the more powerful myths at play in the recent dam removal debates in the Pacific Northwest. I will identify several of the genuinely tough issues that decision makers may face in deliberating on whether to retain or remove dams in the hope of stimulating the thinking of workshop participants on how science might shed light on those tough issues. I will close my remarks by identifying some of the important scientific opportunities that lie ahead in fashioning a more sophisticated means of constructing a scientific approach in this arena.

## THE MYTHS

**Myth One: Science Is Truth.** People confuse science with truth, and many scientists suffer from this same confusion. Science is not truth. Science is a highly disciplined and refined method for observing events through empirical measurement and attempting to discern relationships (correlations) based on those observations that will help to explain why things happen and predict what may happen in the future.

You may choose to believe that science is truth—and many scientists make this choice out of dedication to the scientific method or to tunnel vision or to hubris. Others may believe that the Scriptures are truth. Or that the coyote and the bear are truth. Others still may have no organized sense of truth, but merely a jumble of opinions and thoughts. My point here is not to argue whose truth is correct, but merely to encourage you, as scientists, to appreciate that you may equate your science with truth, but others do not and will not. This may help you to explain your science and to deliver it more effectively and persuasively into the cauldron of public debate over making choices.

**Myth Two: Science Will Tell Us What We Should Do.** This is a major myth that you should guard against. Science does not tell decision makers what they should do; they decide what they want to do and the scientific information may help to inform their choices on how to do it. This is a fine line, to be sure, and one that is crossed frequently. It seriously misstates, in my judgment, the proper function of science in decision making. It also may frequently serve as convenient political camouflage for those messy value choices or priorities that are better left opaque. Politicians and policymakers will often seek to justify their positions and choices on the grounds of "good science," whereas in fact their choices reflect a set of values and priorities that may have little to do with "good science." That their choices appear to flow from "good science" may frequently be more happy coincidence than causation.

The decision tree on dam removal espoused by the panel rightly identified the articulation of goals and objectives as a crucial first step in analyzing retention or removal choices properly. I fully support this, and believe it provides a good opportunity to delineate clearly the policy choices from the scientific information that may inform those choices.

**Myth Three: Society Wants a Science-Based Approach.** When you hear this, pay attention. It may be a genuine statement of preference, or, alternatively, it may serve as cover for a policy preference better left unstated. It may reflect for some a genuine dedication to the scientific method, and for others a political convenience. While this credo may be misused from time to time, the fact that it is useful is itself a cause for optimism for those who, like me, choose to believe in the relevance of the scientific method. Social attitudes are indeed shifting in favor of a more prominent role for scientific information. Reliance on science-based decisions is a basic tenet of many of the major federal and state legal regimes governing natural resources in public choices. Thus, in truth this myth is both myth and fact.

**Myth Four: Something Will Happen Because the Model Says So.** The misuse of modeling in natural resource decision making is routine. Understanding the proper role and function of modeling in scientifically based policymaking is genuinely difficult, and it is a difficulty shared by both scientists and decision makers alike. Models are important tools in predicting the future in a scientific landscape characterized by the wholesale lack of adequate data and information. Models also may serve as highly useful tools in organizing and manipulating large sets of data to better predict outcomes and enable people to make better choices. Decision makers hunger for greater predictive power as they struggle with difficult and important choices, and the scientific community properly responds with an ever more powerful model.

The major challenge for the scientific community is to protect against the misuse of models by its members or by decision makers. Transparency and effective communication about the assumptions and uncertainties that may be embedded in the models are both difficult and important. Often, the language of modeling is extremely obscure to the lay public, and thus caveats that seem clear to the scientific community are completely lost in the din of public debate. Modeling becomes a tool of misinformation as much as a tool of useful information.

**Myth Five: The Government Makes Rational Decisions.** This may not be a widely shared myth across the kingdom, but it deserves mention if only for the faithful civil servants who toil under it. Government responsibilities for managing natural resources are broadly littered across the jurisdictional landscape at the federal, state, tribal, and local levels. Legislative bodies carve up these responsibilities by enacting overlapping laws in fits and starts of shifting political priorities. Agencies in executive branches then build power, constituencies, and influence through the aggressive implementation of their regimes. These regimes may or may not fit together nicely within one level of government—or fit vertically between federal, state, and local authorities. Their fit may reflect a larger rationale to which the legislature in its wisdom adhered. Or it may simply reflect the rough-and-tumble of the political process over time. Expect to encounter these overlaps and inconsistencies in agency missions and mandates. Expect further that they will, in turn, generate incentives for dueling science. Strive as best you can to insulate the integrity of the scientific exercise from the push and pull of interagency and intergovernmental dynamics.

**Myth Six: We Want Somebody in Charge.** Emerging from the clutter of intergovernmental jurisdictions is the oft-stated desire for order and accountability, reflected in the musings that somebody should be in charge. This apparent call for order arises with frequency in the raucous debates about dam removal in the Pacific Northwest, where a tangle of federal, state, tribal, and regional authorities characterize the bureaucratic landscape of natural resource management. There is less here than meets the eye. In fact, we want someone in charge when we are confident that they will do what we want. Where that confidence is lacking, we will frequently choose to protect and expand our independence, our autonomy, and our power. Science and scientists become the tools by which to obtain and exercise power and control. We want somebody in charge only insofar as that somebody will do our bidding.

## THE CHALLENGES

Looking forward with enthusiasm, I caution you to not be too distracted by my tongue-in-cheek comments about the role of science in decision making. Social expectations in our political culture about the proper role of science in decision making are high and growing higher, which should be gratifying to those of us gathered here today who believe in the power and relevancy of the scientific method and to the broader scientific community. These rising expectations present us with important (and difficult) opportunities to improve the use of science in natural resource decision making. While the list of these challenges is no doubt long and expanding, I commend to you some of my favorites, including

- Helping to construct decision criteria that are clear, quantifiable, and reproducible
- Constructing improved scientific predictions in the face of limited data
- Using the scientific method to build trust and discipline among the relevant parties
- Developing methods to compare differing values fairly (profit compared with ecological function, biological benefits compared with power reliability)
- Fostering transparency in our science even while it increases in complexity
- Identifying and quantifying costs and benefits more accurately
- Overcoming scientific balkanization
- Improving communications about the limits of scientific information in the vigorous political and social debates that will no doubt continue

In an increasingly complex world, we can expect the power of science and the responsibilities of scientists to grow substantially. Good science has a hugely important role in improving decisions about managing our natural resources. Be mindful of the many myths and challenges associated with the use of science in decision making, and shape your recommendations over the next several days with wisdom. Thank you for the opportunity to join you today.

## 2

# AMERICAN DAM REMOVAL CENSUS: AVAILABLE DATA AND DATA NEEDS

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***Abstract:*** Although dam removal has recently received substantial attention from the press, the public, and professionals, little national-level information is available on trends in dam removal. This chapter presents the preliminary results of a national quantitative assessment of 20th-century dam removal trends. The study reveals the problems with the current data and the need to improve data collection, management, and dissemination strategies for information on dam removal.

Because it provided the best available dataset at the time, the American Rivers, Inc., dam removal list served as the starting point for developing a new database (American Rivers, Inc., et al., 1999). The primary limitation of the American Rivers list was that it did not distinguish between dams that were breached and those that were completely dismantled, a distinction that has important environmental implications and reflects different river management strategies. From the fall of 2000 through spring of 2002, entries in the American Rivers database were confirmed, corrected if necessary, and augmented with other cases obtained by calling state and federal agencies associated with dam management. Although the American Rivers list includes even the smallest structures removed from rivers, the database presented here includes only dams that were, before dismantling, at least 1.8 meters (6 feet) high or 30.5 meters (100 feet) long. This threshold was adapted from the criteria for inclusion in the National Inventory of Dams (NID) and was established to emphasize dams of substantial environmental significance.

Database analysis indicates that the number of dams being removed and the size of structures being removed have increased in recent decades. Dam razing, which is centered in the northeastern and West Coast states, is motivated primarily by safety concerns or interest in restoring river ecosystems. Even though over 400 dams have been removed from U.S. rivers, the ecological consequences of dismantling dams remain largely unknown.

These data provide preliminary insight into dam removal trends, but the utility of existing dam removal data to scientists, managers, and the public is currently limited by several factors, including (1) differences in reporting styles and nomenclature, (2) inadequate collection and integration of various reports and studies relevant to removal of a given dam, and (3) lack of centralized data management.

Relative to their extent, American rivers are collectively the most regulated hydrologic system in the world (Heinz Center, 2002). According to the U.S. Army Corps of Engineers (1999) over 80,000 dams fragment this nation's streams. If the definition of *dam* is extended to the smallest structures, the number may actually exceed 2 million (Graf, 1993). These dams provide valuable services such as hydroelectric power, water supply, flood control, navigation, and recreational opportunities. However, in the past decade the idea of removing dams has received substantial social and political attention because of changing social values and the age and safety of existing structures. In some instances (e.g., Two-Mile Dam in New Mexico or Waterworks Dam in Wisconsin), it has turned out to be less expensive to remove the dam than to repair or replace the structure, opening the door for consideration of dam removal as a management alternative. In addition, scientific research, particularly during the past few decades, has increasingly demonstrated the environmental costs associated with dams and their operations. Dams have caused large-scale environmental degradation of most major rivers in the Northern Hemisphere (Dynesius and Nilsson, 1994). They modify the natural hydrology, nutrients, and sediment dynamics of streams, and thus the biological and physical characteristics of river ecosystems (Petts, 1984; Williams and Wolman, 1984; Ligon et al., 1995; Pizzuto, 2002; Shafroth et al., 2002; Stanley and Doyle, 2002). These altered conditions may benefit introduced species but they can have deleterious effects on native species reliant on more natural conditions.

Large dams (e.g., Glen Canyon Dam and Hoover Dam on the Colorado River) store a disproportionately large amount of water and sediment relative to smaller dams (Graf, 1999) and thus often change riverine ecosystems substantially (Doyle et al., 2003). For example, after the closure of Glen Canyon Dam, major adjustments in sediment load, downstream hydrology, and water temperature modified channel geomorphology and aquatic and riparian habitats (see overview in Collier et al., 1996). An artificial flood was released in 1996 in an effort to improve downstream conditions, but a recent study suggests that the benefits of this strategy were limited (Rubin et al., 2002). Although more science is needed to aid dam managers and operators, the approach of mitigating the deleterious environmental impacts of large dams through modification of their structure or operations is receiving more attention. By contrast, smaller structures that may have limited economic and social benefits or need expensive safety and environmental upgrades appear to be candidates for removal. Some dams meeting these criteria have been removed in the past several years, such as Edwards Dam in Maine and Colburn Mill Pond Dam in Idaho.

As the topic of dam removal gains national attention, basic information on razed dams is needed at the national level. Scientists investigating past removals to generate theories on the responses of river systems to this action should identify research sites where dams were once in place. Dam and river managers and agencies faced with considering dam removal are often interested in information that can be gleaned from other dams that were removed, particularly those with similar environmental surroundings or restoration goals. Public interest in this issue is rising as well. Not only does dam removal peak the interest of people through national headlines and controversies, but communities increasingly participate in the process of considering dam management alternatives such as dam removal.

Without the availability of high-quality, national data on dam removal, studies to date have been limited to discussing dam removal trends for particular states with good databases (Born et al., 1998), or to estimating national trends using information provided by American Rivers, a nonprofit river advocacy organization (Doyle et al., 2000; Poff and Hart, 2002). American Rivers may have the most accessible and comprehensive national information (widely available on their Web site at http://www.americanrivers.org), but some potential users have concerns about the advocacy nature of the organization. In addition, its list of razed dams does not always distinguish between dams that were removed and those that were only breached. These actions may have significantly different economic costs and environmental consequences.

The objective of the ongoing study described in the rest of this chapter was to compile and analyze a national database of dams that were removed completely and intentionally. The study seeks answers to fundamental questions, including:

- How many dams have been completely dismantled in the United States and for what purposes?
- Have the average and maximum size of razed dams changed in recent decades?
- Which states are removing the most dams?

The following sections describe the data collection process and the preliminary results and then discuss the problems associated with the current information available on dam removal and recommendations for future data collection and management.

## MATERIALS AND METHODS

Construction of a dam removal database was the first step in the analysis of dam removal trends. The databases of agencies that keep dam incident reports (e.g., National Park Service, National Program on Dam Performance) were examined for removals, and dam removals were added from the American Rivers database after verification of removal by the responsible agencies. In addition, a series of formal letters sent to federal and state agencies and organizations involved in dam removal (e.g., Federal Energy Regulatory Commission, state water and environmental departments, state dam safety officers) requested information on dam removals and, when appropriate, asked persons to verify and augment data obtained from existing databases and correspondence with other agencies. All data from these letters were entered into a Microsoft Office Access database for further analysis.

Although numerous characteristics of the dam removal process are of interest to managers and scientists, this preliminary study focused on basic information about the structures, including dam height, length, location, year of removal, and reason for removal. The intent is to build other fields into the database as the research process continues. Two criteria are used for inclusion in the database: (1) intentionally, the dam was completely removed; and (2) the dam must have been at least 1.8 meters (6 feet) in height or 30.5 meters (100 feet) in length before dismantlement. The rationale for use of these criteria is twofold. First, the intent was to examine change in the decision-making process (*intentional* removal), rather than removals with incidental origins such as those associated with floods and failure. The constraint of *completely* removed eliminates structures that have been only breached. Including breached structures was impracticable in terms of data quantity. Furthermore, the economic costs and possibly environmental consequences associated with breached dams differ from those associated with relative structures that are completely dismantled. Finally, insofar as possible, the height and width constraints were intended to be consistent with the National Inventory of Dams (NID). The structure and content of NID is discussed in detail elsewhere (U.S. Army Corps of Engineers, 1999), and NID data have been analyzed by Graf (1999). Although the inclusion criteria for NID emphasize structure height and storage capacity, storage capacity information is lacking for many of the relatively small dams in NID. The storage capacity criterion was therefore replaced with a structure length criterion.

## DATA ANALYSIS

Preliminary data analysis suggests that over 400 sizable dams were intentionally and completely removed from U.S. rivers in the 20th century. Dam removal appears to have been relatively uncommon before the 1970s, but this activity has escalated in recent years (Figure 2.1).

Poor recordkeeping may account in part for the infrequent dam removals cited in the early to mid-1900s. However, the data also may simply reflect that dams were newer and thus were less likely to have safety problems and aging structures and more likely to be meeting economic and social needs. The recent acceleration of removals reflects problems associated with aging structures, growing social interest in restoring rivers and fish passage, new funding opportunities to support dam removal, and national policies aimed at improving the safety of aging structures (e.g., Dam Safety Act of 1972, Water Resources Development Act of 1982) and mitigating the environmental impacts of these structures (e.g., Clean Water Act of 1977, Endangered Species Act of 1973). Although dam removal may be motivated by several factors, safety and environmental concerns appear to be behind most recent dam removals. A discussion of the primary reasons for razing American dams is presented in Pohl (2002).

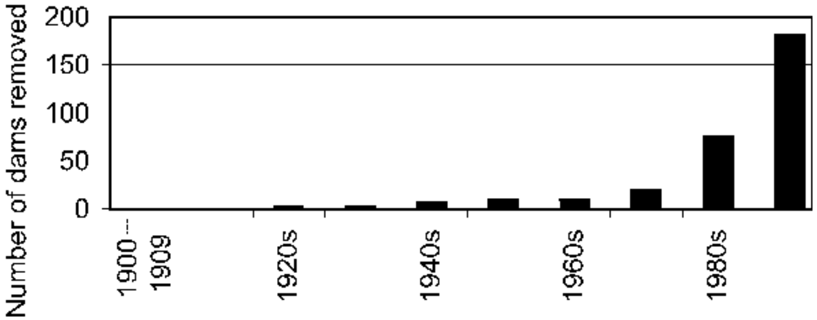

**Figure 2.1** Dam removals in the United States in the 20th century.

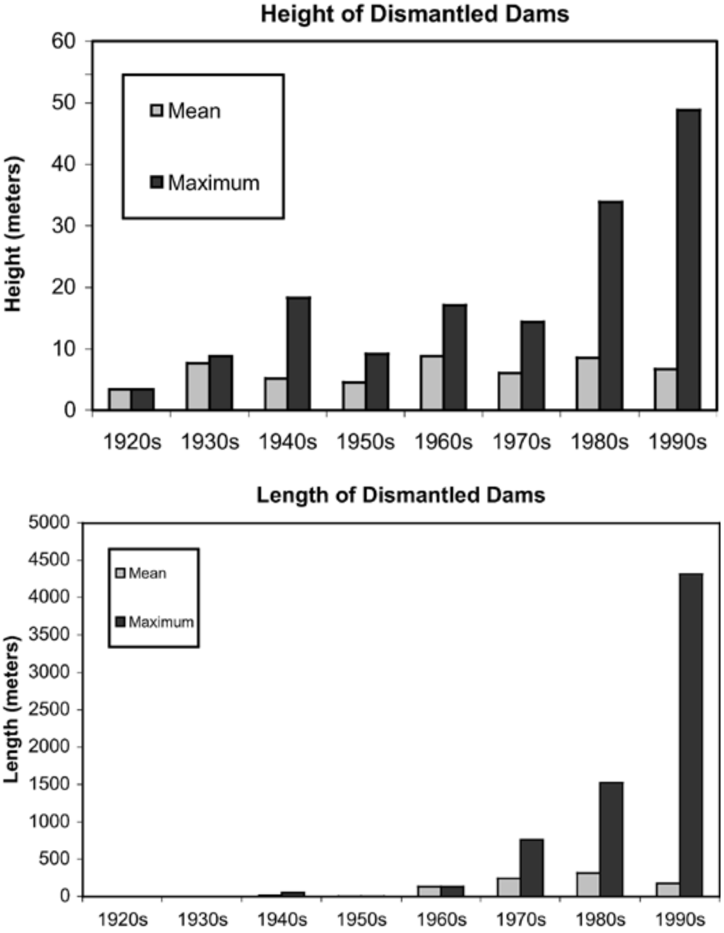

**Figure 2.2** Height and length of dismantled dams by decade, 1920s to 1990s.

The mean height and length of razed dams have not changed significantly in recent decades because the few larger structures being razed are greatly outnumbered by many small dams that are relatively straightforward and inexpensive to dismantle (Figure 2.2). However, the maximum height and length of razed dams have risen in recent years, indicating a willingness to remove dams of significant size in certain cases (Figure 2.2). This trend is likely to continue as relatively large dams (compared with most of those being removed) such as the Elwha River dams of Washington are removed in the near future.

Preliminary data analysis suggests that geography plays a role in the dam removal process. At present, dam removals are more common in the northeastern United States and on the West Coast (a detailed analysis of spatial trends is forthcoming). However, exploratory analysis suggests that the leading states are not those with the greatest numbers of dams or the oldest structures. Instead, states that have funding programs to support removal, agencies that take a leadership role in removal, and advocacy and community support are more likely to remove dams of low utility (Pohl, 2002.)

## PROBLEMS WITH CURRENT DAM REMOVAL DATA

A major challenge in obtaining information on dam removals is that no one organization or agency has formal responsibility for collecting and compiling these data at the national level. State dam safety officers provide "incident" reports for dams in their jurisdiction, and this list may include removals. However, these incident report sheets are long and typically contain little information on dam removals because their main charge is the safety of existing dams rather than detailed reporting of a structure that is removed. The National Program on Dam Performance at Stanford University is making strides by establishing a central Web site (http://npdp.stanford.edu) for searching these incident reports, but to date few structures are found when searching under the term *removed.* A few federal agencies such as the National Park Service also keep incident reports for structures in their jurisdiction, but these valuable resources are limited in geographic extent and focus on specific removals. Thus much of the information on dam removals is found piecemeal through various local, state, and federal agencies and organizations that have responsibility for (or interest in) dams, water, and environmental quality. Collecting data from a wide variety of sources is a long and taxing process, serving as a major barrier to the analysis and dissemination of data on national dam removal.

A second significant problem with dam removal data stems from the varied sources of information. Information on dam removals from any given source tends to be incomplete—that is, limited to the data of interest to a particular organization or agency. In addition, the information is presented from using various reporting styles (e.g., different units of measurement) and nomenclature. These inconsistencies can be corrected with sufficient metadata, but the units are not always clearly indicated in reporting forms. Also, the terms used can be ambiguous. For example, “height” is often available for razed dams, but is this structural height, dam height, or hydraulic height? Because the dams are no longer in place, field verification of reported information is not possible. Finally, even the term *removal* offers challenges. Some dams originally reported as removed were not dismantled, but rather breached or lowered. Agencies interpreted removal broadly even though they were given specific criteria in request letters. These differences in reporting styles and interpretation influence the quality of the data collected on dam removal.

For recent and impending dam removals, sources can often provide a list of engineering or environmental studies that were or are being conducted in association with the removals. These studies provide valuable information on the dam structure and operations, the local environment, why the structure was dismantled, and removal strategies and impacts. However, for dams removed more than 10 years ago, the likelihood of finding detailed sources of information on the removal process declines sharply. In past decades, dam removal was not a major issue, and the investigations, if conducted, are not readily available. Often, sources indicated that they were unaware of any studies conducted before, during, or after the removal, but suspected that there was information “somewhere in the office.” Office staff who were able to provide a report often indicated that other studies were probably conducted, but the location of the complementary studies was unknown. Thus the detailed information needed for analyses of dam removal trends and impacts is difficult to access.

## RECOMMENDATIONS AND CONCLUSIONS

The preliminary results of the study described in this chapter indicate that the number and size of American dams being removed are increasing, and that dam removal efforts are centered in particular states and regions. However, the validity and utility of these trends are dependent on the data used for analysis. Currently, information on dam removal is difficult to obtain and often limited in quality and comprehensiveness.

As suggested elsewhere (Heinz Center, 2002), perhaps the most valuable step that could be taken to remedy this situation is establishment of a national database on dam removals, similar to the National Inventory of Dams, to be managed by a central agency. Such a database would greatly facilitate access to the data and would help to solve the problems with different reporting styles and nomenclature. If this is not possible, a lead organization such as the Stanford University's National Performance of Dams Program could greatly improve the consistency and quality of data by developing a reporting framework that could be used by the diverse agencies and organizations when collecting and reporting dam removal information. This effort would be of limited benefit, however, without a commitment by the agencies and organizations involved in dam removal to provide the funding and personnel needed to track, collect, and report dam removal information. Many individuals contacted in this preliminary research indicated that they were interested in collecting these data, but that their offices had other priorities that limited their ability to concentrate on dam removal.

Dam removal is now receiving substantial national attention because of interest in its economic, social, and environmental consequences. Basic research on dam removal is key to developing greater scientific understanding and a foundation for management decisions, but the limited data on razed dams constrain researchers' abilities to evaluate dam removal trends and to investigate the consequences of past dam removals. If the quality and consistency of dam removal reporting improve, scientists, managers, and the public will have a better foundation from which to advance their understanding of this national issue.

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## 3

# SOCIAL PERSPECTIVES ON DAM REMOVAL

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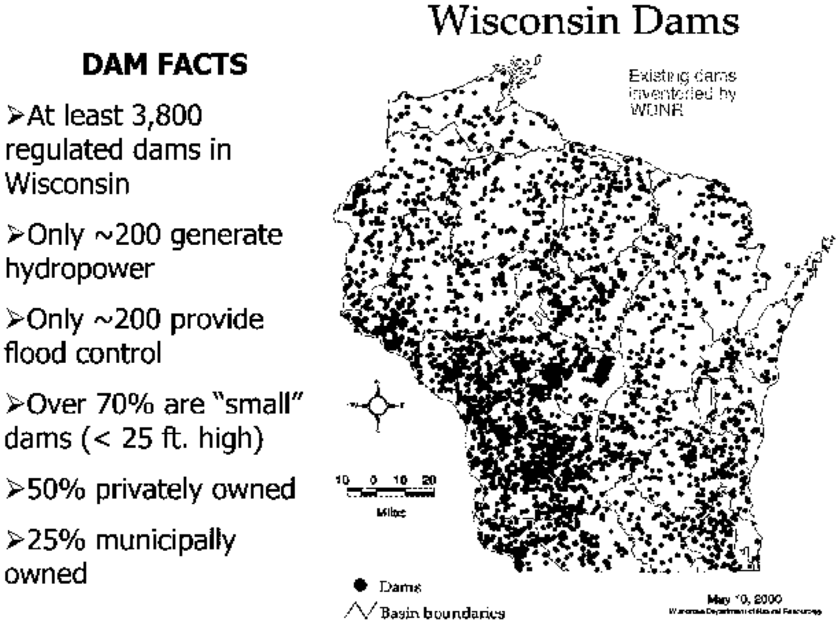
***Abstract:*** Although economic, engineering, and ecological concerns drive the debate about whether to remove or repair a dam, public acceptance of change may be the ultimate determining factor. Nonetheless, little research has looked at the socioeconomic aspects of dam removal. Drawing on Wisconsin's experience with small dam removal, this chapter synthesizes the major public concerns about dam removal and introduces the notion that consideration of dam removal as a viable option is correlated with the degree of public understanding about how rivers and dams function. The chapter also describes how social science tools, such as social marketing and public surveys, can improve the decision-making process. The research needed in this area includes pursuing specific economic, geomorphic, and ecological data as well as well-developed case studies. In doing so, researchers should consider the fate of dams beyond the local scale—that is, at the watershed, state, and national levels.

A RECENT Heinz Center report (2002) concluded that little research exists on the human dimensions, or social science aspects, of dam removal. This conclusion is especially interesting in light of the fact that dams are built to address societal needs, and it is those changing needs that are pushing the issue higher on the public agenda today. Ecological, engineering, and economic factors drive the decision of whether to remove or repair a dam, but public acceptance of change may be the ultimate determining factor (Johnson and Graber, 2002). Furthermore, all the economic issues and virtually all of the biological or technical issues affect humans, and therefore can translate into social issues.

This chapter examines some of the concerns most commonly expressed by community members in the debate over whether to repair or remove obsolete and uneconomical small dams in Wisconsin. It also introduces the notion that there are links between public understanding of river and dam functions and acceptance or rejection of dam removal as a viable option. Finally, it suggests social science theories and practices that may be useful in improving what is typically a poorly informed and divisive decision process, and it identifies the research needed.

Wisconsin is the national leader in dam removal, so this chapter draws on that state's experience with small dam removals (less than 25 feet high). Since 1960, Wisconsin has removed 80 dams, 56 of these since 1990. Removed structures had an average height of 14 feet; average removal costs were $115,500; and average estimated repair costs were $700,000. Typically, these dams were no longer serving an economic function and needed significant repairs. About 3,800 registered dams are in Wisconsin, averaging 15 feet in height. Of these, 75 percent are owned by municipalities or private parties (Figure 3.1). Fewer than 200 of these


**DAM FACTS**

- ➢At least 3,800 regulated dams in Wisconsin
- ➢Only ~200 generate hydropower
- ➢Only ~200 provide flood control
- ➢Over 70% are "small" dams (< 25 ft. high)
- ➢50% privately owned
- ➢25% municipally owned

**Figure 3.1** Location of and some facts about Wisconsin dams. *Source*: Wisconsin Department of Natural Resources (WDNR), May 10, 2000.

dams produce hydropower, and some 200 more provide flood control benefits.

The Wisconsin experience does, however, present some limitations. Some issues discussed here may not be relevant to other situations, such as when considering removal of a large dam or one that is still serving a significant public benefit or generating a profit. Furthermore, hydrological and geomorphic variations in rivers elsewhere may influence what concerns the public will have. Nonetheless, much can be learned from both the successes and the challenges faced in Wisconsin. More dams have been removed in Wisconsin than in any other state, and the state has produced many case studies in which dam removal benefited the river and the community. The information presented in this chapter synthesizes decades of experience with the social issues surrounding dam removal and river restoration.

## COMMON SOCIETAL CONCERNS

Dam removal is a contentious issue in most communities. Before electing to repair or remove a dam, decision makers must carefully consider for both options their environmental, engineering, economic, and societal aspects, which are complex and interrelated (River Alliance of Wisconsin and Trout Unlimited, 2000). Unfortunately, decisions about whether to repair or remove a dam are frequently made with incomplete and inaccurate information (Born et al., 1998). Furthermore, the prospect of what may be perceived as a major change (i.e., loss of an impoundment and dam) can elicit anxiety and a sense of powerlessness among community members, especially if the ultimate decision is to be made outside of the community or includes significant involvement by "outsiders" (e.g., state agency staff or statewide or national conservation groups). Johnson and Graber (2002) have explored how humans tend to respond to decision making in such stressful situations.

Over the past nine years, River Alliance of Wisconsin staff have worked with more than 25 communities on dam removal issues in Wisconsin. The most consistently expressed concerns about dam removal center on what will happen to the river and to exposed land once a dam is removed. The concerns about dam removal most commonly voiced by the public during the dam decision process are the following:

- The river will become a trickle or disappear completely.
- Flooding will increase (even if dam provides no flood control).
- The impoundment will become a permanent stinking mudflat.
- The government will seize the land that should be mine.
- My property values will decline.
- West Nile virus, blastomycosis, and so forth will be rampant.
- We are losing an important historical monument.
- I will never catch "a keeper" in the river.
- The dam is where our children swim, ice skate, and so forth.

Some of these concerns and the associated research needs are described in more detail in the rest of this section.

## COST AND ECONOMIC CONCERNS

Cost and economic factors have consistently been the strongest drivers in the decision to remove a dam (Trout Unlimited, 2001). Of dams that have been removed in Wisconsin, the cost of repair was, on average, three to five times more than that of removal (see Chapter 4 of this volume and Born et al., 1996). Because selective dam removal is increasingly recognized as a cost-effective river restoration tool, state and federal grants and other funding are becoming more readily available for dam removal than for dam repair.

The impact of dam removal on adjacent property values is often of great concern. Riparian landowners, who often view their property as "lake frontage" rather than "river frontage," fear their property values will decline with loss of the dam and impoundment (Born et al., 1998). Little research has been directed toward assessing the impact of dam removal on property values. Preliminary studies in Wisconsin found that riparian property values after dam removal either remained unchanged or decreased temporarily and then rebounded within two years; 10 years after removal, property values were no lower than before removal. Anecdotal evidence in Wisconsin suggests that land adjacent to any water body is considered valuable. For example, when a dam was removed from the Prairie River in Merrill, Wisconsin, in 1999, three riparian landowners put their homes up for sale. All three received their asking price; two of the three properties were purchased by avid trout anglers seeking to live on a newly restored trout stream (Bob Martini, Wisconsin Department of Natural Resources, personal communication). Chapter 4 of this volume deals with the economic issues surrounding dam removal in detail.

The primary research question is: What are the effects of dam removal on property values? It is important to better understand how dam removal affects land and property values and the economic health of the community in the short and long term. This concern is one of the most significant for affected residents and one in which research is sparse.

## OWNERSHIP OF EXPOSED LANDS

Ownership of land once underneath an impoundment must be determined on a case-by-case basis and in accordance with state laws governing ownership relative to bodies of water. At times this can be a straightforward task, such as when the dam owner purchased the property on which an impoundment was created. But when the surrounding land has multiple owners and the deed history is not clear, determining ownership is complicated and potentially contentious. For example, if a deed specifies that a landowner's land extends to the water's edge and the dam owner owns land beneath the impoundment, the lakefront property may lose its access to the lake if the dam is removed. As another example, when the holdings of two owners extend to the center of the riverbed, property boundaries will be defined by how the river reestablishes its course within the former impoundment. Frequently, the records are unclear about who is the owner of record, introducing a further element of uncertainty into an already complicated process.

Ownership may be a sensitive issue for the public because it confers on the owner the right to determine how the land will be used once the dam is removed. One homeowner in Columbus, Wisconsin, expressed this concern during a public meeting to discuss the option of dam removal. "I bought this property because I had access to the water. If dam removal means I get a restored river running through my backyard, then great! If it means that there is suddenly public access and tons of people walking through my backyard, then I have a big problem with dam removal, even though I support restoring the river" (Columbus, Wisconsin, October 10, 2002).

## RECREATIONAL CONCERNS

Is the impoundment used frequently for fishing, boating, swimming, or ice skating? In communities where the impoundment is an important recreational resource, the loss of this resource would understandably frustrate residents. In smaller municipalities with limited funds, the activities associated with an impoundment may be some of the only recreational outlets in the community. Conversely, if the impoundment has become filled with sediment and is not much used for recreation, the possibility of enjoying the greater recreational opportunities associated with a restored river may be appealing to local residents. This issue highlights the challenge of use conflicts, pitting the desires of residents who fish for panfish in the impoundment against the desires of residents who would like a free-flowing river on which to canoe. There is no simple answer to such a challenge, but it does point to the critical need to identify stakeholder concerns during the decision-making process and to consider the situation in the larger context—for example, whether other similar recreational opportunities are available nearby.

The primary research questions are: After removal of a dam, do people adapt their recreational activities to the free-flowing river, and are new recreational opportunities anticipated and realized? Do recreational changes after removal translate into community economic development opportunities? Similar information is needed when dams are not removed.

## AESTHETIC CONCERNS

One of the biggest and most consistent concerns expressed is about the appearance of the former impoundment after dam removal. Some concerns reflect personal preference—for example, a preference for still water views rather than flowing water views. Other concerns reflect a lack of understanding of how both rivers and dams work. For example, two of the most commonly expressed aesthetic concerns are that the river will dry up without the dam and that removal will leave an eyesore in the form of a permanent mudflat. Different perceived values also play a role. For example, whereas for a river advocate dam removal may conjure up images of meandering rivers and beautiful riverwalks, for a riparian landowner dam removal may conjure up visions of acres of mudflats and rivers running dry (Figures 3.2 and 3.3).

At several dam removal sites where riparian areas were restored and community-based revitalization efforts were carried out, residents came to appreciate their restored river as much as or more than their millpond. As a community leader of West Bend, Wisconsin, explained

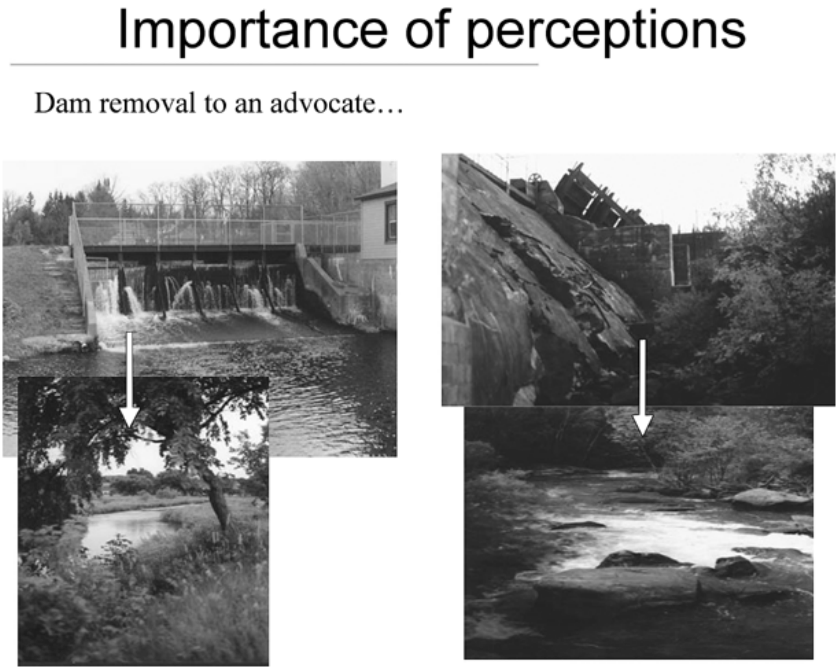
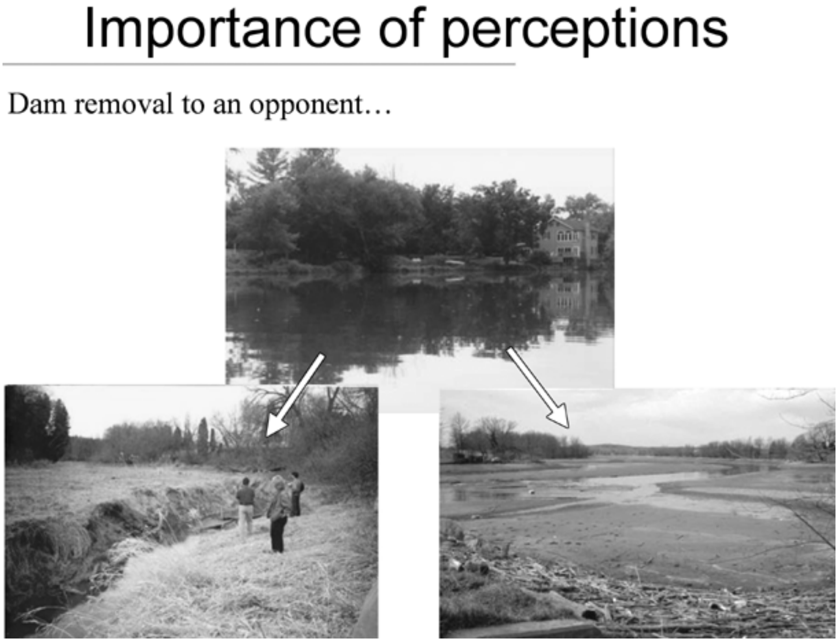


**Figure 3.2** Perception of a supporter of dam removal. *Source*: River Alliance of Wisconsin.

about removing the local dam and creating a 60-acre park, “At first people were very skeptical of what was going to happen. But of course now people know very well what has happened and the whole city is happy about it” (River Alliance of Wisconsin and Trout Unlimited, 2000).

Experience has shown that aesthetic concerns can be alleviated by helping stakeholders to envision the site after dam removal through the use of artist renderings or computer-generated visual simulations of the restored river (Figure 3.4). Such visual aids are extremely helpful in easing fears that the former impoundment will be an eyesore. Some communities will prefer a managed public space such as recreational parks and playing fields, while others will seek to create a natural wildlife habitat within the former impoundment. A West Bend alderperson had this advice to offer other communities considering dam removal: “The most important thing is to have an alternative [plan of the former impoundment]



Importance of perceptions

Dam removal to an opponent…

**Figure 3.3** Perception of an opponent of dam removal. *Source*: River Alliance of Wisconsin.

for people to look at. What will the area be like? Will it be an asset to the community, to my property? You've got to have a vision" (River Alliance of Wisconsin and Trout Unlimited, 2000).

The primary research questions are: What information is needed to help manage sediment after dam removal? What further study will facilitate successful restoration of the river and of the impoundment to achieve the most desirable biological and aesthetic outcomes, including strategies to minimize colonization by invasive or other undesirable species?

Some of the concerns just identified, such as loss of recreational opportunity, loss of waterfront access, and effect of removal on property values, should be addressed on a case-by-case basis; others, such as fear that the river will disappear or that mudflats will be permanent, require public education on how rivers function and how dams work.

**Figure 3.4** Computer simulations help the community visualize a former impoundment after removal. (*Top*) Photo of Franklin Dam, Sheboygan River, Wisconsin. *Source*: River Alliance of Wisconsin. (*Middle*) Computer simulation by a WDNR biologist of the site after dam removal. *Source*: Wisconsin Department of Natural Resources. (*Bottom*) Photo of the actual site after 12 months. *Source*: River Alliance of Wisconsin.

## USING SOCIAL SCIENCE THEORIES AND PRACTICES TO IMPROVE DECISION PROCESSES

As described earlier, most of the dams facing a "repair or remove" order have been functionally obsolete for years and are a financial burden on the owner. Experience and research show that selective removal of these structures can result in public benefits such as permanent removal of a public safety hazard, cost-effective improvements in water quality and riverine habitats, and opportunities for economic revitalization and associated quality of life enhancements around a restored river (American Rivers, 1999; Trout Unlimited, 2001).

Despite the public benefits that could accrue from removal, most communities faced with a decision to repair or remove an obsolete dam choose to repair and keep the old structure, often at great cost to the dam owner, the river, and the community. In the 1990s, only 9 out of 174 dams requiring repair were removed (Born et al., 1996). For every dam that is removed in the state today, five more are repaired or built (Meg Galloway, Wisconsin Department of Natural Resources, state dam safety engineer, personal communication).

In recent years, opinion has shifted in Wisconsin, and dam removal is more routinely considered to be a viable option and given due process. However, practitioner experience indicates that lack of public understanding of river and dam functions is a major obstacle to informed decision making. Several surveys of communities in Wisconsin (described later in this section) point to a relationship between public education about rivers and dams and willingness to consider removal as an option. In many other states, however, dam removal continues to be frequently excluded out of hand; it never really gets "on the radar screen" as a viable option that can be accepted or rejected on its merits.

## SOCIAL MARKETING

Johnson and Graber (2002) explore how social science concepts and principles can be applied to increase consideration of dam removal as an option, including a practice called social marketing—that is, marketing a service or idea in which the benefit accrues not to the "seller" but to society. Social marketing, which draws on proven commercial marketing practices, has been used most extensively to achieve societal benefits in the areas of public health and safety (Andreasen, 1995). Its efforts are outcome-based; they are designed to produce a change in individual human behavior, as opposed to the typical information and education programs which are designed simply to increase awareness and understanding. Social marketing is based on the long-standing body of scientific literature on diffusion of innovations—that is, how new products or new ideas (such as removing the dam the community has always known) spread and gain acceptance within a community or other social settings.

At the heart of social marketing is the goal of identifying and addressing perceived barriers to the desired behavior—in this case, gaining a thorough understanding of why community members do not view dam removal as a viable option and directly addressing those concerns. An emerging practice called community-based social marketing concentrates on the community level (rather than on the individual level), encouraging environmentally sustainable behavior as well as consideration of public health issues (McKenzie-Mohr, 2000).* Information about perceived barriers is obtained through a variety of means such as focus groups, or lower-cost means such as telephone interviews and written surveys.

## SURVEYS

Wisconsin researchers and state natural resources agency personnel have used written surveys in at least three situations in which dam removal was an option or could have been an option: during a public information effort and before and after such an effort. A primer on using surveys for dam removals and a sample survey are offered online from the University of Wisconsin's Water Resource Management Workshop (Gaylord Nelson Institute for Environmental Studies, 2000).

In 1997, during an "open house" in the city of Baraboo, Wisconsin, a written survey was used by the state natural resources agency to gather community opinions on current recreational use of the impoundment in Baraboo and potential uses of the river if the Waterworks Dam were removed. Most respondents anticipated little change in recreational use of the river with dam removal (Figure 3.5). Respondents also preferred certain improvements after dam removal such as construction of a river walkway (64 percent) and boat and canoe access (53 percent) rather than dredging, fish stocking, or historical interpretation (all less than 35 percent). These results are telling because the top choices allow residents to interact directly with the restored river. The response to the survey ultimately guided the decision by the Wisconsin Department of Natural Resources (WDNR) and city of Baraboo to incorporate specific design components into the restoration project, such as a river walkway and an

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* The Canadian government and a private partner provide case studies and a planning guide for practitioners based on community-based social marketing principles at http://www.toolsofchange.com (accessed January 19, 2003).

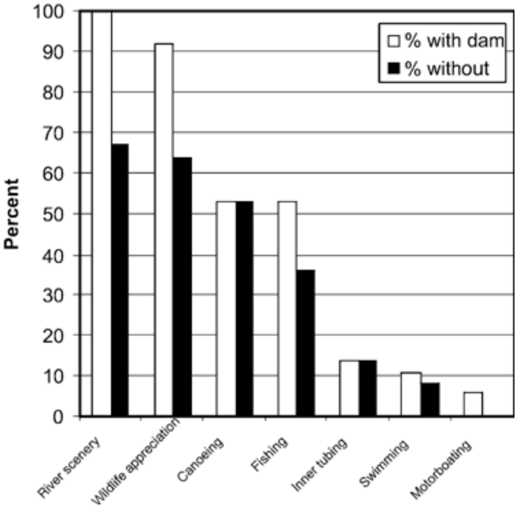

**Figure 3.5** Percentage of survey respondents who engage in various river-associated activities with the dammed river and percentage who predict they will engage in that activity after removal. *Source*: Survey conducted at a public meeting to discuss the future of Waterworks Dam, Baraboo River, Wisconsin, 1996; provided by R. Hansis, Wisconsin Department of Natural Resources.

accessible fishing hole along the riverbank (R. Hansis, WDNR, personal communication).

A survey conducted after public information efforts can be an effective way to hear from an informed community and can clarify whether community members are willing to pay for their desired outcome (and, if so, how much). In 1999, in the town of Rockdale, Wisconsin, University of Wisconsin extension staff administered a written survey after a three-hour public information meeting on the option of dam removal. Despite significant opposition to removal from a vocal minority, 45 percent of respondents wanted the millpond removed and another 33 percent were indifferent. Of those who wanted the millpond to stay, 40 percent were not willing to pay anything (through taxes or special assessments) toward repair of the dam (Table 3.1). Because the owner of the dam, a prominent community member, did not want to harm the community, it was especially important for him to hear the opinions in the survey prior to making the final decision to remove Rockdale Dam in 2000.

**Table 3.1** Summary of Survey Administered at Public Information Meeting on Option of Removing Rockdale Dam on Koshkonong Creek, Wisconsin

| Survey Question | Percent Negative | Percent Neutral | Percent Positive |
|---|---|---|---|
| Effects of millpond on quality of life | 10 | 35 | 55 |
| Changing pond to river | 21 | 42 | 37 |
| Economic impact of millpond | 14 | 74 | 11 |
| Desirability of retaining millpond | 45 | 33 | 22 |
| Willingness to pay to keep dam (and amount) | 40 | 25 unsure | 20 ($50–100)<br>10 ($100–300)<br>5 ($300–500) |

*Note*: The table illustrates the percentage of respondents who felt they would be positively, negatively, or neutrally affected by dam and river restoration and what they would be willing to pay to keep the dam. *Source*: Habecker and Rizzo (2000).

In 2002 the village of Pardeeville, Wisconsin, in conjunction with University of Wisconsin researchers, conducted a random mail survey of the community as part of an effort to manage the degraded water quality of the local impoundment, which was suffering from excessive sediment loads, weed growth, turbidity from high carp densities, and disruptive algal blooms (Gaylord Nelson Institute of the Environment, 2002). The survey was conducted by mail before any public information on the relative merits of different management options, including removal of the dam, was released. Of the 266 respondents, only one percent thought the dam contributed to the water quality problems in the impoundment, and no one thought dam removal would improve the water quality. The results illustrate the need for public education about the potential effects of the dam on water quality, especially if the village is investing substantial financial resources in improving water quality.

Social scientists should undertake social marketing campaigns to determine the effectiveness of using these campaigns and other practices designed to effect social change around dams and rivers. Similarly, research should explore the use of less sophisticated but critically important information-gathering tools, such as written surveys, to determine current levels of understanding of dam and river functions and the effects of keeping or removing dams and to guide public information and education efforts around dam decision making.

## CONCLUSIONS

Research (Born et al., 1996) and practitioner experience point strongly to the need for information that can be used to better predict outcomes associated with both keeping and removing dams. Over the past decade, nongovernmental conservation organizations such as the River Alliance of Wisconsin, Trout Unlimited, and American Rivers, Inc., published resources to help decision makers in individual dam removal situations; these organizations recognized that the scientific literature was lacking information about what happens after a dam is removed. The case studies and other information gathered by these citizen advocacy organizations have been referenced heavily by agency personnel, elected officials, and other decision makers. Nonetheless, peer-reviewed university and agency research is critical to the credibility of public education efforts on natural resource issues, especially if the issue is controversial, as is typical of dam removal questions (Johnson and Jacobs, 1994).

Decision-making processes will be vastly improved when reasonable predictions can be made about what will happen to the river, the community, and the dam owner in both the short and long term if the dam is repaired and if the dam is removed. Specific research needs for the concerns most frequently expressed by community members facing a repair/remove decision are identified both in this chapter in the section on cost and economic concerns and in Chapter 4.

Scientific research also is needed to inform policy decisions above the local level—that is, at the watershed or basin, county, state, and national levels. Although individual dams have been the focus of much attention, the potential cumulative impacts of aging dams have not gone unnoticed by elected officials and continue to be pushed higher on the public agenda. Some states (e.g., Pennsylvania, Wisconsin, and California) have revisited laws, some over a century old, affecting dams and their host rivers. Socioeconomic research is needed to inform such policy decisions at this level. For example, it is important to quantify the potential economic liabilities and benefits associated with aging low-head dams (in one watershed, one state, or the nation) and to identify what portion of this cost is likely to be borne by taxpayers and what part by private dam owners and to whom the benefits accrue. It also is important to quantify the cumulative costs of mitigating water quality, fisheries, and other environmental impacts associated with repairing and keeping the structures and to balance these against the potential environmental benefits such as preventing migration of invasive or contaminated species or containment of contaminated sediments. Investigators must then identify to whom these costs accrue (i.e., are they public or private?) and to whom the benefits accrue.

As Born et al. (1996), the Rockdale Dam survey, and practitioner experience indicate, public understanding of the functions and values of both rivers and dams is typically very low. In addition to the need for scientists to disseminate research findings, resource agencies (at all levels), university extension services, nongovernmental groups, dam owners themselves, and private foundations are among those who must take responsibility for improving decision processes by ensuring that information is available—and in a form that is understandable to those who have a stake in the outcome of the decisions (Johnson and Graber, 2002). But informational and educational efforts and more sophisticated efforts directed at social change, such as social marketing, are not without cost.

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# 4

# POTENTIAL ECONOMIC BENEFITS OF SMALL DAM REMOVAL

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***Abstract:*** More than 500 dams have been removed in the last century in the United States, usually for economic reasons. The majority of these have been small dams, defined as those whose fate can be discussed and determined by local communities and local government agencies.

From the perspective of a community considering options for a nearby dam, economic issues can be both the driving force and the major sticking point for dam removal. Many aging and deteriorating small dams have been removed after a direct cost comparison of repair and removal. Particularly when the long-term costs of maintenance and future repairs are taken into account, removing a dam has typically been less expensive than repairing a deteriorating structure.

This direct cost comparison may be the most obvious economic issue, but removing a small dam also can have other benefits, including relief from certain financial burdens and improved opportunities for local economic growth. Removing a small dam can also remove the financial burdens of future maintenance and repair, liability costs, impoundment water quality management, and watershed and fisheries management. Opportunities for economic growth include the economic activity associated with improved fishing and boating, community revitalization around a riverine waterfront, and quality-of-life improvements associated with improved aesthetics and recreational opportunities, but not all of these benefits are realized or can be realized for all small dam removals. Little research has been conducted on the *long-term* economic benefits and impacts of small dam removal. The long-term impact of small dam removals on nearby property values is often a sticking point in discussions and is consequently an issue in particular need of additional research.

MORE THAN 500 dams have been removed in the last century in the United States (American Rivers, Inc., et al. 1999; American Rivers, Inc., 2001). Although economic issues do not commonly initiate removal discussions, they usually drive decision making. Dams are removed for a variety of reasons, but many small dam removals are triggered by safety concerns. Once a dam no longer conforms to modern safety standards, the dam's fate is generally decided by a direct comparison of the cost of repairing the structure and the cost of removing it. Even for dams that are removed purely for water quality improvement or habitat restoration, the availability of funding can be the fundamental decision-making point. Simply put, dam removals are dependent on economics.

Despite the number of dam removals, little research has been conducted on their economic impacts. A review of the literature reveals studies that assess preremoval willingness to pay (Boyle et al., 1991; Freeman and Shipman, 1995; Loomis, 1996; Gilbert et al., 1996) or predict the economic impacts of dam removal (Marcouiller et al., 1999), but none that actually look at postremoval data to assess the impact on the community, local businesses, or property values. Much of the information that does exist comes from Wisconsin, where more than 80 dams have been removed (American Rivers, Inc., et al., 1999).

This chapter looks exclusively at "small" dams. Different agencies use different criteria to distinguish between small and large dams, but the criteria of dam height and impoundment size are common. A dam's physical characteristics may offer an approximation of the economic scope in dam removal discussions, but does not really capture the distinction from an economic standpoint. This chapter will use the following, less precise definition: a "small" dam is one whose fate can be discussed and determined by the local community and local resource managers. Based on this definition, the majority of dams that have been removed are small. Large dam economics includes a range of regional and even national issues that do not occur with small dams and therefore require a different set of analyses.

In 2001 Trout Unlimited produced a publication that reviews the economic benefits for dam owners, communities, and local businesses of removing small dams. This chapter draws frequently on that report, but the chapter is not intended to present an in-depth economic analysis of dams and dam removal. Because of the minimal amount of research available on the topic, much of this chapter will offer anecdotes and a discussion of possibilities rather than a rigorous scientific analysis.

## DIRECT COST COMPARISON: REPAIR VS. REMOVAL

Aging small dams are often removed after the direct costs of repair and the costs of removal are compared. Although dam removal is usually less expensive than dam repair, it also is accompanied by additional economic benefits. These benefits include relief from certain expenses associated with the dam such as operations and maintenance, liability costs, impoundment management, and fisheries management. The opportunities for economic growth include the economic activity associated with improved fishing and boating, community revitalization around a riverine waterfront, and quality of life improvements associated with improved aesthetics and recreational opportunities.

Data from 31 small dams that were ultimately removed reveal that the lower-end repair cost estimates for an aging small dam are three to five times higher than the cost of removal (Born et al., 1996; Trout Unlimited, 2001). Indeed, for several dams repair cost estimates were more than 10 times removal costs. The repair cost estimates varied significantly, from $30,000 to $5 million, and included costs to bring the dams up to modern safety standards, repair operation facilities, or provide effective fish passage. In addition, small dam repair costs are typically underestimated because project managers often do not realize the extent of repairs until the work has begun, and surprises are common because the interior of the dam can be in worse condition than expected.

Assessments of such direct cost comparison data can be clouded by the range of options and differing environmental requirements guiding the removal process. For example, rebuilding the deteriorating Woolen Mills Dam on the Milwaukee River in Wisconsin was estimated at $3.3 million. The cost of removing the dam in 1988 was $82,000. However, an additional $2.3 million was spent on the project for engineering design, grading, seeding, channel work, fisheries improvements, construction of a new bridge, and development of a park over 61 acres of the former impoundment (Trout Unlimited, 2001—see figures 4.1 and 4.2 for before and after views of the dam site). In the end, then, the cost estimate to repair the dam was still greater than that for the entire removal project, but there was a smaller difference in the cost figures when the additional project costs were included.

Such additional costs have not been typical, because in the past little work was done in addition to removing structures. Now, however, a greater emphasis is placed on doing additional channel and floodplain work for habitat, stabilization, and recreation. But such work can add significantly to removal project costs. If significant sediment management is necessary, particularly if there is contaminated material in the impoundment, dredging or removing material can be the most expensive aspect of

**Figure 4.1** Woolen Mills Dam on the Milwaukee River before removal. Courtesy of the River Alliance of Wisconsin.

**Figure 4.2** The Milwaukee River 10 years after removal of Woolen Mills Dam. Courtesy of the River Alliance of Wisconsin.

a removal project and can cost an order of magnitude greater than simple structure removal (see Chapter 6).

These additional costs raise the important issue of who pays removal costs. Dam owners are frequently responsible for removal, and will make decisions based on their direct expenses. Usually, these direct expenses include only the cost of dam repair versus the cost of structure removal. Other project costs, such as developing recreational facilities, are commonly met by grants or other funding means. Therefore, the total costs of the removal project are frequently divided among different entities.

Many small dams are not viable flood control or hydropower facilities, but they can provide services such as water supply. If the dam or impoundment serves such a purpose, the cost of replacing its uses should be considered in removal costs.

## RELIEF FROM FINANCIAL BURDENS

A direct cost comparison between dam removal and repair, while the most obvious economic issue, does not take into account a range of other potential economic activity involved and only includes short-term costs. Removing a dam is a onetime cost, whereas maintaining a dam involves recurring costs over time. Dam removal can provide relief from many of these financial burdens.

*Operations and maintenance*, needed daily to operate a structure and to keep it safe and in working order, include tasks such as keeping gates and other structures operational and maintaining proper signage, security, the property and any other facilities, and liability insurance. An example of the costs of operations and maintenance is provided by two small dams in Wisconsin from 15 to 20 feet high. Their operating costs are $10,000–$60,000 a year (Trout Unlimited, 2001).

Dams are constructed with a finite design life, although a well-designed and maintained structure can last many decades. Repairs are necessary at some point, and most likely repeatedly, to keep a dam operational for its intended uses. Common repairs are fixing inoperable control gates, repairing cracking concrete, and reconstructing effective fish passage. As an example of the magnitude and recurrence of repairs, the 30-foot-high Little Falls Dam on Wisconsin's Willow River was built in the 1920s and had repair costs greater than $250,000 each year in 1980, 1990, 1991, and 1996 (Trout Unlimited, 2001).

Another cost of dams is related to the *liability* associated with dam failure, personal injury on or near the structure, or drowning. Even small dams can pose significant risks. In 1999 the Federal Emergency Management Agency (FEMA) reported to Congress: "Failure of even a small dam releases sufficient water energy to cause great loss of life, personal injury, and property damage." Although small dam failures generally do not cause the same degree of damage as large dam failures, they occur more frequently because small dams are commonly older structures, not as routinely maintained, and have less spillway space to relieve flood pressure.

Overall, the National Performance of Dams Program estimates that the safety costs for aging dams in the United States will be about $1 billion a year for the next 20 years. These costs include those for upgrades of unsafe dams, dam failures, and state dam safety programs (McCann, 1998).

The combined cost of insuring against dam failures and accidents can result in high liability costs. For the largest number of dams, those that are small and privately owned, dam insurance can be prohibitively expensive. Because of the uncertainty of risk, insurance companies charge rates according to worst-case scenarios (FEMA, 1999).

Dam removal also eliminates the need to meet certain *impoundment management* costs. Dam impoundments collect sediment and nutrients that normally flow downstream. Over time, many small dam impoundments fill in with sediment, algae, and plant growth. As they fill in, they can lose their ability to support both operational and recreational uses. Many dam owners (often small communities) choose to dredge impoundments to maintain uses and aesthetics. Dredging is usually expensive, with onetime costs ranging from $200,000 to $700,000 for a 30–100-acre impoundment (Marshall, 1988). But dredging is not a permanent solution because it does not remove the source of the material filling the impoundment. Consequently, an impoundment that needs to be dredged will likely have to be dredged again. Some dam owners will harvest excessive vegetation from impoundments as an alternative or in addition to periodic dredging. Although harvesting is cheaper than dredging, it can lead to considerable expenses over time because it often must be done every year.

Certain *fisheries management* costs incurred because of a dam also can be relieved by dam removal. For example, thermal problems often arise in streams as water sits impounded under the sun during the summer. The results are significant, particularly affecting coldwater fisheries. In addition, dams can impede the movement of fish to upstream spawning grounds. In many states, fish managers will annually stock coldwater species in rivers, despite the fact that thermal and connectivity conditions prevent the fish from sustainably reproducing. Removing the dam would eliminate the costs of stocking, provided other habitat needs are also met. For example, more than a mile of a Class 1 trout stream—meaning a sustainably reproducing population—was restored in Wisconsin's Tomorrow River by the removal in the mid-1980s of Nelsonville Dam (Trout Unlimited, 2001).

## OPPORTUNITIES FOR ECONOMIC GROWTH

Although communities usually recognize that dam removal will mean the loss of impoundment-based recreation, they may not realize that dam removals can bring significant gains related to river-based recreation. Improved recreational opportunities can bring outside money into communities through tourism-related activities such as shopping and lodging. Dam removal also can serve as a catalyst for community revitalization and can improve aesthetics, both of which can bring more people to the waterfront. Any action that brings more people to an area usually brings economic growth to that area. Maximizing the economic potential of dam removal may require thoughtful plans to foster these recreational improvements or revitalize communities.

### FISHING

Removing a small dam may harm a fishery by allowing previously blocked invasive species to move upstream. However, more commonly, removing a small dam simply changes the assemblage of fish over time from flatwater to flowing-water species and sometimes from warmwater to coldwater species, depending on natural, free-flowing thermal conditions. The potential thermal change highlights an important distinction between large and small dams. Some large dams with impoundments of sufficient depth that release water from the bottom of the impoundment can create high-value coldwater fisheries downstream. Small dams do not have impoundments with sufficient depth to release cold water if the system was not previously coldwater. Therefore, small dam removals either will have no effect on the thermal regime or will make the water colder in the summer by removing the slow-moving, exposed, high-surface-area impoundments that were previously warmed under the sun. Such changes can result in fisheries with higher economic value. Walsh et al. (1992), who compiled the results of numerous economic studies on water-based recreation, found that outcomes vary from site to site, but that, on average, migratory and coldwater fisheries have greater overall economic value than warmwater fisheries.

Dam removal also restores connectivity and can improve the dissolved oxygen regime, which can help to improve fisheries overall.

The arrival of more anglers at a river will bring more economic activity. Fishing carries a high economic value because anglers spend annually more than $37.8 billion (Maharaj and Carpenter, 1998).

## BOATING

Removing a dam also changes boating recreation from flatwater-based to riverine-based. The resulting economic change has not been the subject of much research, but it is known that canoeing and kayaking can bring recreation dollars to areas with free-flowing stretches. The tens of thousands of small dams in the United States are a hindrance and sometimes even a danger to canoeing and kayaking. The scarcity of free-flowing stretches alone can increase the economic value of these increasingly popular sports. For example, since removal of Ontario Dam from Wisconsin's Kickapoo River in the early 1990s and other restoration work, nonlocal canoeists spend $1.2 million a year in an economically depressed rural region of the state on rentals, lodging, gas, and other items (Anderson et al., 2001). Dam removals also have created opportunities for tubing and associated camping facilities (Trout Unlimited, 2001).

## Community Revitalization

Dam removals have served as catalysts for local communities to revitalize their riverfronts. For example, the community of Baraboo, Wisconsin, is planning downtown enhancements brought about by renewed interest in the river after three dam removals near the downtown area. Its plans include developing fishing access, a riverwalk, and a park, as well as renovating a bridge to improve visibility of the river.

In addition to community planning, developers along the Kennebec River in Maine have taken an interest in riverfront properties since removal of Edwards Dam in 1999. On this trend along the Kennebec, a recent *Wall Street Journal* article reported, “Having a hard time revitalizing your downtown? You may want to consider knocking the dam down” (Grant, 2000). The article goes on to explain that real estate speculators are spending millions of dollars buying properties and renovating them, focusing on the river and the potential for a waterfront community.

## Local Business

Although there has been very little research on the topic, local businesses can benefit from the revitalization efforts and improved recreational opportunities associated with dam removals. For example, more than 37,000 people a year now use a park in downtown West Bend, Wisconsin, built over the former impoundment of Woolen Mills Dam where there had been very little activity. Increased use of the area translates into more activity and exposure for nearby businesses. A local business executive also noted that the improved quality of life associated with the new recreational opportunities and improved aesthetics helps his business to recruit and keep employees (Trout Unlimited, 2001).

## Cost-Effective Systemwide Restoration

Removing dams may be a cost-effective way to improve a systemwide river habitat. For example, at a cost of under $1 million 17 dams have been removed from the Conestoga River in Pennsylvania since 1996. The removals have allowed the return of American shad to the river, which had been absent for more than 80 years. The rejuvenated fishery is expected to generate $2–3 million a year for local economies (Trout Unlimited, 2001). A similar project is under way on Connecticut's Naugatuck River, where eight dams either have been removed or are pending removal or modification to improve water quality and habitat. The first four dams were removed for under $400,000 (Trout Unlimited, 2001).

## RESEARCH NEEDS

A recent study in Wisconsin found that local decisions on dams are often based on incomplete and inaccurate information on environmental and economic factors related to dams and rivers (Born et al., 1996). Even when available, the best scientific data are not always used in contentious community decisions (Johnson and Graber, 2002), but for dam removal the research is not even available. More research on the relevant economic issues could help communities make more informed decisions (Heinz Center, 2002).

Because the physical effects of dam removal change over time as a denuded impoundment evolves into a flowing river surrounded by vegetation, it is likely that economic impacts also will vary with time. Therefore, economic research should concentrate on both the short-term and long-term effects of dam removal. Important topics for research include the overall economic effects of dam removal on local businesses, communities, and individuals. More specifically, the effect of dam removals on nearby property values is usually the most important issue to a community discussing the fate of a dam. Consequently, it is an issue that especially needs additional applied research.

Studies have shown that the land values of properties near water are tied to water quality (Young, 1984; Bouchard et al., 1996; Jobin, 1998). For example, Jobin (1998) found that poor water quality in the Neponset Reservoir in Massachusetts depressed surrounding property values by 40 percent. As collection areas for sediment and nutrients, dam impoundments often have low dissolved oxygen levels and higher water temperatures, resulting in poor water quality.

Proximity to open space such as parks or water also can increase property values (Miller, 1992). Both rivers and impoundments could be considered open space, and therefore both could increase property values. Research is needed to assess the relative influence of impoundment open space versus free-flowing river open space on land values.

## CONCLUSIONS

Because so little research has been conducted on dam removal economics, any discussion of the impacts of small dam removals is largely limited to speculation based on reasoning and anecdotal information. It is known, however, that small dam removal is typically less expensive than repairing an aging structure. In addition, removal is a one-time cost and can relieve financial burdens such as the costs of maintenance, future repairs, liability, impoundment management, and certain aspects of fisheries management. A newly free-flowing river also can provide renewed boating and fishing recreation and bring more people to riverfronts, which could bring more economic activity to local businesses.

Not all, or even most, of the potential economic benefits will materialize each time a small dam is removed. The extent of benefits may depend on the treatment of the former impoundment. Numerous case studies show that communities that have implemented thoughtful plans for recreation or revitalization have realized economic benefits. However, additional research is needed to characterize the extent of economic change from impoundments to flowing rivers.

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# 5

# Ecological Effects of Dam Removal

## An Integrative Case Study and Risk Assessment Framework for Prediction

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***Abstract:*** A coordinated research strategy is required to develop models that can predict ecological responses to dam removal. At the outset is the need for case studies that examine the physical, chemical, and biological responses to dam removal at the appropriate spatial and temporal scales. We initiated an interdisciplinary study in 1999 that examined ecological responses to the removal of a 2-meter-high dam on Manatawny Creek in southeastern Pennsylvania. After removal in 2000, increased sediment transport led to major changes in channel form in the former impoundment and downstream reaches. Water quality did not change markedly after removal, however, probably because of the impoundment's short hydraulic residence time (less than two hours at base flow) and infrequent temperature stratification. When the impoundment was converted to a free-flowing reach, the benthic macroinvertebrates and fish in this portion of

Manatawny Creek shifted dramatically from assemblages dominated by lentic taxa to lotic taxa. Some fish species inhabiting the free-flowing reach downstream from the dam were negatively affected by the large-scale sediment transport and habitat alteration that followed dam removal, but this appears to be a short-term response.

HUNDREDS OF DAMS have been removed from streams and rivers throughout the United States during the last century, and the rate of removal is likely to increase in coming decades (Doyle et al., 2000; Heinz Center, 2002; Poff and Hart, 2002). This trend reflects a wide array of concerns—and especially the concern that many old dams are in poor repair and no longer provide the kinds of socioeconomic benefits for which they were originally designed (Aspen Institute, 2002; Bednarek, 2002). Whether the primary motivation for removing dams is to eliminate safety and liability concerns or to restore the health of river ecosystems, there is a critical need to improve the basis for predicting ecological responses to dam removal (Hart et al., 2002). Better predictions of dam removal responses can enhance the process for making watershed management decisions in at least four ways: (1) helping stakeholders understand what kinds of environmental changes to expect when dams are removed; (2) identifying particular dams and watersheds where large adverse impacts of dam removal could occur; (3) determining how short-term ecological impacts can be mitigated; (4) setting priorities about which dams should be removed to maximize the watershed-level benefits of such practices.

The goal of this chapter is to evaluate different approaches for improving scientific predictions about ecological responses to dam removal. It begins by examining briefly what has already been learned from case studies of specific dam removals, and looks in particular at an integrative ecological study of the removal of a small dam from Manatawny Creek in southeastern Pennsylvania. A comparison of the results of different case studies suggests that responses to removal are likely to vary, depending on dam type and operation, river characteristics, and watershed setting. The chapter then develops an explicit framework for understanding these sources of variation and for incorporating such variation into models that can lead to more accurate predictions of responses to dam removal.

## CASE STUDIES OF DAM REMOVAL

Although hundreds of dams have been removed in the United States, relatively few studies of observed ecological responses have been published. Recent reviews of this limited literature (e.g., Bednarek, 2001; Hart et al., 2002) have reached three conclusions: (1) most studies have examined responses of only a few ecosystem components, primarily sediments or fish; (2) most studies have employed sampling designs that have limited spatial and temporal replication; and (3) observed ecological responses often differ among systems and locations. This section illustrates various ecological effects of dam removal by briefly describing our study of physical, chemical, and biological responses to the removal of a 2-meter-high mill dam on Manatawny Creek, a fourth-order piedmont stream in southeastern Pennsylvania (see Bushaw-Newton et al., 2002, for more details). This 30-meter-wide timber crib dam was first constructed more than 200 years ago, and it created an impoundment about 500 meters long with an average depth of about 1 meter (Figures 5.1 and 5.2).

Our study was designed to investigate different spatial and temporal components of removal impacts. Spatially, the design compared responses in three different river sections (Figure 5.3): (1) the impounded portion of the stream that lies above the dam; (2) the free-flowing portion of the stream above the impoundment; (3) the free-flowing section of the stream below the dam. Temporally, we assessed ecological conditions for up to one year before the dam was removed, during the four-month removal process that began in August 2000, and for nearly two years after removal.

The optimal sampling design for a dam removal study would include several to many years of pre- and postremoval monitoring. To date, however, few published studies have met these criteria. Moreover, despite the benefits of employing more comprehensive sampling designs that also monitor other dammed and undammed rivers to overcome limitations associated with pseudoreplication (e.g., Bushaw-Newton et al., 2002; Downes et al., 2001), such designs have not yet been used (Hart et al., 2002). Eventually, it also will be useful to perform metaanalyses of dam removal responses. Such analyses can be strengthened by adopting standardized sampling designs and monitoring protocols.

Because many different ecological components of streams and rivers are likely to be affected by dam removal, our study was designed to provide an integrative assessment of physical, chemical, and biological

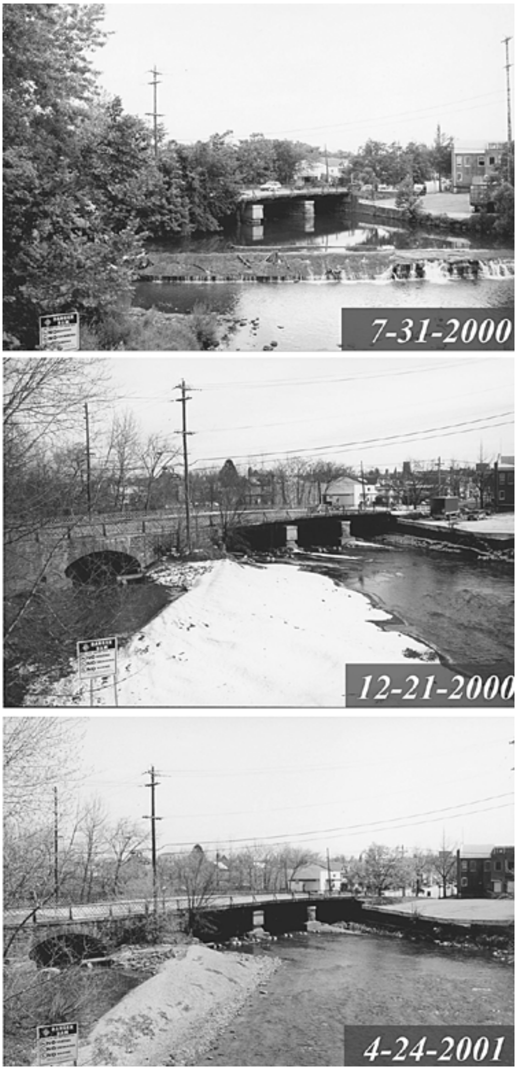

**Figure 5.1** Channel of Manatawny Creek before (July 2000) and after (December 2000, April 2001) dam removal. The views are looking upstream directly at the dam. The run-of-the-river dam was about 2 meters in height. After the two-phase removal in August and November 2000, efforts were made to stabilize the left bank of the stream. In mid-December 2000, a significant flow event (2.5-year recurrence interval) caused large amounts of coarse gravel to accumulate at the dam site. With each subsequent runoff event, the bar has been decreasing in size because of sediment migration farther downstream. At present, the right bank area, which has been blocked off from the main channel because of the sediment bar, is a wetlands area. Courtesy of Karen Bushaw-Newton.

**Figure 5.2** Changes in the impoundment area of Manatawny Creek before (July 2000) and after (April 2001, 2002) dam removal (the right bank of the creek is shown in the left-hand column and the left bank in the right-hand column). Prior to removal, water levels in the impoundment were between 1 and 2 meters. After removal, the water levels decreased to less than 0.3 meters in many areas, resulting in exposed banks and a large sediment bar on the left bank. With each major rainfall, coarse gravel sediment has migrated downstream through the former impoundment. Observable in the postremoval photos, a new channel has formed along the right bank of the former impoundment, while sediment has accreted on the left side of the former impoundment. In the fall of 2001, the right bank underwent restoration through regrading and replanting of native vegetation, and the growth is evident in the April 2002 photo. Courtesy of Karen Bushaw-Newton.

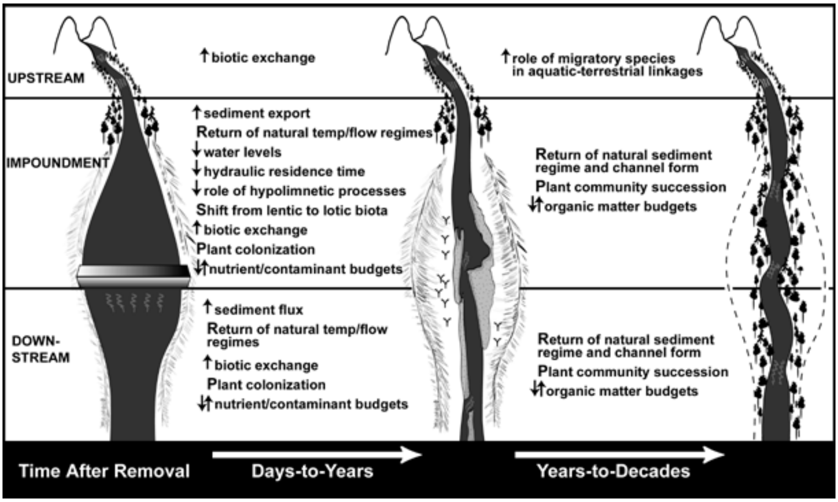

**Figure 5.3** A simple spatial and temporal framework for examining the potential ecological responses to dam removal, with hypothetical responses indicated for different spatial locations and time frames. *Source*: Hart et al. (2002).

responses. We looked especially at changes in fluvial geomorphology, sediment contamination, water quality, periphyton, benthic macroinvertebrates, and fish. In the rest of this section we summarize some of the major responses we observed, and compare these results with those of other dam removal studies.

## MANATAWNY CREEK

Before dam removal, a large amount of sediment had accumulated in the Manatawny Creek impoundment, despite the fact that the impoundment was dredged in the 1970s. This sediment, dominated by sand, pebbles, and cobbles, was considerably coarser than the clay and silt particles that have dominated the sediment behind several other small dams that have undergone removal (e.g., Pawlowski and Cook, 1993; Stanley and Doyle, 2001). Because of these coarse particles, the removal of the dam resulted in little sediment transport. It was not until the occurrence of high flows more than one month after dam removal that large amounts of sediment began to move downstream. After 10 months, the intermittent high flows had removed nearly 0.5 meters of sediment in the former impoundment and the bed had coarsened markedly because of the differential entrainment and transport of finer sediment. Alternate and midchannel bars also began to form during this period, although the pattern of pool-riffle spacing evident in upstream reference reaches had not yet been established. Channel aggradation occurred in riffles and pools downstream from the site of the former dam, and the cobble particles that had been common in riffles became buried by fine sediment in some places and were scoured in others. Current models of river form and process are inadequate for predicting the complex three-dimensional nature of channel aggradation, degradation, and floodplain development that have occurred so far in Manatawny Creek. It also appears that the channel may not reach a quasiequilibrium for more than a decade (Bushaw-Newton et al., 2002; Pizzuto, 2002).

Biogeochemical processes are often altered dramatically by dam removal, especially because of reductions in sediment deposition and hydraulic residence time when the impoundment is transformed into a free-flowing reach and because of changes in the nature of sediment–water interactions. For example, impoundments with long hydraulic residence times often undergo thermal stratification, which frequently results in anoxic bottom waters. Many studies have observed large differences in various water quality parameters (e.g., dissolved oxygen, temperature, and nutrient concentrations) in free-flowing reaches that are located upstream and downstream from the impoundment (Stanley and Doyle, 2002). When dam removal occurs and the impoundment is transformed into a free-flowing reach, the magnitude of these upstream-downstream differences is sometimes reduced (Stanley and Doyle, 2002). In Manatawny Creek, however, we generally observed small upstream–downstream differences in water quality parameters before dam removal, probably because of the impoundment's short hydraulic residence time (less than two hours at base flow), the absence of thermal stratification, and the low proportion of fine sediment in the impoundment. Few differences in water quality parameters also were observed before and after dam removal, suggesting that the loss of the impoundment did not markedly affect most biogeochemical processes.

The large changes in hydraulic conditions and channel morphology that often accompany dam removal can, in turn, control many biological responses. In Manatawny Creek, the impoundment was characterized by a variety of biota that are common to pond and lake environments, including a benthic macroinvertebrate assemblage dominated by oligochaete worms, chironomid midges, and caenid mayflies, as well as a fish assemblage that included goldfish, carp, sunfish, golden shiner, and creek chubsucker. After less than one year after dam removal, the biota within newly formed riffles in the former impoundment was represented by taxa more typical of flowing waters, including benthic fish species such as shield darter, margined madtom, and longnose dace, as well as a diverse array of mayfly, stonefly, and caddisfly genera. Increased sediment transport also caused channel aggradation in reaches downstream of the former dam, which resulted in short-term, local declines in the abundance of some riffle-inhabiting fish and benthic macroinvertebrate taxa. Loss of the scour hole at the base of the dam and transient aggradation in some downstream pools produced local decreases in some fish species that prefer pool habitats.

## COMPARISON OF CASE STUDIES

Although some of the ecological responses to dam removal that we observed in Manatawny Creek are similar to those observed elsewhere, many responses differed from those documented in other studies. For example, large amounts of accumulated fine sediment are often transported downstream within hours to days after dam removal (Stanley et al., 2002; Winter, 1990), whereas most of the sediment within Manatawny Creek's former impoundment remained in place for weeks to months before it began to be transported downstream by occasional high flows.

Dam removal often leads to marked alterations in water quality in the former impoundment and downstream reaches because of the qualitative and quantitative changes in various biogeochemical processes that occur when the impoundment is eliminated (Hill et al., 1994; Stanley and Doyle, 2002). By contrast, the lack of upstream/downstream or before/after-removal differences in Manatawny Creek's water quality parameters suggests that its impoundment played a smaller role in modifying biogeochemical processes.

Biotic assemblages located downstream from dams are sometimes very different from those located in upstream free-flowing reaches (Petts, 1984; Ward and Stanford, 1979), which suggests that dam removal should lead to the reduction or elimination of those differences. In Manatawny Creek, however, the biota inhabiting upstream free-flowing reaches were similar to those living downstream, and differences in assemblage composition before versus after removal were usually minimal or limited in duration. Because of the presence of downstream dams, the removal of the Manatawny dam did not affect anadromous fish.

Despite the small number of studies, there appears to be a wide range of ecological responses to dam removal. It is therefore difficult to predict responses to future removals. If a sufficiently large number of dam removals were accompanied by quantitative studies of ecological responses, then it might be possible to develop statistical models relating observed ecological responses to variation in important dam, river, and watershed characteristics. Unfortunately, few dam removal studies have been conducted to date, and fewer still have used consistent sampling designs that would facilitate such comparative analyses. Thus it is currently difficult to identify the causal factors that account for observed variation in dam removal responses. Because it may take many years to obtain a large set of comparable studies, other approaches probably also are needed to help explain potential variation in ecological responses to dam removal.

## DEVELOPING INFERENCES ABOUT RESPONSES TO DAM REMOVAL

One alternative approach to understanding variation in potential ecological responses to dam removal is to look at the effects of existing dams. This approach assumes that many ecological responses to the removal of a particular dam are likely to involve a reversal of the effects of the existing dam. For example, if a dam acts as a barrier to fish passage, then dam removal could enhance biotic dispersal. Similarly, if water quality and flow variation are modified in the free-flowing reaches below a dam, then dam removal could reduce the magnitude of these alterations. Some ecological attributes of streams and rivers are unlikely be completely reversible, however, and further studies that examine ecological responses to actual dam removals are needed to learn more about the extent of reversibility. The trajectory of ecological responses to dam removal is also important, and the growing knowledge of responses to natural disturbances in rivers may provide a valuable reference for developing such

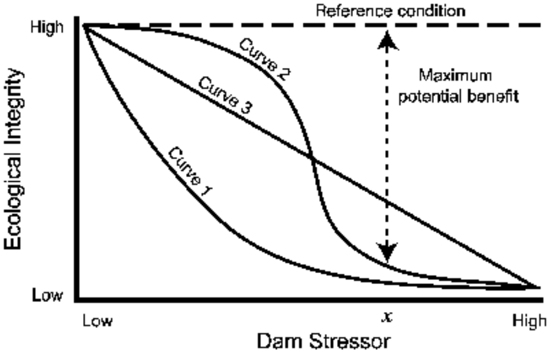

**Figure 5.4** Hypothetical stressor-response relationships between ecological integrity and different dam stressor levels. For a given level of dam stressor, the difference between the observed level of ecological integrity and the level of integrity for the reference condition provides and estimate of the maximum potential benefit of dam removal. *Source*: Hart et al. (2002).

understanding (Stanley and Doyle, 2003). Nonetheless, it may be possible to improve predictions of ecological responses to dam removal by concentrating on the factors that account for variation in the ecological effects of existing dams.

Variation in the effects of existing dams can be examined via stressor-response relationships (Hart et al., 2002), which form the foundation for ecological risk assessment models. For example, a sample of dams could be examined to quantify how variations in dam height (a stressor) affect downstream water quality parameters (a response) that are dependent on the extent of thermal stratification within the impoundment. Figure 5.4 illustrates various hypothetical stressor-response relationships, and Curve 2 might represent a situation in which a particular water quality parameter in the downstream free-flowing reach is minimally affected by dams low in height because of lack of thermal stratification in shallow impoundments. Above some threshold in dam height, however, further height increments result in stratification, which in turn leads to much larger changes in water quality.

If such stressor-response relationships could be combined with estimates of the level of ecological integrity that would exist in the absence of the dam (i.e., the reference condition), then it should be possible to predict the *maximum potential benefit* of dam removal. For example, ecological conditions in free-flowing reaches located upstream from the impoundment might serve as the reference condition for many water quality parameters in downstream free-flowing reaches, as well as for various downstream biota whose dispersal is unaffected by the dam (e.g., the larval stage of flying aquatic insects). Thus for a given stressor level the difference between the stressor-response curve and the reference condition provides a measure of the predicted change in ecological integrity if the effects of the existing dam are completely reversed after dam removal (Figure 5.4). Predicted responses to dam removal are particularly interesting in the case of nonlinear stressor-response relationships. For example, the relationship depicted by Curve 2 in Figure 5.4 indicates that the removal of dams below a given size threshold would yield little or no ecological benefit.

Developing this approach from its current conceptual stage to a more rigorous and predictive form will require a careful assessment of its potential strengths and limitations. In theory, it should be easy to quantify stressor-response relationships for a wide range of dam sizes and types simply by gathering data from the published literature on the ecological effects of dams. In practice, however, it is difficult to assemble a relevant and consistent dataset, particularly one that includes the smaller dams (i.e., less than 5 meters high), which are the ones most likely to be removed (Doyle et al., 2000). For example, data collection is hindered by dam-specific differences in upstream and downstream conditions related to riparian land use, point sources, and bridges, as well as the effects of multiple dams on single streams.

An alternative strategy is to quantify these stressor-response relationships based on a field study examining a carefully studied, representative sample of dammed streams. This approach can ensure that all data are gathered consistently and that the sampling design spans a desirable range of dam stressor levels. It lacks, however, the rigor of a true experimental design because treatments usually cannot be assigned randomly and among-group variation in "background" environmental conditions is often difficult to control. The selection of suitable reference sites for measuring ecological integrity also is likely to be challenging. For example, because the free-flowing reaches located upstream from dams cannot serve as reference sites for fish that are blocked by those dams, it will be necessary to identify suitable control watersheds that lack dams but are otherwise similar to the watersheds in question.

Despite these challenges, we believe that the stressor-response approach outlined here holds considerable promise in developing a more rigorous method of predicting ecological responses to dam removal. Indeed, we have initiated a pilot study examining a sample of 15 piedmont streams in the Mid-Atlantic region that contain dams ranging in height from 1 to 57 meters. For each stream, we have measured a broad array of physical, chemical, and biological components of ecological integrity. The stressor-response relationships that result from this study will be combined with appropriate information on reference conditions, thereby providing a more objective basis for predicting the maximum potential change in different components of ecological integrity after dam removal. By coupling this risk assessment approach with continued studies of actual dam removals and further development of mechanistic models of dam removal responses (e.g., Hart et al., 2002), researchers should be able to achieve significant improvements in scientific understanding of ecological responses to dam removal and better strategies for restoring rivers via dam removal.

## CONCLUSIONS

Researchers have gained valuable insights into the ecological responses to dam removal, but more research is needed to enhance understanding and guide restoration practices. Because dams generally act as barriers, dam removal can not only result in greater upstream movement of fish and other biota, but also permit greater downstream sediment flux. Similarly, dam removal usually transforms impoundments into free-flowing reaches, with a corresponding shift from a biotic assemblage that is characteristic of lentic environments to a lotic assemblage. Although many ecological responses to dam removal are strongly influenced by changes in river form and process, limited understanding of the magnitude and rate of such geomorphic changes currently hinders the development of predictive models. By examining the connections between physical, chemical, and biological responses to dam removal, interdisciplinary research can simultaneously provide deeper insights into cause-effect relationships and enhance the effectiveness of river restoration efforts.

## ACKNOWLEDGMENTS

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# 6

# DAM REMOVAL AND SEDIMENT MANAGEMENT

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***Abstract:*** Over 76,000 dams that are at least 6 feet in height exist in the United States today. These dams serve many different purposes, including water supply for irrigation; municipal, industrial, and fire protection needs; flood control; navigation; recreation; hydroelectricity; water power; river diversion; sediment and debris control; and waste disposal (Heinz Center, 2002; ASCE, 1997). Although the great majority of these dams still fulfill a vital function for society, some may need to be removed for various reasons such as, economics, dam safety and security, legal and financial liability, ecosystem restoration (including fish passage improvement), site restoration, and recreation.

Three recent publications present the overall considerations related to dam removal. The American Society of Civil Engineers publication describes the decision-making process, the alternatives to removal, and the important factors in dam removal (ASCE, 1997). The publication by The H. John Heinz III Center for Science, Economics and the Environment summarizes the state of scientific knowledge on dam removal and provides recommendations for additional research (Heinz Center, 2002). The Aspen Institute (2002) "recommends that the option of dam removal be included in policy and decision making that affects U.S. dams and rivers."

The downstream effects associated with dam removal can include aggradation of the riverbed and increased sediment concentrations and turbidity. Dam removal during low-flow periods can deliver sediment to the downstream river channel (through head-cut erosion) at a time when river flows are least capable of transporting the sediment. Excessive aggradation of the riverbed can result in increased flood stage, channel braiding, increased channel migration, bank erosion, and channel avulsion. Increased sediment concentration and turbidity can affect water quality for the aquatic environment and downstream water users. To a large extent, controlling the rate of dam removal can control these impacts. This chapter looks at the sediment management aspects of dam removal.

RAINFALL RUNOFF, snowmelt, and river channel erosion continually supply sediment that is hydraulically transported and deposited in reservoirs and lakes. Because of the very low velocities in reservoirs, they tend to be very efficient sediment traps. Reservoir sediment disposal using mechanical methods could be very costly for large volumes of sediment. Therefore, the management of reservoir sediment is often an important and controlling issue related to dam removal (ASCE, 1997). Sediment erosion, transport, and deposition probably are among the most important physical effects of dam removal (Heinz Center, 2002).

The sediment-related impacts associated with dam removal could occur in the reservoir and in the river channel, both upstream and downstream from the reservoir. Depending on the local conditions and the removal alternative, the degree of impact can range from very small to very large. For example, the removal of a small diversion dam that had trapped only a small amount of sediment would not have much impact on the downstream river channel. The top portion of a dam might be removed in such a way that very little of the existing reservoir sediment would be released into the downstream river channel. In this case, the effects on the downstream river channel might be related only to the future passage of sediment from the upstream river channel through the reservoir. If dam removal resulted in a large quantity of sediment being released into the downstream river channel, then the impacts to both the upstream and downstream channels could be significant.

The size of the reservoir and the extent of the sediment management problem can be estimated from five indicators:

- The reservoir storage capacity (at the normal pool elevation) relative to the mean annual volume of river flow
- The purposes for which the dam was constructed and how the reservoir has been operated (i.e., normally full, frequently drawn down, or normally empty)
- The reservoir sediment volume relative to the mean annual capacity of the river to transport sediment of the same particle sizes within the reservoir
- The maximum width of the reservoir relative to the active channel width of the upstream river channel in an alluvial reach of river
- The concentration of contaminants present within the reservoir sediments relative to the background concentrations

The first two indicators help to describe how much sediment could be stored within the reservoir. Indicators 3, 4, and 5 help to scale the amount of reservoir sediment, and its quality, to the river system on which the reservoir is located.

The relative size of the reservoir (ratio of the normal reservoir capacity to mean annual flow volume) can be used as an index to estimate the reservoir sediment trap efficiency. The greater the relative size of the reservoir, the greater is the sediment trap efficiency and the amount of reservoir sedimentation. The sediment trap efficiency primarily depends on the sediment particle fall velocity and the rate of water flow through the reservoir (Strand and Pemberton, 1987). For a given reservoir storage capacity, the sediment trap efficiency would tend to be greater for a deeper reservoir, especially if river flows pass over the crest of the dam.

Brune (1953) developed an empirical relationship for estimating the long-term reservoir trap efficiency based on the correlation between the relative reservoir size and the trap efficiency observed in Tennessee Valley Authority reservoirs in the southeastern United States. According to this relationship, reservoirs with a capacity to store more than 10 percent of the average annual inflow would be expected to trap between 75 and 100 percent of the inflowing sediment. Reservoirs with a capacity to store 1 percent of the average annual inflow would be expected to trap between 30 and 55 percent of the inflowing sediment. When the reservoir storage capacity is less than 0.1 percent of the average annual inflow, the sediment trap efficiency would be nearly zero.

The purposes for which a dam was constructed, along with legal constraints and hydrology, determine how the reservoir pool is operated. The operation of the reservoir pool will influence the sediment trap efficiency and the spatial distribution and unit weight of sediments deposited within the reservoir. The sediment trap efficiency of a given reservoir will be greatest if substantial portions of the inflows are stored during floods when the sediment concentrations are highest. If the reservoir is normally kept full (run-of-the-river operation), flood flows would pass through the reservoir and trap efficiency would be less. Coarse sediments would deposit as a delta at the far upstream end of the reservoir. When reservoirs are frequently drawn down, a portion of the reservoir sediments will be eroded and transported farther downstream. Any clay-sized sediments that are exposed above the reservoir level will compact as they dry out (Strand and Pemberton, 1987).

The ratio of reservoir sediment volume to the annual capacity of the river to transport sediment is a key index. This index can be used to estimate the level of impact that sediment release from a dam removal would have on the downstream river channel. When the reservoir sediment volume is small relative to the annual sediment transport capacity, the impact on the downstream channel is likely to be small. Reservoirs have a finite capacity to trap and store sediment. Once that capacity is filled with sediment, the entire sediment load supplied by the upstream river channel is passed through the remaining reservoir. For example, the pool behind a diversion dam is typically filled with sediment within the first year or two of operation. Therefore, the relative volume of reservoir sediment may not be large, even if the dam is considered old. When a reservoir has a multiyear sediment storage volume, the removal plan should consider staging removal over multiple years to avoid excessive aggradation of the downstream riverbed. The dam removal investigation should determine how much of the reservoir sediment would actually erode from the reservoir.

The width of the reservoir relative to the width of the active river channel in an alluvial reach upstream from the reservoir can indicate how much sediment would be released from the reservoir both during and after dam removal. When a reservoir is many times wider than the river channel, the river may not be capable of eroding the entire reservoir sediment volume, even long after dam removal (Randle et al., 1996; Morris and Fan, 1997).

The presence of contaminants in the reservoir sediment at concentrations significantly higher than background levels would likely require mechanical removal or stabilization of the reservoir sediments prior to dam removal. Even if contaminants are not present in the reservoir sediments, the turbidity created by sediment erosion during dam removal may affect the aquatic environment of the downstream river channel. Increased turbidity also could be a concern for downstream water users.

As an example, the five indicators were applied to three dams in the Pacific Northwest that are being considered for removal to improve fish passage: Gold Hill Dam near Gold Hill, Oregon (U.S. Bureau of Reclamation, 2001a); Savage Rapids Dam near Grants Pass, Oregon (U.S. Bureau of Reclamation, 2001b); and Glines Canyon Dam near Port Angeles, Washington (Randle et al., 1996). These three dams range in size from small to large, and their potential effects on sediment management range from negligible to major (see Figure 6.1 and Table 6.1).

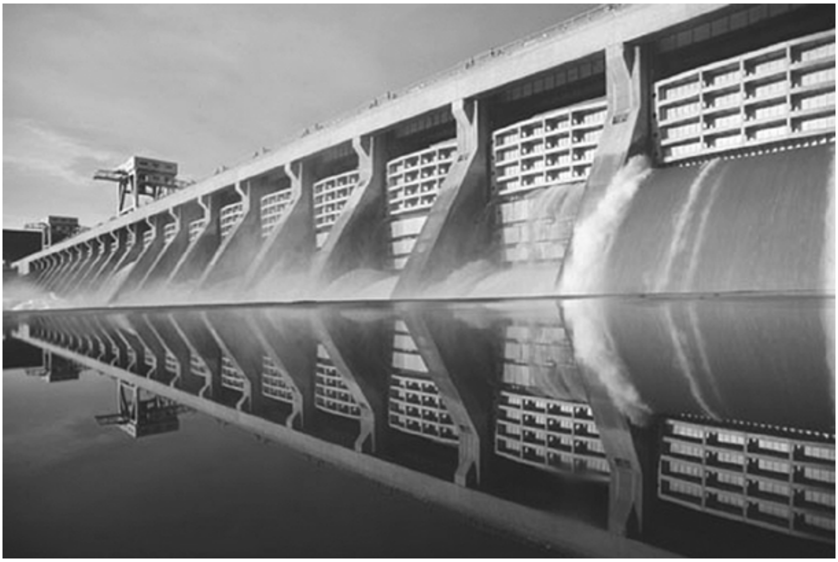

**Figure 6.1** Savage Rapids Dam is slated for removal in 2005. *Source*: http://oregonstate.edu/groups/hydro/trips/SR-Dam02/trip-index.html.

The major issues associated with sediment management related to dam removal may include cost, water quality, flooding, operation and maintenance of existing infrastructure, cultural resources, the health of fish and wildlife and their habitats (including wetlands), recreation, and restoration of the reservoir area. Sediment management plans are important to prevent the following impacts:

- If a large volume of coarse sediment were eroded too quickly from a reservoir, the sediment could aggrade the downstream river channel, cause channel widening and bank erosion, increase flood stage, plug water intake structures, and disrupt aquatic habitats.
- If large concentrations of fine sediment were eroded from the reservoir, turbidity would increase in the downstream river channel and may significantly degrade water quality for the aquatic environment and for water users.
- If the reservoir sediment contains significant concentrations of contaminants, the contaminants could be released into the aquatic environment and into municipal water treatment plants and wells.

**Table 6.1** Application of Reservoir Sediment Impact Indicators to Three Dams in Pacific Northwest

| Indicator | Gold Hill Dam (near Gold Hill, Oregon) | Savage Rapids Dam (near Grants Pass, Oregon) | Glines Canyon Dam (near Port Angeles, Washington) |
|---|---|---|---|
| River (distance from mouth) | Rogue River (river mile 121) | Rogue River (river mile 107.6) | Elwha River (river mile 13.5) |
| Active river channel width in alluvial reach | 150 feet | 150 feet | 200 feet |
| Type of dam | Concrete gravity | Concrete gravity and multiple arch | Concrete arch |
| Hydraulic height | 1–8 feet | 30–41 feet | 210 feet |
| Dam crest length | 1,000 feet ("L" plan shape) | 460 feet | 150 feet |
| Reservoir properties | Gold Hill | Savage Rapids | Lake Mills |
| Reservoir length | 1 mile | 3,000 feet | 2.3 miles |
| Reservoir width | 150 to 350 feet | 290 to 370 feet | 1,000 to 2,000 feet |
| Reservoir capacity | 100 acre-feet | 290 acre-feet | 40,500 acre-feet |
| Sediment management indicators | Gold Hill | Savage Rapids | Lake Mills |
| Relative reservoir capacity | 0.005 percent | 0.01 percent | 4.5 percent |
| Reservoir operations | Run-of-the-river | Reservoir pool raised 11 feet during the summer irrigation season | Run-of-the-river |
| Relative reservoir sediment volume | Negligible | 1–2-year supply of sand and gravel | 75-year supply of sand and gravel, 54-year supply of silt and clay |
| Relative reservoir width | 2.3 (all sediment would be eroded from the reservoir) | 2.5 (nearly all sediment would be eroded from the reservoir) | 10 (about one-third of the sediment would be eroded from the reservoir) |
| Relative concentration of contaminants or metals | Less than background levels | Less than background levels | Only iron and manganese are above background levels |
| Resulting magnitude of the sediment management problem | Negligible | Moderate | Major |

- If the reservoir sediment has to be mechanically removed, disposal sites could be difficult to locate and the sediment removal cost could be the most expensive portion of the dam removal project.
- If a delta is eroded from the upstream end of the reservoir, the erosion of sediment deposits could continue to progress along the upstream river channel. Sediment deposited along the backwater of the reservoir pool will begin to erode once the reservoir pool is drawn down.

The possible impacts of the erosion, transport, and deposition of reservoir sediment should be at least considered in all dam removal studies. If the impacts could be significant, a sediment management plan should be developed. Such a plan could reduce or avoid the impacts. In some cases, benefits may arise from the controlled release of reservoir sediment such as the introduction of gravel, woody debris, and nutrients for the restoration of downstream fish habitats. The beneficial release of gravel from a reservoir to the downstream river channel is expected for the Elwha River Restoration Project, but until the dam is actually removed documented proof will not be available.

## SEDIMENT MANAGEMENT ALTERNATIVES

Development of alternative sediment management plans for dam removal requires concurrent consideration of engineering and environmental issues. Sediment management alternatives can be grouped into four general categories:

- *No action.* Leave the existing reservoir sediment in place. If the reservoir sediment storage capacity is not already full, then either allow sedimentation to continue or reduce the sediment trap efficiency to enhance the life of the reservoir.
- *River erosion.* Allow the river to erode at least a portion of sediment from the reservoir through natural processes.
- *Mechanical removal.* Remove sediment from the reservoir by hydraulic or mechanical dredging or conventional excavation for long-term storage at an appropriate disposal site.
- *Stabilization.* Engineer a river channel through or around the reservoir sediment and provide erosion protection to stabilize the reservoir sediment over the long term (ASCE, 1997).

A sediment management plan also can consist of a combination of these categories. For example, fine sediment could be mechanically removed from the downstream portion of the reservoir to reduce the impacts on water quality. At the same time, the river could be allowed to erode coarse sediment from the reservoir delta to resupply gravel for fish spawning in the downstream river channel.

## INTEGRATION OF DAM REMOVAL AND SEDIMENT MANAGEMENT ALTERNATIVES

The sediment management alternative will depend on the dam removal alternative (see Table 6.2). For example, the rate of river erosion is directly influenced by the rate of dam removal; the amount of reservoir sediment eroded by river flows will increase as more of the dam is removed. The cost of mechanically removing sediment from deep reservoirs (mean depth greater than 15 feet) will be lower if the sediment can be removed as the reservoir is drawn down. The cost and scope of reservoir sediment stabilization will decrease as more of the dam is retained.

The interplay is continual between balancing the scope of the sediment management alternative, the requirements of dam removal, acceptable environmental impacts, and cost. The steps to prepare a sediment management plan are shown in Box 6.1. Each sediment management alternative should include proper mitigation to make the alternative as feasible as possible.

### NO-ACTION ALTERNATIVE

Under this alternative, the dam, reservoir, and sediment would be left in place. For most diversion dams and other small structures, the sediment storage capacity of the reservoir pool is already full. In this situation, a decision to leave the dam and reservoir in place will not change the existing effects of the dam and its operation. If the reservoir sediment storage capacity is not already full, sedimentation could be allowed to continue at existing rates, or actions could be taken to reduce these rates and prolong the life of the reservoir.

**Table 6.2** Relationship Between Dam Removal and Sediment Management Alternatives

| Sediment Management Alternative | Dam Removal Alternatives | | |
|---|---|---|---|
| | Continued Operation | Partial Dam Removal | Full Dam Removal |
| No action | Reservoir sedimentation continues at existing rates<br>Inflowing sediment loads are reduced through watershed conservation practices<br>Reservoir operations are modified to reduce sediment trap efficiency | Applicable only if most of the dam is left in place<br>The reservoir sediment trap efficiency will be reduced<br>Some sediment may be eroded from the reservoir | Not applicable |
| River erosion | Sluice gates installed or modified to flush sediment from the reservoir<br>Reservoir drawdown to help flush sediment | Partial erosion of sediment from the reservoir into the downstream river channel<br>Potential erosion of the remaining sediment by sluicing and reservoir drawdown | Erosion of sediment from the reservoir into the downstream river channel. Erosion rates depend on the rate of dam removal and reservoir inflow. The amount of erosion depends on the ratio of reservoir width to river width |
| Mechanical removal | Sediment removed from shallow depths by dredging or by conventional excavation after reservoir drawdown | Sediment removed from shallow depths before reservoir drawdown<br>Sediment removed from deeper depths during reservoir drawdown | Sediment removed from shallow depths before reservoir drawdown<br>Sediment removed from deeper depths during reservoir drawdown |
| Stabilization | Sediments already stable because of presence of dam and reservoir | Lower portion of dam retained to prevent release of coarse sediments or most of dam's length across the valley retained to help stabilize sediments along the reservoir margins<br>Construction of a river channel through or around the reservoir sediments | Construction of a river channel through or around the existing reservoir sediments<br>Relocation of a portion of sediment to areas within the reservoir area that will not be subject to high-velocity river flow |

*Source*: Adapted from ASCE (1997).

**Box 6.1** Steps to Preparing Alternative Sediment Management Plans

1. Examine the possible range of dam removal alternatives (continued operation, partial dam removal, and full dam removal).
2. Determine the reservoir sediment characteristics, including volume, spatial distribution, particle size distribution, unit weight, and chemical composition.
3. Investigate the existing and pre-dam geomorphology of the river channel upstream and downstream of the dam.
4. Inventory the existing infrastructure around the reservoir, along the downstream river channel, and along the upstream portion of the river channel influenced by the reservoir.
5. Determine the feasible range of sediment management alternatives and formulate specific alternatives.
6. Coordinate the details of each sediment management alternative with the other aspects of the dam removal alternative.
7. Conduct an initial assessment of the risks, costs, and environmental impacts of each sediment management alternative.
8. Determine what mitigation measures may be necessary to make each alternative feasible and include these measures in the alternative.
9. Finalize the assessment of the costs, environmental impacts, and risks for each modified sediment management alternative.
10. Document the risks, costs, and environmental impacts of each alternative for consideration with the engineering and environmental components of the study. Provide technical support to the decision-making process.

*Source*: Adapted from ASCE (1997).

## RIVER EROSION ALTERNATIVE

Sediment removal from the reservoir by river erosion can be applied to all dam removal alternatives. River erosion is a frequently employed sediment management practice associated with the removal of dams of all sizes. In fact, this is the preferred alternative for the removal of the large Elwha and Glines Canyon Dams on the Elwha River in Washington (Olympic National Park, 1996). The reservoirs behind these two dams contain 18 million cubic yards of sediment (Gilbert and Link, 1995).

Allowing reservoir sediments to erode and discharge into the downstream river channel may be the least-cost alternative if the downstream impacts can be accepted or mitigated. However, water quality considerations may make this alternative unacceptable if the reservoir sediments contain high concentrations of contaminants or metals. The advantage of the river erosion alternative is that the cost of physically handling the sediments is eliminated. However, these benefits must be weighed against the risks of unexpected riverbed aggradation or unanticipated increases in turbidity downstream.

## Description of River Erosion

When the decision is made to continue dam operations, sluice gates with adequate discharge capacity can be used to initiate and maintain sediment transport through the reservoir. This step is normally taken in conjunction with reservoir drawdown to increase the flow velocities through the reservoir and increase the sediment transport (Morris and Fan, 1997). For partial dam removal, the amount of reservoir sediment eroded by river flows will depend on how much of the dam is removed and how much of the reservoir pool is permanently and temporarily drawn down.

For small dams with relatively small reservoirs and sediment volumes, the rate of dam removal may not be critical. However, for dams that have relatively large reservoirs or sediment volumes, the rate of final reservoir drawdown (corresponding with dam removal) can be very important. A deterioration in water quality and flooding can occur if the reservoir drawdown rate is too fast. By contrast, dam removal would take too long to implement and perhaps cost too much if the reservoir drawdown rate were unnecessarily slow. The rate and timing of staged reservoir drawdown should meet the following general criteria:

- The reservoir discharge rate is slow enough to avoid a downstream flood wave.
- The release of coarse sediment is slow enough to avoid severe riverbed aggradation that would cause flooding of property along the downstream river channel.
- The concentration of fine sediment released downstream is not too great, or its duration too long, that it would overwhelm downstream water users or cause unacceptable impacts to the aquatic environment.

These general criteria would have to be specifically defined for each local area. To reduce the effects of the downstream channel, dam removal may have to be implemented over a period of months or years, depending on the size of the reservoir, height of the dam, and volume of sediment. The structural and hydraulic stability of the partially removed dam must be analyzed at various stages to ensure adequate safety and to prevent a large and sudden release of water or sediment. With the proper rate of reservoir drawdown, the magnitude of the downstream impacts can be reduced and spread out over time. In some cases, it may be more desirable to have the impacts occur over a shorter period of time with higher magnitudes than over a longer period of time with lower magnitudes. For example, shorter-duration high turbidity may affect only one or two year classes of fish, whereas longer-duration, chronic levels of turbidity may affect multiple year classes of fish.

For reservoirs that are much wider than the upstream river channel, river erosion during dam removal may result in only a portion of the sediment being transported to the downstream river channel. Because the river will tend to cut a relatively narrow channel through the reservoir sediment. This erosion channel would likely widen over time through channel migration, meandering, and floodplain development, but the entire erosion width may still be less than the initial reservoir sediment width. Moreover, riparian forests may naturally colonize the remaining sediment terraces and prevent or slow their erosion. Vegetation also could be planted to speed up the natural process and prevent the establishment of non-native species.

Some reservoirs are many times wider than the river channel, and have relatively thick delta deposits (more than 10 feet) at the upstream end of the reservoir. For these, it may be desirable to induce lateral erosion of the delta sediment and redeposition across the receding reservoir. This step would leave the remaining delta sediment, in the form of a series of low, stable terraces rather than one high terrace that is potentially unstable. During a reservoir drawdown increment, the river would cut a relatively narrow channel through the exposed delta. As long as a reservoir pool remains in place during dam removal, the eroded delta sediment would redeposit as a new delta across the upstream end of the lowered reservoir. As a new delta deposit forms across the receded lake, the erosion channel is forced to move laterally to meet deeper areas of the reservoir. Thus the sediment erosion width is narrow at the upstream end, but increases to reservoir width where the channel enters the receded lake. This outcome can be produced by holding the reservoir level at a constant elevation between drawdown increments. The duration of constant reservoir elevation between drawdown increments (a few days to a few week) would correspond to the time needed for the river channel to redeposit the eroding reservoir sediment across the width of the receded reservoir (Randle et al., 1996).

After enough of the dam and reservoir have been removed, the eroding delta sediment will have reached the dam, and the reservoir pool will be completely filled in with sediment (Randle et al., 1996). At this critical point, further dam removal will result in the downstream release of coarse sediments. Also, the horizontal position of the river erosion channel would be relatively fixed where the river channel passes the dam site, and subsequent erosion widths through the reservoir sediment would be a function of river flow and the bed material load.

## River Erosion Effects

The amount and timing of reservoir sediment release and any resulting downstream effects on water quality and flooding can be estimated using computer modeling, but thorough knowledge and experience with the model are required. The optimum rate of dam removal, for sediment management purposes, can be determined by modeling a range of dam removal rates.

Any sediment released downstream would be deposited somewhere, either because of decreasing river channel slopes downstream or because the river enters a lake or estuary. Depositional effects and sediment concentrations in the downstream river channel, lake, or estuary must be studied carefully to determine whether the impacts from sediment management alternative are acceptable or can be mitigated. Monitoring is essential during reservoir drawdown to verify these predictions and, if necessary, slow the rate of dam removal and reservoir drawdown.

The amount and rate of reservoir sediment that is eroded and released to the downstream river channel affect both short- and long-term impacts, the risk of unintended impacts, and cost. The period of short-term impacts could be the period of dam removal plus three to five years. Over the short term, the release of fine lakebed sediment (silt and clay-sized material) would affect water quality, including suspended sediment concentration and turbidity. The release of coarse sediment (sand, gravel, and cobble-sized sediment) could increase flood stage, the rate of river channel migration, and deposition in a downstream lake or estuary. The release of gravel might improve existing fish spawning habitat. Over the long term, the amount and timing of sediment supplied to the downstream river channel would return to pre-dam conditions. The pre-dam conditions may be close to natural conditions if there are no other dams upstream. However, the presence of upstream dams may still leave the river system in an altered condition.

Flood flows may have different effects on sediment release, depending on whether they occur during or after dam removal. Dam removal operations may have to be discontinued during flood flows. Such a temporary halt would tend to prevent large increases in the amount of sediment eroded from the reservoir. However, floods that occur immediately after dam removal could erode substantial amounts of reservoir sediment. After the first flood flow, significant channel widening in the former reservoir area would occur only during subsequently higher flood flows. Sediment releases downstream would rapidly decrease over time because higher and higher flood flows would be required to cause additional erosion. The time required to reestablish the natural river channel within the former reservoir area depends on the rate of final reservoir drawdown and future flood flows. If a period of drought occurs just after final reservoir drawdown and dam removal, the last phase of sediment erosion in the reservoir would be delayed. Conversely, if a major flood occurs just after reservoir drawdown and dam removal, large amounts of sediment could be transported downstream over a short period of time.

In the short term, full dam removal may lead to temporary aggradation of the downstream river channel and increased suspended sediment concentration and turbidity. Over the long term, it will lead to full restoration of the upstream sediment supply to the downstream river channel. This outcome may approach predam conditions, depending on the level of development in the upstream watershed.

## Monitoring and Adaptive Management

For projects in which the reservoir sediment volume is significant, monitoring and adaptive management are critical components of the river erosion alternative. The effects of the river erosion alternative should be predicted ahead of time and those predictions confirmed by monitoring. If necessary, corrective actions should be taken before impacts exceed the predictions. For example, the rate of dam removal could be temporarily slowed or halted to mitigate for unanticipated consequences.

Typically, the objectives of the sediment monitoring plan are to detect and avoid severe impacts related to flooding, erosion of infrastructure, and water quality. The monitoring program also could assess project performance and provide scientific information applicable to other projects. A monitoring program could be designed to provide two types of information: (1) real-time data on physical processes that would assist project managers in decisions on the water treatment plant operations, bank erosion protection, flood protection, and the rate and timing of dam removal; and (2) long-term data that would both identify and quantify physical processes associated with ecosystem restoration after dam removal. Monitoring categories may include the following processes:

- Reservoir sediment erosion and redistribution
- Hill slope stability along the reservoir and downstream river channel
- Water quality (including suspended sediment concentration)
- Riverbed aggradation and flood stage along the downstream river channel
- Aquifer characteristics
- River channel planform and channel geometry
- Large woody debris
- Coastal processes, including the delta bathymetry and turbidity plume

Not all of these processes may occur (or need to be monitored), and some processes may require detailed monitoring. The key is to determine whether any of these processes could cause undesirable consequences and implement a monitoring program for early detection.

The monitoring program could be divided into two categories: *adaptive management* and *restoration*. The adaptive management monitoring program could provide real-time information directly to project managers, verify or modify dam deconstruction scheduling, and trigger contingency actions required to protect downstream water quality, property, and infrastructure.

The adaptive management responses could include the following:

- Modify monitoring techniques, locations, or frequencies.
- Improve water treatment techniques.
- Locally mitigate flooding and bank erosion.

- Slow rate of dam removal.
- Temporarily halt dam removal.

The restoration monitoring program could provide a body of scientific knowledge applicable to understanding and interpreting natural river restoration processes. Such information could be used to guide management decisions over the long term and would be applicable to future dam removal projects in other locations.

The frequency and duration of monitoring activities depend on the local project conditions, including the relative volume of the reservoir sediment, rate of dam removal, time of year, hydrology, and budget. The initial conditions should be measured to establish a monitoring baseline for comparison. Monitoring should then be conducted prior to dam removal, for a period long enough to test monitoring protocols and determine the range of variability in the data. As monitoring continues during dam removal, the results of certain parameters could be used to trigger the monitoring of additional parameters. For example, monitoring of aggradation in the downstream river channel could be initiated after coarse sediment is transported past the dam site. Monitoring should continue after dam removal until all of the reservoir sediment has eroded or stabilized in the reservoir and sediment has been flushed from the downstream river channel.

## MECHANICAL REMOVAL ALTERNATIVE

Under this type of alternative, all or a part of the reservoir sediment would be removed and transported to a long-term disposal site. This type of sediment management alternative can be used with any removal scenario (continued operation, partial dam removal, or full dam removal). Sediment could be removed by conventional excavation, mechanical dredging, or hydraulic dredging. Transport to a disposal site could be by means of a slurry pipeline, a truck, or conveyor belt. Long-term disposal sites could include old gravel pits, landfills, or ocean disposal areas.

Mechanical removal reduces the downstream concentration of sediment and turbidity by removing sediment from the reservoir before it erodes. This alternative is the most conservative and, potentially, the most costly. All costs are upfront—for construction—but the long-term risks are relatively low (ASCE, 1997). Costs can be reduced by not removing all of the reservoir sediment. For example, only the sediment within the pre-dam floodplain would have to be removed to prevent river erosion. The remaining portion could be allowed to stabilize within the reservoir. Coarse sediment that may be present in a reservoir delta could be allowed to erode downstream if it is considered a resource needed to restore river gradient or spawning gravels for fish habitats. The coarse sediments, especially gravel, would likely be transported as bedload and would not increase turbidity as much as fine sediments (clay, silt, and fine sand). The three components of the mechanical removal alternative are: (1) sediment removal, (2) conveyance, and (3) long-term disposal.

## Sediment Removal

Several methods are available for removing sediment. The main factors in selecting a removal method are the size and quantity of sediment and whether it will be removed under wet or dry conditions (ASCE, 1997). An overview of each method follows.

- *Conventional excavation* requires lowering the reservoir or rerouting the river to undertake sediment excavation and removal under dry conditions. After sediment has become dry enough to support conventional excavating equipment, the sediment can be excavated by dozers and front-end loaders and hauled by truck to an appropriate disposal site. The viability of this approach depends on the facilities available, sediment volume, amount of time required to dry the sediment, and haul distance to the disposal site. If the sediment volume is small and the sediment is not hazardous, this disposal process can be done economically. In 1989, at a shallow 10-acre reservoir in northeastern Illinois, some 15,000 cubic yards of “special waste” sediment were removed and placed at a nearby landfill at a total cost of $350,000, or about $25 per cubic yard.
- *Mechanical dredging* is performed using a clamshell or dragline, without dewatering the site, but the excavated material must be dewatered prior to truck transport to the disposal facility. In 1987, the cost to dredge some 35,000 cubic yards of sediment from behind a low-head dam in northeastern Illinois was estimated at $25 per cubic yard.

- *Hydraulic dredging* is often the preferred approach to removing large amounts of sediment, particularly when the sediment is fine-grained, because it is removed underwater. The sediment is removed as a slurry of about 15–20 percent solids by weight. Hydraulic dredging, normally conducted from a barge, can access most shallow areas of the reservoir. Dredging could begin in the shallow areas of the reservoir (5–30 feet) and continue to deeper areas as the reservoir is drawn down. If delta sediment is to be left to river erosion, dredges working from barges could pick up lake-bed sediment immediately downstream from the eroding delta front. Submersible dredges also could be used to dredge deep areas of the reservoir before drawdown. Woody debris or tree stumps may prevent the removal of sediment from the lowest layer of the reservoir bottom. Design considerations would include volume and composition of material to be dredged, reservoir water depth, dredge capacity, and distance to and size of the disposal facility. In 1989, 280,000 cubic yards were hydraulically dredged from a 180-acre lake in central Illinois and disposed of at a facility constructed on the owner's adjacent property for a total cost of $900,000 and with a unit cost of about $3 per cubic yard.

## Sediment Conveyance

Methods of conveyance include transport through a sediment slurry pipeline, by truck, and by conveyor belt. A sediment slurry pipeline can be an efficient and cost-effective means of conveying sediment over long distances, especially under gravity flow conditions. Conveyer belts may be efficient over short distances. Trucking, a conventional method, is often the most expensive because of the large quantities of sediment involved.

For a sediment slurry pipeline, the route and distance to the disposal site are an important design consideration. An alignment along the downstream river channel may allow gravity flow and avoid pumping costs. However, construction in canyon reaches could be difficult, and the pipeline would have to be protected from river flows. The pipeline could be buried or secured above ground with lateral supports. These supports might consist of large concrete blocks or rock anchors. If gravity flow is not possible, a pumping plant would be needed. Booster pumps also may be needed for slurry pipelines of long distance. The pipeline and any pumping stations could be removed after the sediment has been dredged from the reservoir.

A certain amount of water would be required to operate the slurry pipeline (80–85 percent water by weight), and this amount would reduce downstream river flows. If water is scarce, the slurry pipeline operation may have to be temporarily curtailed or discontinued during low flow periods to maintain minimum river flows.

Silt- and clay-sized sediments will flow easily by gravity through the sediment slurry pipeline. However, sand-size and larger sediment may abrade or clog the pipeline. Therefore, a settling basin or separator may be needed to prevent sand and coarser material from entering the slurry pipeline. The coarse sediment that is excluded could be discharged back into the reservoir or transported to the disposal site by conveyor belt or truck.

### Long-Term Disposal

Disposal sites include old gravel pits, landfills, or ocean disposal areas. Distance from the reservoir is an important factor in the selection of a disposal site, because conveyance costs increase as the distance to the disposal site increases. If the disposed sediment contains high concentrations of contaminants, a land disposal site may have to be lined to prevent groundwater contamination. For a slurry pipeline, the sediment-water mixture is discharged into a settling basin at the disposal facility. The disposal facility should large enough to provide adequate settling times so that the return flow (effluent) meets regulatory criteria. Reservoir sediment volumes at the disposal site may be large (hundreds of thousands or millions of cubic yards) and require large land areas (tens or hundreds of acres). For example, disposal of the nearly 18 million cubic yards of sediment in two reservoirs on the Elwha River would require a 560-acre site if piled 20 feet high.

## STABILIZATION ALTERNATIVE

Under this alternative, sediment would be stabilized in the reservoir by constructing a river channel through or around the reservoir sediment.

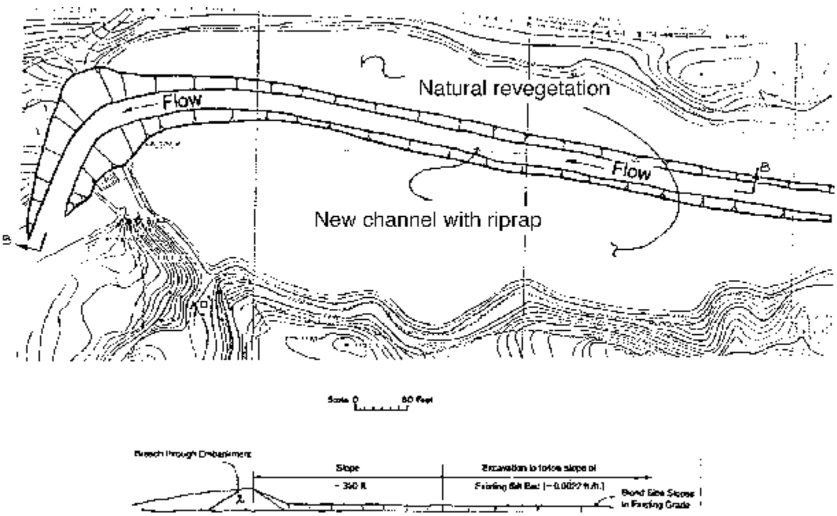

**Figure 6.2** River channel constructed through the stabilized reservoir sediment. *Source*: ASCE (1997).

Stabilization of the reservoir sediment would prevent it from entering the downstream river channel. The cost of this alternative would typically be more expensive than river erosion, but less expensive than mechanical removal. This alternative may be desirable if the reservoir sediment is contaminated. One disadvantage of this alternative is that the reservoir topography would not be restored. If a river channel were constructed through the reservoir sediment (see Figure 6.2), then only some of the sediment would have to be moved and only short distances. But, there is the risk that the sediment could erode during flood flows and be transported into the downstream river channel. The challenge is to keep the reservoir sediment stable over the long term. A stable channel design should take into account a range of river discharges and upstream sediment loads. The risk of erosion could be reduced by including a floodplain in the design. Thus, if topographic conditions permit, the river channel and floodplain could be constructed around the reservoir sediment. Leaving the sediment in the reservoir may be an attractive alternative if restoring the reservoir topography is not an objective and the risk of erosion during floods is acceptable.

For partial dam removal, the lower portion of the dam could be left in place to hold back the existing reservoir sediment. However, some fine sediment may be eroded downstream during drawdown of the upper reservoir. A portion of the dam also could be breached down to the pre-dam riverbed, but the remaining length of the dam could be used to help retain sediment deposited along the reservoir margins.

For full dam removal, a stable channel to pass river flows would have to be designed and constructed either through or around the reservoir sediment. Mechanical or hydraulic dredging equipment could be used to excavate a new river channel through the sediment, and the excavated sediment could be redeposited along the reservoir margins. Through control of the lake level, the power of the river also could be used to excavate and transport sediment (similar to the river erosion alternative).

The size of the channel to be excavated is based on the hydrological, hydraulic, and sediment load characteristics of the river basin and an acceptable level of risk (e.g., the 100-year flood). Matching the alignment, slope, and cross section of a new river channel (excavated through the reservoir sediment) to that of the old pre-dam river would help to ensure a stable channel over the long term. A channel with relatively low velocity and slope would reduce the risk of bank erosion, but may result in the deposition of the upstream sediment supply. A channel with relatively high velocity and slope would decrease the risk of sediment deposition, but may result in erosion during floods. The width, depth, and slope for a stable the channel can be computed for a given discharge, roughness, and upstream sediment supply. The procedure uses Manning's equation, the conservation equation ($Q = VA$), a sediment transport equation, and the minimum stream power theory ($VS =$ minimum).

Vegetation can be planted to help stabilize the remaining sediment from surface erosion. Bank protection structures may be required for the channel and the terrace banks at the edge of the floodplain. However, these structures would have to be maintained over the long term. If the bank protection fails during a flood, large quantities of sediment could be transported downstream. A diversion channel may be needed to route water around the work area while the channel and bank protection are constructed. This alternative can become quite costly if the channel to be excavated and protected extends a significant distance upstream of the existing dam.

The influence of tributary channels entering the reservoir area should be considered in the stabilization alternative. Local storms may cause floods in these tributary channels, erode large amounts of the sediment, and damage the main channel protection. Channels may need to

**Table 6.3** Summary Comparison of Sediment Management Alternatives

| Sediment Management Alternative | Advantages | Disadvantages |
|---|---|---|
| No action | Low cost | Continued problems for fish and boat passage<br>For storage reservoirs, continued reservoir sedimentation, loss of reservoir capacity, and reduced sediment supply to the downstream river channel |
| River erosion | Potentially low-cost alternative<br>Sediment supply restored to the downstream river channel | Generally large risk of unanticipated impacts<br>Temporary degradation of downstream water quality<br>Potential river channel aggradation downstream and channel degradation upstream from the reservoir |
| Mechanical removal | Generally low risk of reservoir sediment release<br>Low impacts on downstream water quality<br>Low potential for short-term aggradation of the downstream river channel | High cost<br>Possible difficulty in locating a disposal site<br>Effects of contaminated sediments, if present, on groundwater at the disposal site |
| Stabilization | Moderate cost<br>Impacts avoided at other disposal sites<br>Low to moderate impacts on downstream water quality<br>Low potential for short-term aggradation of the downstream river channel | Long-term maintenance costs of the river channel through or around reservoir sediments<br>Potential for failure of sediment stabilization measures<br>Reservoir area not restored to natural conditions |

*Source*: ASCE (1997).

be excavated for these tributaries to prevent sediment erosion. To properly convey tributary inflow, the entire reservoir area must be mapped to identify these local inflow drainages, and erosion protection should be provided to contain the sediment on the floodplain.

A network of dikes could be constructed within the reservoir area to contain any excavated sediment. If one dike fails, only a portion of the stabilized sediment would be released downstream. If the dikes can be placed above the design flood stage, then protection from river flows would not be necessary. If the dikes are exposed to river flows, stream bank protection is needed to prevent erosion. Stream bank protection structures could be constructed from natural materials such as rock, vegetation, or woody debris. For large volumes of sediment, the slope of the stabilized sediment or dikes is an important consideration. Although mild slopes are generally more stable than steep slopes, mild slopes require a larger area of the reservoir to be occupied by the stabilized sediment.

## CONCLUSIONS: SUMMARY COMPARISON OF ALTERNATIVES

The best sediment management alternative will depend on the management objectives and design constraints, which depend in turn on engineering, environmental, social, and economic considerations. Some of the basic advantages and disadvantages of the sediment management alternatives are listed in Table 6.3.

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# 7

# SEDIMENTATION HAZARDS DOWNSTREAM FROM RESERVOIRS

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***Abstract:*** Many reservoirs trap most or all of the entering sediment, creating sediment-depleted conditions downstream. The result may be channel adjustment in the form of bank erosion, bed erosion, substrate coarsening, and channel planform change. Channel adjustment also may result from episodic sediment releases during reservoir operation or from sediment evacuation after dam removal. Channel adjustment to the increased influx of sediment depends on the magnitude, frequency, duration and grain-size distribution of the sediment releases and on the characteristics of the downstream channel. Channel adjustment may take the form of a change in substrate-size distribution, filling of pools, general bed aggradations, lateral instability, a change in channel planform, or floodplain aggradation. The increased sediment availability may alter aquatic and riparian habitat, reduce water quality, distribute adsorbed contaminants along the river corridor, and provide germination sites for exotic vegetation. Mitigation of these sedimentation hazards requires

- Mapping grain-size distribution within the reservoir and estimating the grain-size distributions of sediment that will be mobilized through time
- Mapping shear stress and sediment transport capacity as a function of discharge on the basis of channel units for the length of the river likely to be affected
- Mapping potential depositional zones, as well as aquatic habitat and "acceptable losses," along the downstream channel and comparing these volumes with the total sediment volume stored in the reservoir as a means of estimating the total transport capacity required to mobilize reservoir sediment delivered to the channel
- Designing discharge and sediment release regimes (magnitude, frequency, duration) to minimize adverse downstream impacts
- Developing plans to remove, treat, contain, or track contaminants, and to restrict the establishment of exotic vegetation.

The North Fork Cache la Poudre River in Colorado is used to illustrate this approach to mitigating sediment hazards downstream from reservoirs.

As dams built during the past century accumulate ever greater volumes of sediment, the sedimentation hazards downstream from reservoirs are receiving more attention. Storage of sediment both decreases reservoir capacity and the operating efficiency of the dam and creates a "sediment shadow" downstream where sediment-starved flows commonly erode channel boundaries and create long-term channel instabilities. Numerous studies have documented the downstream channel changes resulting from sediment depletion and altered annual hydrograph associated with a dam. These changes include channel narrowing, reduction in braiding, and associated loss of habitat complexity (Ligon et al., 1995; Van Steeter and Pitlick, 1998a, 1998b; Surian, 1999); bed erosion and a reduction in the overbank flooding that is critical to many riparian species (Baxter, 1977; Brooker, 1981; Lagasse, 1981; Erskine, 1985; Ligon et al., 1995; Friedman and Auble, 2000); substrate coarsening (Collier et al., 1997); and bank erosion (Petts, 1984; Williams and Wolman, 1985). The specific changes produced downstream from a dam by reservoir sediment trapping will depend on the changes in flow regime and sediment transport capacity downstream from the dam; the erodibility of the downstream channel boundaries, as governed by the presence of vegetation and grain size of the channel substrate; the presence of tributaries, hill slope mass movements, or other sources of sediment to the main channel; and the amount and size distribution of sediment released from the reservoir.

Sediment may be deliberately released from a reservoir in an attempt either to reduce downstream channel instability or to increase reservoir capacity. Large, episodic sediment releases from reservoirs have received relatively little detailed study (Wohl and Cenderelli, 2000; Rathburn and Wohl, 2001). However, channel response to such releases may be inferred from published studies of other large, episodic sediment inputs resulting from dam failure (Jarrett and Costa, 1986; Pitlick, 1993; Cenderelli and Wohl, 2001), dam removal (Williams, 1977), heavy rainfall and associated flooding (Shroba et al., 1979; Lisle, 1982; Madej and Ozaki, 1996), mining (Pickup et al., 1983; James, 1991, 1993; Hilmes and Wohl, 1995), and volcanic eruptions (Montgomery et al., 1999; Simon, 1999).

Channel adjustment to increased sediment influx depends on the magnitude, frequency, duration, and grain-size distribution of the sediment releases and on the downstream channel characteristics. If the sediment introduction exceeds the transport capacity of the downstream channel, selective or general sediment accumulation occurs. During selective sediment accumulation, sediment is stored at sites of locally reduced transport capacity, such as pools. Preferential pool filling, a common response to sediment increase along pool-riffle channels, is often used to assess channel response to various land-use activities (Lisle, 1982; Madej and Ozaki, 1996; Montgomery and Buffington, 1997). More generalized sediment accumulation throughout a channel may result in a change (usually a fining) in streambed grain-size distribution (Wilcock et al., 1996); widespread bed aggradation (James, 1993); or a change in channel planform (Hilmes and Wohl, 1995), which commonly occurs at the initiation of braiding in a once single-thread channel. Excess sediment also may be deposited on adjacent floodplain surfaces, reducing channel–floodplain connectivity (Pickup et al., 1983). In addition to altering channel configuration and reducing lateral and vertical channel stability, the introduction of excess sediment to a channel substantially affects aquatic and riparian ecosystems by altering habitat type and stability, reducing water quality, distributing adsorbed contaminants such as heavy metals along the river corridor, and providing germination sites for exotic vegetation (LaPerriere et al., 1985; Wagener and LaPerriere, 1985; Van Nieuwenhuyse and LaPerriere, 1986; McLeay et al., 1987; Miller et al., 1999; Stoughton and Marcus, 2000).

The widespread presence of dams and reservoirs suggests that a systematic, rather than haphazard, approach to addressing downstream sedimentation hazards associated with these structures is imperative. This approach would require careful consideration of both general patterns and site-specific characteristics.

## MITIGATION OF DOWNSTREAM SEDIMENTATION HAZARDS

Sedimentation hazards downstream from dams and reservoirs can be mitigated using a five-step procedure.

1. *Map grain-size distribution within the reservoir and estimate the grain-size distributions of sediment that will be mobilized through time.* Downstream sediment transport and storage will be governed by the balance between the transport capacity of the flow and the sediment volume and grain-size distribution. For example, a sediment release drawing only on the downstream end of the reservoir may be mobilizing only the finest sediments, which are readily transported in suspension. By contrast, a sed-

iment release drawing on the entire reservoir may mobilize progressively coarser sediments with time, so that downstream transport will shift from suspended to bed load sediment. The grain-size distribution of sediment released from the reservoir will partly determine the mode (wash, suspended, bed load) of downstream sediment transport, and thus determine transport distance and type of sediment deposition and storage.

2. *Map shear stress and sediment transport capacity as a function of discharge on the basis of channel units for the length of the river likely to be affected.* Sediment deposition and storage commonly occur on a site-specific basis. Estimates of downstream sediment dynamics after a reservoir sediment release are thus more precise if they account for differences in transport capacity among channel units such as pools and riffles rather than use a cross-sectional or reach-scale average estimate for transport capacity. These estimates of channel unit transport capacity will be very dependent on discharge. Laterally constricted pools, for example, have uniformly low-velocity flows during lower stages of flow, and sediment in transport is likely to form an even veneer across the pool (Wohl and Cenderelli, 2000). A central jet of high velocity and transport capacity and marginal eddies with low transport capacity become increasingly pronounced within laterally constricted pools as the stage of flow increases (Thompson et al., 1998, 1999). These conditions produce substantial sediment storage along the pool margins, but this sediment may be remobilized during the falling stage as the central jet declines in strength and marginal sediment slumps into the pool thalweg (Wohl and Cenderelli, 2000).

3. *Map potential depositional zones, as well as aquatic habitat and "acceptable losses," along the downstream channel and compare these volumes to the total sediment volume stored in the reservoir as a means of estimating the total transport capacity required to mobilize reservoir sediment delivered to the channel.* If sediment supply is likely to exceed storage capacity, the discharge accompanying the sediment release must be sufficient to transport excess sediment out of the river reach of concern. In many laterally confined channels, for example, pools are the primary sediment storage sites. Pools also contain critical aquatic habitat, in that some minimum volume or depth of water during low flow is necessary to ensure fish survival. If this minimum can be specified for a given river and fish population, available pool volume in excess of the minimum may be regarded as temporary sediment storage and thus an acceptable loss after reservoir sediment release.

4. *Design the discharge and sediment release regime (magnitude, frequency, duration) to minimize adverse downstream impacts.* This step refers primarily to minimizing downstream aggradation or channel change by comparing available sediment storage volume with sediment supplied. The timing of the sediment release also must take into account the flow regime in the downstream channel and the life cycles and resiliency of downstream organisms. Flow regime controls sediment transport after the sediment release. The worst-case scenario would be a sediment release during declining flows, followed by a prolonged period of very low flow. A much better scenario for enhancing downstream sediment mobility would be to release sediment during the rising stage of flow, thereby maximizing downstream transport and redistribution of the released sediment. The life cycles of downstream aquatic and riparian organisms may influence the timing of sediment releases in that some fish species spawn in the autumn, whereas others spawn in the spring. A sediment release during declining autumn flows would not only maximize the duration of sediment storage along the river, but also would interfere with the flow of oxygenated water past the fish eggs for a much longer period of embryo development. The resiliency of organisms to a pulse of sediment transport or storage varies among types of organisms and among species. A diverse community of macroinvertebrates is likely to lose both density and taxa richness after a sediment release. Some species can recover within days, whereas others require more than a year to recover (Zuellig et al., 2002).

5. *Develop plans to remove, treat, contain, or track contaminants, and to restrict establishment of exotic vegetation.* Downstream dispersal of mining sediments contaminated with heavy metals creates long-term hazards for aquatic and riparian organisms and human communities (Prokopovich, 1984; LaPerriere et al., 1985; Graf et al., 1991; Miller et al., 1999; Stoughton and Marcus, 2000). Reservoir sediments also may be contaminated by adsorbed heavy metals, organochlorine compounds such as pesticides and PCBs (polychlorinated biphenyls), or excess nutrients from agricultural runoff (Graf, 1990). Because of the hazards posed by these contaminants, it is critical to contain or at least monitor the downstream dispersal of the contaminated sediments. Newly created depositional surfaces also may serve as germination sites for exotic riparian vegetation such as tamarisk (*Tamarix chinensis*) or Russian olive (*Elaeagnus angustifolia*). These species may outcompete native riparian vegetation (Olson and Knopf, 1986), reduce riparian habitat for native birds and other species (Ohmart et al., 1977), and alter water and sediment

movement along rivers and thus the channel planform (Graf, 1978). If the release of sediment from a reservoir is likely to provide new germination sites for such exotic species, measures to minimize germination potential—such as timing the sediment release to account for plant growth cycles or actively seeding newly deposited surfaces with native species—may be necessary.

## CASE STUDY: NORTH FORK CACHE LA POUDRE RIVER, COLORADO

Approximately 7,000 cubic meters of sediment ranging in size from clay to gravel were released from Halligan Reservoir into the North Fork Cache la Poudre River in late September 1996 (Figure 7.1). The sediment was released at the end of the annual snowmelt hydrograph peak, as the reservoir was being drawn down for the winter. During the sediment release, the discharge was 4 cubic meters per second but it was decreased to 0.06 cubic meters per second immediately after the release. As a result, reservoir sediment accumulated along the channel for more than 8 kilometers downstream and about 4,000 fish were killed.

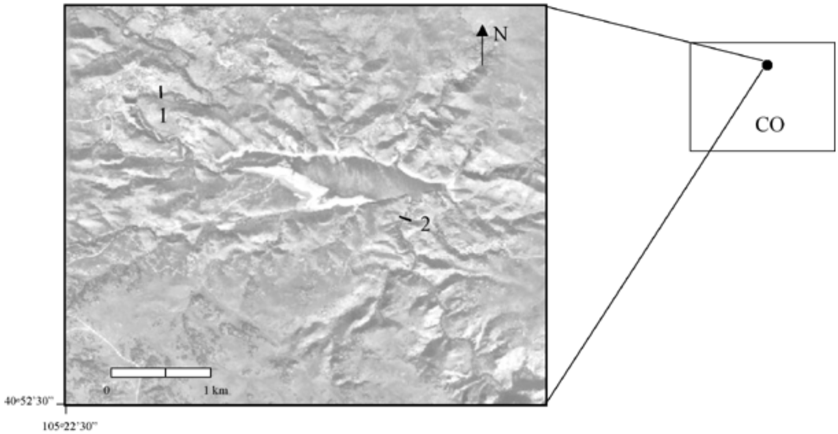

**Figure 7.1 Aerial photograph and location map of Halligan Reservoir. Upstream and downstream sample cross sections are numbered 1 and 2, respectively.** Courtesy of John Fusaro, Natural Resource Conservation Service, 1993.

## DESCRIPTION OF RELEASE

The North Fork is a bedrock-controlled, pool-riffle channel that flows through a deep canyon. Channel substrate is bedrock, or cobble to boulder-size sediment.* The coarser bed material is not mobilized during normal snowmelt years. Pools occur where bedrock outcrops laterally constrict the channel. Sediment released from the reservoir accumulated preferentially in the pools as a function of distance downstream from the dam. At 0.5 kilometers downstream, pools up to 3.5 meters deep were completely filled; at 3.2 kilometers downstream, pools were half-filled. Infilling sediment became progressively finer grained downstream. Sediment also formed a thin but continuous veneer over the riffle and run sections of the streambed and infiltrated the coarse sediment to a depth of 6 centimeters. The net effect of the sediment deposition was to reduce the undulations in bed topography associated with the pools and riffles and to create a more uniform planebed channel that maximized sediment transport.

The onset of the snowmelt hydrograph in February 1997 initiated remobilization of the reservoir sediment. By September 1997, 80–90 percent of the sediment stored in pools had been remobilized and transported downstream. The remaining sediment has not been removed from the pool margins. There, it is effectively stabilized by riparian vegetation or shielded from erosion by the presence of flow separation.

Remobilization of reservoir sediment began in February 1997 with a flush of suspended sediment transport that lasted only a few days. Discharge increased again in March 1997 with continued snowmelt and peaked in June at 10 cubic meters per second. The timing and duration of bed load transport during spring runoff varied with distance downstream because of the storage created by pools, which acted as a series of sediment sources and sinks. Bed load sediment was temporarily stored in and remobilized from each pool, so that upstream portions of the channel became depleted of reservoir sediment earlier in the snowmelt hydrograph, while downstream portions were still receiving sediment remobilized from upstream pools. The magnitude of discharge, which influenced the strength of marginal circulation and eddy storage in the pools, and the duration of discharge, which influenced the progressive downstream movement of

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* This description was taken largely from Wohl and Cenderelli (2000), Rathburn (2001), Rathburn and Wohl (2001), and Rathburn and Wohl (in press).

bed load from pool to pool, were both critical controls on sediment remobilization and transport from the portion of the North Fork affected by the reservoir sediment release.

The five-step procedure was applied to Halligan Reservoir as part of an ongoing study that began in 1996 after the sediment release. Total maximum daily load (TMDL) standards developed for Halligan Reservoir (CDPHE, 2001) drives much of this recent research. The TMDL is designed to limit sediment releases downstream to protect aquatic ecosystems. There is also growing interest in replacing or enlarging Halligan Dam, possibly by as much as six times, for potential future municipal water supply (ECI, 2002). As a result, recent work has focused on developing a sediment budget for the reservoir to quantify sediment inputs and outputs, to determine the effectiveness of reservoir drawdown as a sediment management practice, and to provide critical sediment data for dam design-life predictions.

## METHODS

*Step 1*—mapping grain-size distributions within Halligan Reservoir—involved collecting grab samples along the perimeter of the reservoir at low water and coring the sediment within the upstream delta. Preliminary results indicate a bimodal distribution of delta sediment composed of grussified gravel and coarse sand ($d_{50} = 0.6$ mm), and dark brown, organic-rich silt and fine sand ($d_{50} = 0.043$ mm).

Data specific to the sediment budget are instrumental in quantifying the grain-size distributions that are mobile over time. Suspended and bed load samples were collected over the 2002 snowmelt hydrograph. Because of an extremely low snowpack, discharge never exceeded 1.5 cubic meters per second along the North Fork in the spring, a mere 15 percent of normal. As a result, minimal suspended and bed load sediments were transported along the North Fork. Integrating over the 45-day sampling period results in a total load estimate of 2.3 metric tons transported during reservoir inflow.

During the fall reservoir drawdown, suspended sediment samples were collected during each stepdown of the flow. No bed load was in transport during the drawdown. Although the instantaneous values of suspended sediment concentrations during the outflow were greater than those during the inflow, integrating under the curve over the two-day fall sampling resulted in an estimate of 19 metric tons of suspended sediment in transport. Sediment discharge into Halligan Reservoir approximated output during the 2002 drought year, given that the bed load component (4 metric tons) was probably trapped locally by beaver dams upstream from the reservoir. Judging by grain-size sampling after the 1996 release, sediment mobilized and transported through the system is fine-grained, with a $d_{50}$ of very fine sand (0.092 mm) (Rathburn and Wohl, 2001).

*Step 2*—mapping shear stress and sediment transport capacity—involved the use of one- (HEC-6) and semi-two-dimensional (GSTARS 2.0) sediment transport models of pool-riffle sequences within the downstream reaches of the North Fork. A comparison of model results with field data collected during the 1997 snowmelt hydrograph indicates that the one-dimensional model yielded the closest agreement between predicted and measured changes in pool elevation as a function of discharge magnitude and duration (Rathburn and Wohl, 2001). More than 50 percent of the actual scour and deposition within the three pools investigated was modeled using a purely one-dimensional model. Because the modeling concentrated on pool recovery after the sediment release to reestablish critical overwinter habitat for fish, a two-dimensional hydraulic model (RMA-2) also was used to improve the accuracy of modeling sediment transport into and out of eddy pools. A particle stability index, as the ratio of bed shear stress to critical shear, was useful in delineating general areas of scour (high velocity and shear stress) and deposition (low velocity and shear stress). The RMA-2 model improved delineation of flow hydraulics in areas of flow separation and recirculation within the pools, but it failed to represent the simultaneous aggradation and degradation measured in the pools (Rathburn and Wohl, in press).

In s*tep 3*, depositional zones downstream from Halligan Dam were mapped after the 1996 sediment release. Other researchers at Colorado State University and state agency personnel simultaneously evaluated macroinvertebrate recolonization and conducted fish surveys. Target values from the TMDL standards are now available for acceptable minimum trout biomass, total macroinvertebrate taxa, and EPT (Ephemeroptera + Plecoptera + Trichoptera) abundance (CDPHE, 2001).

Depending on the management objectives for the downstream, identifying "acceptable losses" may allow for a wide range of depositional volumes. A bathymetric survey recently completed at Halligan Reservoir quantified the total sediment volume in the reservoir. Topographic maps of the reservoir from 1906 (predam) and 1941 indicate that maximum deposition in the reservoir is 2.5 vertical meters, concentrated in areas of the original channel of the North Fork. Much of this sediment accumulated within the 31 years after dam closure in 1910. Ultimately, we plan to compare volumes of in-channel deposition to volumes in the reservoir to estimate total 1996-style sediment releases that are needed to restore storage capacity within Halligan Reservoir.

In s*tep 4*, design discharge and sediment release regimes for Halligan Reservoir that avoid pool infilling and fish and macroinvertebrate mortality are based on a conceptual model of sediment transfer within pools (Rathburn and Wohl, in press). Such a model must have sufficient resolution to capture specific processes governing sediment transport within and between pools. Such processes include development of a strong shear zone that prevents scour of eddy sediment at high discharges. Within the downstream reaches of the North Fork, the trajectory of water and sediment entering pools at low flows allows released sediment to be sluiced through the channel at low discharges (Rathburn and Wohl, in press). A flushing discharge that transports sediment during high flow also may be a useful sediment management practice, provided the life cycles and spawning needs of the aquatic organisms are considered.

As for s*tep 5*, we did not look at the removal or containment of contaminated sediment from the reservoir because to date no contaminated water or sediment issues are associated with the North Fork system.

## CONCLUSIONS

The accuracy and effectiveness of the five-step procedure, particularly step 2) mapping shear stress and sediment transport capacity), step 3 (mapping potential depositional volume), and step 4 (designing a discharge regime), depend largely on the nature of the simplifying assumptions used in the procedure. For example, laterally constricted pools were the key channel unit determining long-term sediment storage and remobilization along the North Fork. These pools have strong zones of flow separation and associated strong cross-pool gradients in shear stress, sediment transport capacity, and storage volume. Use of a cross-sectional average value for these variables, as in the HEC-6 model, might produce results that are too imprecise to be useful. However, a program such as GSTARS 2.0, which uses a stream tube approach that allows for differential erosion and deposition across a cross section, does not accommodate large differences in grain sizes of bed sediment over short distances (such as between riffles made up of boulders and adjacent pools of fine sand). The application of these models revealed the limitations on producing precise, quantitative descriptions of sediment dynamics within a reach of river affected by reservoir sedimentation. Indeed, different limitations compromised each of the three models applied to the North Fork system. Such limitations are likely to similarly affect attempts to model sediment dynamics in many of the channels downstream from dams, which commonly have the characteristics that limited the accuracy of sediment modeling along the North Fork: large spatial differences in bed grain size; strongly three-dimensional flow and associated differential scour and deposition across a cross section; temporal changes in sediment supply and bed material grain-size distribution; and the presence of spatially discontinuous portions of immobile bed material (e.g., boulder riffles).

The five-step procedure outlined is an ideal one. The ability to mitigate sediment hazards downstream from dams using this procedure will depend on (1) the spatial and temporal resolution at which field measurements and modeling are undertaken for a given reach of river, and (2) the accuracy with which individual processes of hydraulics and sediment transport can be described. The first limitation is one of time and cost; the second limitation depends on quantitative understanding of processes. Significant progress in mitigating downstream sediment hazards will probably depend on advances in understanding and simulating processes in rivers subjected to reservoir sediment releases.

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# 8

# FRAMEWORK FOR MONITORING AND PRELIMINARY RESULTS AFTER REMOVAL OF GOOD HOPE MILL DAM

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***Abstract:*** Good Hope Mill Dam was removed from Conodoguinet Creek in Cumberland County, Pennsylvania, over a period of three days beginning on November 2, 2001. The U.S. Geological Survey, in cooperation with Pennsylvania State University, studied the effects of this removal on channel characteristics, water quality, macroinvertebrates, and fish. Data collection was scheduled for completion in early 2003. The results and interpretations presented in this chapter are based on data collected from July 30, 2001, to January 10, 2002.

Low-flow conditions, coupled with erosion-resistant bedrock upstream and downstream of the dam, resulted in little change to the channel bed or banks upon dam removal. Cross-sectional surveys of the channel 115 feet upstream and 126 feet downstream of the dam indicate that block failure of dewatered banks or channel-altering mobilization of bed sediment did not occur. Turbidity data from these same sites during removal indicate some sediment was mobilized, but apparently it was fine enough to be transported through the system.

Diurnal fluctuations of temperature, dissolved oxygen, pH, and specific conductance were captured by continuous measurement of these constituents. Dissolved oxygen was particularly variable, with a daily range of up to 10 milligrams per liter. Dissolved oxygen maxima are coincident with temperature maxima, suggesting that temperature does not control oxygen levels during periods of elevated photosynthetic activity. Measurement of dissolved oxygen during dam removal indicates that this constituent reached a low of 80 percent saturation (8.7 milligrams per liter), allaying concerns that anoxia would occur as impounded water was released.

The removal of Good Hope Mill Dam resulted in a timing shift in water quality constituents measured within the impoundment. Before dam removal, daily extremes of temperature, dissolved oxygen, pH, and specific conductance within the impoundment were out of phase with a site above the impoundment

by about 12 hours. Once the dam was removed, the diurnal pattern within the impoundment shifted and converged with that of the site above the impoundment. The offset before removal may be related to a lag time stemming from decreased velocity through the impoundment.

A dataset of nutrients, suspended sediment, and flow measured at Hogestown gage (4.9 miles upstream of Good Hope Mill Dam) over a six-year period provides a context for comparing concentrations of these constituents during dam removal. Ammonia plus total organic nitrogen at Hogestown gage ranged from 0.1 to 2.1 milligrams per liter and was poorly correlated with flow. Ammonia plus total organic nitrogen concentrations measured below the dam during removal ranged from 0.34 to 0.92 milligrams per liter, suggesting that dam removal resulted in minimal ammonia loading. Similarly, suspended sediment concentrations during removal were not extreme when viewed in the context of the long-term gage data. Suspended sediment at Hogestown gage ranged from 1 to 490 milligrams per liter compared with a range of from 2.8 to 98 milligrams per liter during dam removal. The correlation between flow and sediment data suggests that the maximum sediment concentration measured during removal occurs over a range of flows (1,100–5,900 cubic feet per second; recurrence interval equals less than 1 to 1.5 years).

Dominant macroinvertebrate taxa remained the same after dam removal at all stations except the one within the impoundment. Water levels behind the dam decreased 3 feet upon removal, setting the stage for a shift in the macroinvertebrate community in the newly exposed riffle habitat of the former impoundment. The dominant taxon within the formerly impounded reach changed from Gammaridae to Caenidae, with the genus *Caenis* making up 66 percent of the sample.

SMALL DAMS are common features of Pennsylvania's river systems. The Pennsylvania Fish and Boat Commission has identified nearly 300 small dams across the state with impoundments that are restricted to the channel and that allow water to flow over the entire dam (Pennsylvania Fish and Boat Commission, 2002). These structures are usually referred to as "run-of-the-river" dams. The dams were built to provide a water supply, irrigation, power generation, and recreation, among other benefits. However, many of Pennsylvania's run-of-the-river dams, including the Good Hope Mill Dam on Conodoguinet Creek in Cumberland County, have become obsolete, turning the public's attention from the benefits they once provided to the safety and ecological concerns they now pose (Figure 8.1). For Good Hope Mill Dam, removal was a cheaper option for mitigating safety and ecological concerns than rebuilding or retrofitting the structure to meet current safety and environmental regulations. The dam was removed over a three-day period, beginning on November 2, 2001, to

**Figure 8.1 Good Hope Mill Dam on Conodoguinet Creek before removal.** Courtesy of Jeffrey J. Chaplin.

eliminate safety concerns, permit resident and migratory fish passage, and improve habitat for native fish (Figure 8.2).

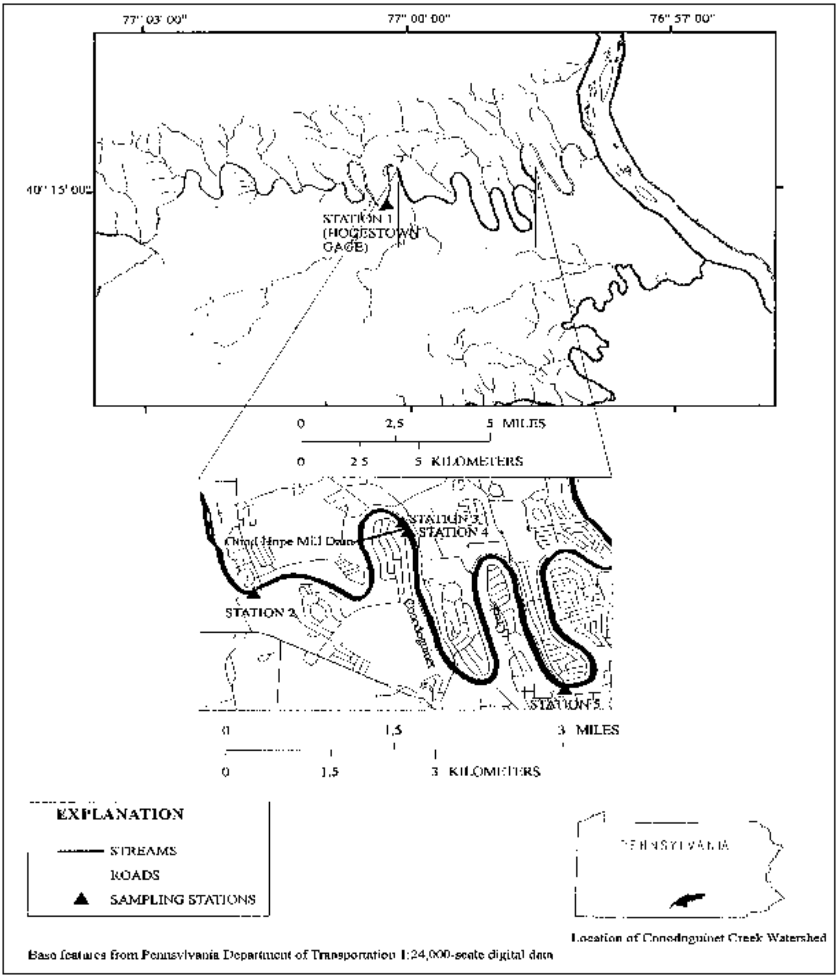
Dam removal alters the longitudinal profile of a stream and changes the upstream impoundment from a lentic system to a higher velocity lotic system within a short time. The implications of removal for channel characteristics, water quality, macroinvertebrates, and fish are not well understood because only a small number of removals have been studied, and comprehensive studies that document the effects of dam removal are just beginning to be published. Most dam removal research has focused on larger dams or on the response of a single variable such as macroinvertebrates. This limited knowledge base underscores the need for additional empirical research on responses to removal so that outcomes can be better predicted. This chapter presents a monitoring framework and the preliminary results after removal of Good Hope Mill Dam. The results presented characterize geomorphologic, water quality, and macroinvertebrate community conditions before, during, and shortly after removal.

**Figure 8.2 Conodoguinet Creek after removal of Good Hope Mill Dam.** Courtesy of Jeffrey J. Chaplin.

## DESCRIPTION OF STUDY AREA

The dam is located on Conodoguinet Creek at the former Good Hope Mill, 13.5 miles upstream of the confluence of Conodoguinet Creek and the Susquehanna River. The 6-foot-high, 220-foot-wide concrete structure was constructed on bedrock over 100 years ago. The original purpose of the dam was to provide waterpower for the mill. The drainage area at the dam site is 492 square miles, and the mean annual flow is 619 cubic feet per second (cfs) based on 72 years of daily streamflow recorded at Station 1 (Hogestown gage), located 4.9 miles upstream (Figure 8.3). Under normal flow conditions, the dam impounded a 1-mile reach and held approximately 52 acre-feet of water, all of which was contained within the channel.

The upstream and downstream channel substrate was characterized by erosion-resistant gray shale that was exposed in high-energy reaches but was overlaid by beds of gravel, cobble, and silt in low-energy reaches. Fine sediment in the silt-clay fraction covers the bedrock surface



Location of Conodoguinet Creek Watershed

Base features from Pennsylvania Department of Transportation 1:24,000-scale digital data

**Figure 8.3** Sampling stations upstream and downstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

at a depth of 1–3 inches within the impoundment, except for a solitary depositional feature that was removed with the dam. This feature, on the north side of the channel, covered about 240 square feet, had a maximum depth of 1.5 feet, and was composed of a mix of coarse woody debris, gravel, and fine sediment. Concern about downstream sediment loading prompted removal of this feature with the dam, although it was not considered a source of contamination—bed sediment samples indicated that metal concentrations were less than published guidelines for contaminated sediment (MacDonald et al., 2000).

## MONITORING FRAMEWORK

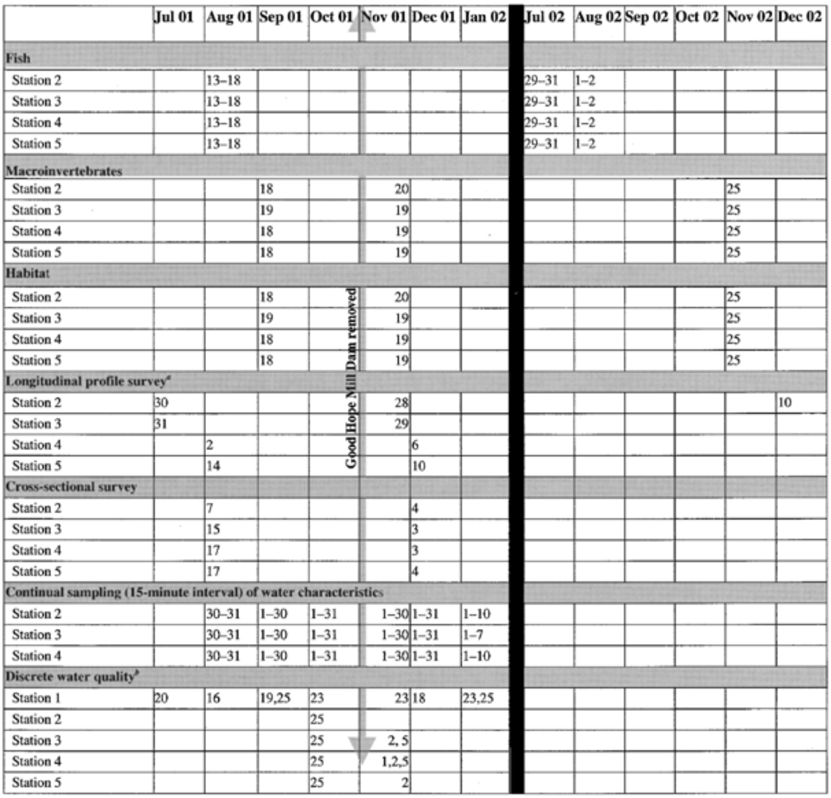
The monitoring framework used for Good Hope Mill Dam had spatial and temporal components. Attributing changes near the dam directly to removal necessitated sampling locations upstream of the impoundment where no effects of removal were anticipated and near the dam site where the most change was anticipated. Five sampling sites were established (Figure 8.3). Stations 1 and 2—located 4.9 and 2.5 miles, respectively, upstream from the dam—were control sites where baseline conditions were documented and no changes resulting from dam removal were anticipated. The greatest effect of removal was expected to be at Stations 3 and 4—located 115 feet upstream of the dam and 126 feet downstream of the dam, respectively. Station 5, located about 5 miles downstream, was used to characterize the spatial extent of changes associated with dam removal.

From a temporal perspective, the channel, water quality, macroinvertebrate community, or fish community may respond to removal immediately or over time. The general approach of this study was to monitor selected constituents shortly before removal, shortly after removal, and about a year later. Monitoring began in July 2001 and was to conclude in the first quarter of 2003. Specific monitoring dates are summarized in Table 8.1. Water quality constituents were monitored continually (15-minute intervals) from August 2001 to January 2002.

## METHODS

Channel characterization includes longitudinal and cross-sectional surveys of the channel, as well as habitat surveys within the channel. Elevations of the thalweg, relative to an arbitrary datum, were measured from Station 2 through Station 5, a distance of about 7 miles (Figure 8.3), to produce the longitudinal profile of the streambed. Cross sections of the channel were surveyed at Stations 2, 3, 4, and 5 (Figure 8.3). Habitat surveys, following Barbour et al. (1999), were completed at Stations 2, 3, 4, 5 before and after dam removal (Table 8.1).

**Table 8.1** Summary of Monitoring Dates



| | Jul 01 | Aug 01 | Sep 01 | Oct 01 | Nov 01 | Dec 01 | Jan 02 | Jul 02 | Aug 02 | Sep 02 | Oct 02 | Nov 02 | Dec 02 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fish** | | | | | | | | | | | | | |
| Station 2 | | 13–18 | | | | | | 29–31 | 1–2 | | | | |
| Station 3 | | 13–18 | | | | | | 29–31 | 1–2 | | | | |
| Station 4 | | 13–18 | | | | | | 29–31 | 1–2 | | | | |
| Station 5 | | 13–18 | | | | | | 29–31 | 1–2 | | | | |
| **Macroinvertebrates** | | | | | | | | | | | | | |
| Station 2 | | | 18 | | 20 | | | | | | | 25 | |
| Station 3 | | | 19 | | 19 | | | | | | | 25 | |
| Station 4 | | | 18 | | 19 | | | | | | | 25 | |
| Station 5 | | | 18 | | 19 | | | | | | | 25 | |
| **Habitat** | | | | | | | | | | | | | |
| Station 2 | | | 18 | | 20 | | | | | | | 25 | |
| Station 3 | | | 19 | | 19 | | | | | | | 25 | |
| Station 4 | | | 18 | | 19 | | | | | | | 25 | |
| Station 5 | | | 18 | | 19 | | | | | | | 25 | |
| **Longitudinal profile survey**[a] | | | | | | | | | | | | | |
| Station 2 | 30 | | | | 28 | | | | | | | | 10 |
| Station 3 | 31 | | | | 29 | | | | | | | | |
| Station 4 | | 2 | | | | 6 | | | | | | | |
| Station 5 | | 14 | | | | 10 | | | | | | | |
| **Cross-sectional survey** | | | | | | | | | | | | | |
| Station 2 | | 7 | | | | 4 | | | | | | | |
| Station 3 | | 15 | | | | 3 | | | | | | | |
| Station 4 | | 17 | | | | 3 | | | | | | | |
| Station 5 | | 17 | | | | 4 | | | | | | | |
| **Continual sampling (15-minute interval) of water characteristics** | | | | | | | | | | | | | |
| Station 2 | | 30–31 | 1–30 | 1–31 | 1–30 | 1–31 | 1–10 | | | | | | |
| Station 3 | | 30–31 | 1–30 | 1–31 | 1–30 | 1–31 | 1–7 | | | | | | |
| Station 4 | | 30–31 | 1–30 | 1–31 | 1–30 | 1–31 | 1–10 | | | | | | |
| **Discrete water quality**[b] | | | | | | | | | | | | | |
| Station 1 | 20 | 16 | 19,25 | 23 | 23 | 18 | 23,25 | | | | | | |
| Station 2 | | | | 25 | | | | | | | | | |
| Station 3 | | | | 25 | 2, 5 | | | | | | | | |
| Station 4 | | | | 25 | 1,2,5 | | | | | | | | |
| Station 5 | | | | 25 | 2 | | | | | | | | |

Good Hope Mill Dam removed

[a] The longitudinal profile was completed over a 7-mile reach. Dates shown under longitudinal profile indicate when each Station was surveyed.

[b] Discrete water quality samples were collected at Station 1 from August 1996 to June 2002. The sampling timeframe at all other stations was July 2001 to December 2002. Therefore, sampling dates at Station 1 that fall outside of this timeframe are omitted.

Water quality constituents, including specific conductance (microsiemens per centimeter, µS/cm), pH, turbidity, (Nephelometric Turbidity Units, NTU), dissolved oxygen (milligrams per liter), and temperature (°C) were measured at Stations 2, 3, and 4 on a continual basis (15-minute intervals). In addition to continual monitoring of the above water quality constituents, discrete samples for nutrients and suspended sediment were collected at Stations 2, 3, 4, 5 following methods in Wilde et al. (1998). Streamflow, ammonia plus total organic nitrogen, and suspended sediment measurements were made at Station 1 from August 1996 to June 2002 and will be used to characterize the variability of these parameters and to provide a context for observations during dam removal.

Benthic macroinvertebrates were sampled at all sites except Station 1. Stations 2, 4, and 5 are at free-flowing natural riffles and were conducive to kick sampling (Barbour et al., 1999) during both sampling events (Table 8.1). Because Station 3 was impounded prior to dam removal, midchannel locations were inaccessible by wading, and there was insufficient sediment to warrant capture of benthic organisms through the bed sediment. Instead, habitat, such as downed trees and rocks near the dam and periphery of the channel, was selectively jab sampled (Barbour et al., 1999). After dam removal, Station 3 converted to a free-flowing riffle and was kick sampled in the same manner as Stations 2, 4, and 5. Macroinvertebrates were identified to the lowest possible taxa at the U.S. Geological Survey (USGS) biology lab in New Cumberland, Pennsylvania.

The fish community was sampled by Pennsylvania State University at four sites. Stations 2, 4, and 5 were sampled using backpack electroshockers (pulsed DC) with a single zigzag pass to cover the entire channel, starting from the downstream end of the stream reach and working upstream. Because Station 3 was impounded prior to dam removal, this site was sampled at night by completing a single boat electrofishing pass along the entire shoreline to collect fish as they congregated in the shallows to feed (Reynolds, 1996). After dam removal, Station 3 was sampled in the same manner as the other sites. The fish community data, which are not yet compiled and interpreted, are not presented in this chapter.

The variety of data collected for this project necessitated rigorous adherence to established quality control measures. Investigators used standard surveying techniques and collected duplicate water quality samples and the New York Department of Environmental Conservation and USGS checked, respectively, macroinvertebrate and fish identifications. These measures assured that the data are of good quality and that interpretation can be made with confidence.

## CHANNEL CHARACTERISTICS

Streamflow during dam removal was less than 20 percent of the annual mean flow (R.R. Durlin, written communication, U.S. Geological Survey, 2002). Low-flow conditions, coupled with erosion-resistant bedrock

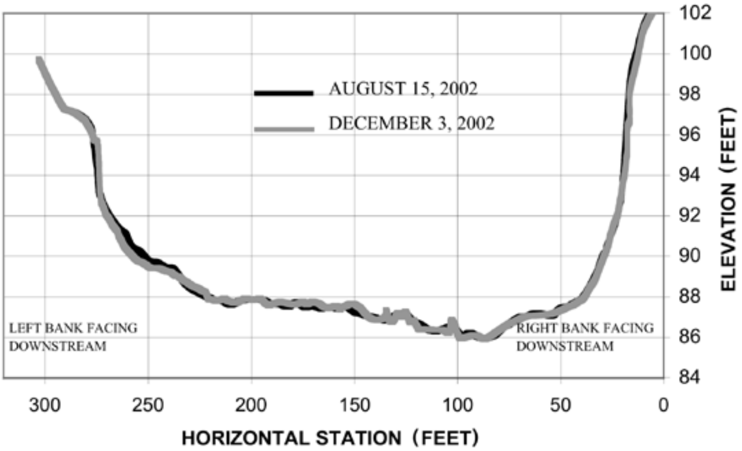


**Figure 8.4** Cross-sectional survey indicating surveyed bed and bank elevations at Station 3, 115 feet upstream of Good Hope Mill Dam.

upstream and downstream of the dam, resulted in little change in bed or bank elevations at Station 3 (Figure 8.4) or Station 4 (Figure 8.5) upon dam removal. Turbidity upstream of the dam increased from 5 NTU to a maximum of 60 NTU (Figure 8.6) within one hour after the dam was breached. This increase indicates that sediment or detritus from within the impoundment was entrained and transported downstream as veloc-

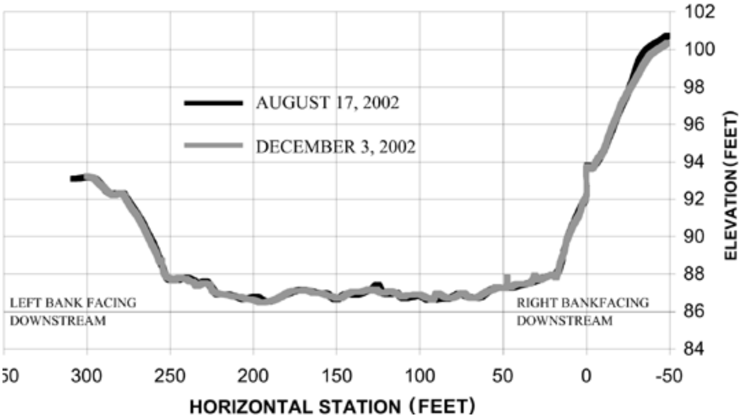


**Figure 8.5** Cross-sectional survey indicating surveyed bed and bank elevations at Station 4, 126 feet downstream of Good Hope Mill Dam.

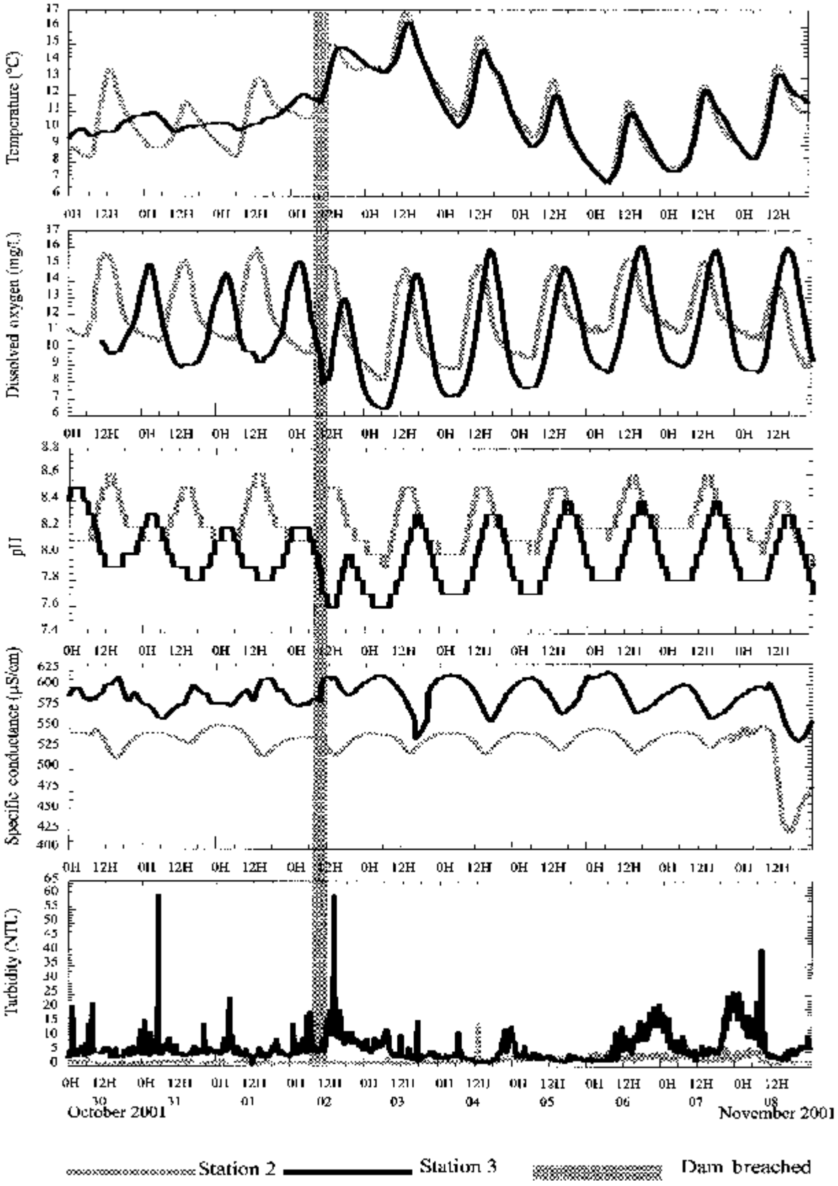


**Figure 8.6** Continual measurements (15-minute intervals) of selected water quality constituents (partial record) at Stations 2 and 3. Note: mg/L = milligrams per liter; µs/cm = microsiemens per centimeter; NTU = Nephelometric Turbidity Units.

ity increased through the formerly impounded reach. The lack of change in bed elevations suggests that mobilized sediment was fine enough to be transported through the system, or, if it was deposited below the dam, there was insufficient quantity to measurably alter bed elevation.

## WATER QUALITY

Figure 8.6 illustrates the diurnal fluctuations of temperature, dissolved oxygen, pH, specific conductance, and turbidity observed in this system. Because of the variability of these constituents, continual monitoring was essential for quantifying concentrations. The range of daily dissolved oxygen was as much as 10 milligrams per liter (Figure 8.6). The controlling influence on dissolved oxygen appears to be photosynthetic activity as opposed to temperature because dissolved oxygen maxima are coincident with temperature maxima.

Before dam removal, daily extremes of temperature, dissolved oxygen, pH, and specific conductance at Station 2 were out of phase by about 12 hours with Station 3. Once the dam was removed, the pattern at Station 3 shifted and converged with the pattern at Station 2. The offset before removal may be related to a lag time stemming from decreased velocity through the impoundment. Continual measurement suggests that impounded conditions did not influence the magnitude of daily extremes of dissolved oxygen, pH, or specific conductance, but did influence the timing of the extremes.

Discrete cross-sectional measurements of dissolved oxygen at Station 3 on October 19, 2001, reached a low of 82 percent saturation (9.0 milligrams per liter) within the impoundment, allaying concerns that oxygen demand from reduced forms of nitrogen and other constituents could result in a plume of anoxic water upon removal. Cross-sectional measurements of dissolved oxygen during dam removal affirmed that downstream migration of anoxic water did not occur, but demonstrated that concentrations varied by as much as 15 percent across the stream and reached a low of 80 percent saturation.

Monitoring of nutrients and suspended sediment was limited to discrete sampling only because technology is not available for continual measurement of these constituents. Even so, 111 discrete observations of nutrients and 97 observations of suspended sediment collected over a six-

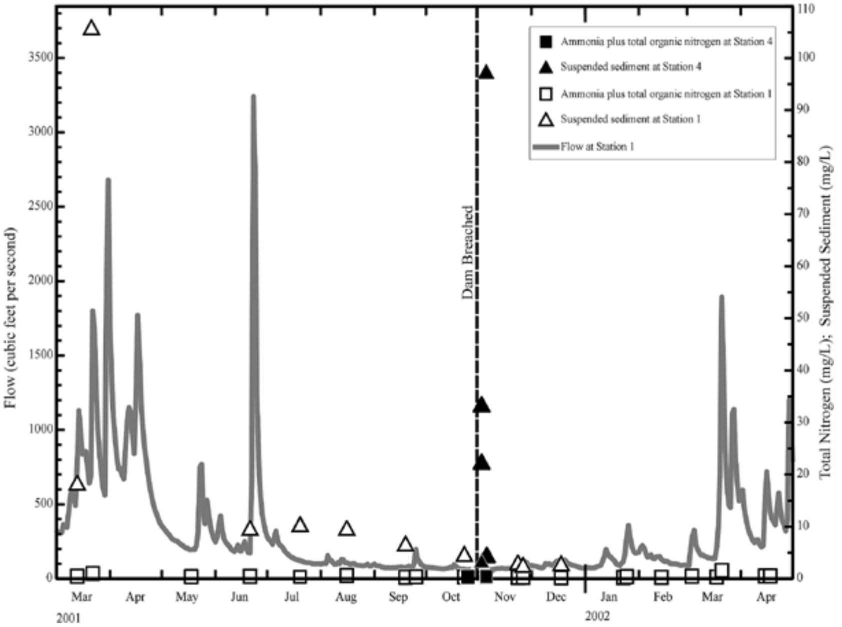


**Figure 8.7** Concentration of ammonia plus total organic nitrogen and suspended sediment measured at Station 4, 126 feet downstream of Good Hope Mill Dam, compared with concentrations measured at Station 1 (Hogestown gage) under varying hydrologic conditions.

year period preceding dam removal helped to put concentrations measured near the dam during removal in context. Ammonia plus total organic nitrogen concentrations (Figure 8.7) measured below the dam during removal ranged from 0.34 to 0.92 milligrams per liter, suggesting that dam removal resulted in minimal ammonia loading. Similarly, suspended sediment concentrations during removal were not extreme when considered in the context of long-term gage data. Suspended sediment at Hogestown gage ranged from 1 to 490 milligrams per liter, compared with a range of from 2.8 to 98 milligrams per liter during dam removal. Correlation between flow and sediment data suggests that the maximum sediment concentration measured during removal occurs over a range of flows (1,100–5900 cubic feet per second; recurrence interval equals less than 1 to 1.5 years).

## MACROINVERTEBRATES

The macroinvertebrate community at Station 2 was nearly unchanged after the dam was removed. Twenty-four taxa were collected before removal and 22 after. The dominant taxon, Hydropsychidae, was the same for both samples (Figure 8.8).

The dominant taxa after removal remained the same at all sites except within the impoundment (Figure 8.8). Water levels behind the dam decreased 3 feet after removal, setting the stage for a shift in the macroinvertebrate community within the newly exposed riffle habitat of the former impoundment. The dominant group in the impounded reach was an isopod, Gammaridae; after removal, the dominant group was Caenidae (mayflies), of which the genus *Caenis* made up 66 percent of the sample.

Station 4 did not experience the same shift in dominant taxon as Station 3 even though it is only 240 feet downstream. The dominant group at Station 4 before and after dam removal was Elmidae (Figure 8.8).

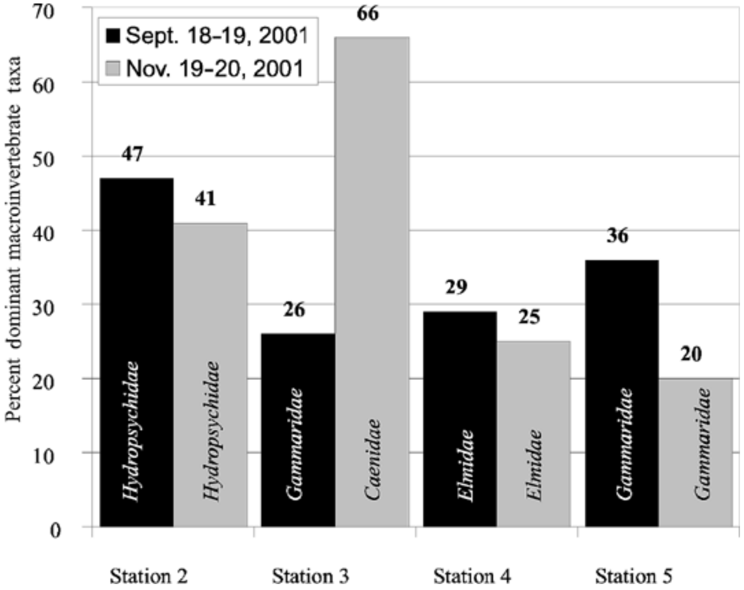


**Figure 8.8** Percentage of dominant macroinvertebrate taxa before and after removal of Good Hope Mill Dam. Dates indicate when sampling occurred. The dam was removed over a three-day period beginning November 2, 2001.

The lack of change in the community at Station 4 indicates that *Caenis* preferentially colonized vacant substrate of the former impoundment where little competition was encountered. Station 5 was consistent with Station 4 in that the dominant group did not change after dam removal. Gammaridae was the dominant group at Station 5 on both occasions.

## LIMITATIONS OF THE STUDY

This study was limited by time, space, and hydrologic conditions that did not typify Conodoguinet Creek. From a temporal perspective, data collection concluded in early 2003, only slightly more than one year after dam removal. Upon completion of the study, a "snapshot" of conditions about one year after removal would be compared to conditions before and shortly after removal. It is unclear whether one year will be long enough to quantify all changes resulting from dam removal.

The spatial aspect of this project focused on 10 miles of Conodoguinet Creek extending from Station 1 to Station 5 (Figure 8.3). Sampling stations were situated where the greatest effects of removal were anticipated, but other changes may have taken place between or beyond these stations. Interpretation is therefore limited to what occurred at a specific station, and can only be extended upstream or downstream with caution.

Hydrologic conditions over the study period were dominated by below-average precipitation resulting in an extended drought. Streamflow during dam removal, when the most dramatic response was anticipated, was less than 20 percent of the mean annual flow. Compared with normal flow, low-flow conditions are characterized by less shear stress, less substrate available to macroinvertebrates and fish, and increased solute concentration. As a result, responses presented here may not be indicative of what would occur under different hydrologic conditions.

## ACKNOWLEDGMENTS

The following institutions and organizations participated in this study. Conodoguinet Creek Watershed Association coordinated contracts with various partners and provided project support. The Pennsylvania Fish and Boat Commission and American Rivers provided guidance and financial

support and coordinated the dam removal with other project activities. The Pennsylvania Department of Environmental Protection handled the removal permit and provided lab services. And Pennsylvania State University coordinated fish community surveys before and after removal.

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# 9

# THE LEGAL AND REGULATORY REQUIREMENTS OF DAM REMOVAL

ELIZABETH MACLIN
*American Rivers, Inc.*

***Abstract:*** Removing a dam from a river requires permits from state, federal, and local authorities.* These permits are generally needed to ensure that the removal is carried out in a safe manner that minimizes the short- and long-term impacts on the river, floodplain, and downstream landowners. Permit requirements differ by state and local government. This chapter summarizes the types of federal, state, and local permits that may be required for removal, and offers some general observations on how best to approach the permitting process for dam removal projects.

## FEDERAL PERMITTING REQUIREMENTS

**Clean Water Act (CWA) Section 404 Dredge and Fill Permit.** Most dam removals require a CWA Section 404 permit, issued by the U.S. Army Corps of Engineers for dredging of a navigable waterway (33 U.S.C. §1344). A guideline pursuant to this statutory requirement establishes a policy of no net loss of wetlands (Environmental Protection Agency and Department of the Army, 1990). To obtain Corps approval, a project (1) should not cause or contribute to significant degradation of the waters or result in a net loss of wetlands; (2) should be designed to have minimal adverse impact; (3) should not have any practicable alternatives; and (4) should be in the public interest. To obtain a permit in situations in which dam removal will result in a net loss of wetlands, the Corps

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* Some material in this chapter was taken from an article published by Margaret Bowman, American Rivers, Inc., in 2002 (Legal perspectives on dam removal, Bioscience 52(8): 739–747) and is used here with her permission.

will have to find that the benefits of dam removal outweigh the loss of wetlands. In October 2001, the Corps issued a Regulatory Guidance Letter that permits mitigation of wetlands impacts with nonwetland habitats. Other federal agencies are currently commenting on this letter, and it remains to be seen whether the letter effectively abandons the no-net-loss-of-wetlands policy.

**Rivers and Harbors Act Permit.** In conjunction with a CWA Section 404 permit, the Corps will issue a Rivers and Harbors Act Section 10 permit (33 U.S.C. §403). The Rivers and Harbors Act is administered by the Corps for federal activities affecting a navigable waterway. The Corps will issue the permit if there is no adverse impact on interstate navigation.

**FERC License Surrender or Non–Power License Approval.** If the dam to be removed is a hydropower dam regulated by the Federal Energy Regulatory Commission (FERC), the dam owner must apply for surrender of the FERC license or issuance of a non–power license. FERC can impose conditions on how the dam should be removed as part of this approval.

**National Environmental Policy Act (NEPA) Review.** Action by the Corps or FERC may require the preparation of an environmental impact statement or environmental assessment pursuant to NEPA (42 U.S.C. §4321 *et seq.*). This document examines the environmental impacts of the proposed activity and any alternatives. An opportunity for public comment is a required part of the NEPA review. Only a short form environmental assessment may be required if the dam removal is expected to have environmental benefits. If a NEPA environmental document was already prepared as part of the process of deciding whether to remove the dam, it may not be necessary to prepare a new NEPA document; only a supplemental document may be required.

**Federal Consultations.** In issuing their permits, the Corps or FERC may conduct the following consultations to meet the requirements of other federal laws:

- *Endangered Species Act Section 7 consultation.* If threatened or endangered species are present at or near the dam, the Corps or FERC may need to consult with the U.S. Fish and Wildlife Service or the National Marine Fisheries Service (NMFS) about the impact of the removal on these species. The removal should not destroy the designated critical habitat of the species or result in the killing of members of the species. Some conditions may be imposed on the dam removal to avoid injury to the threatened or endangered species.

- *Magnuson-Stevenson Act consultation.* The Corps or FERC also may need to consult with the NMFS pursuant to the Magnuson-Stevenson Act about the impact of the removal on any fishery management plan developed by a regional fishery management council (16 U.S.C. §1855[b][2]). This consultation is carried out to ensure that the removal will not adversely affect any essential fish habitat established in the fishery management plan.
- *National Historic Preservation Act compliance.* The Corps's or FERC's activities also may trigger an obligation on their part to assess the impact of the proposed action on historic properties pursuant to Section 106 of the National Historic Preservation Act (16 U.S.C. §470f). In assessing this impact, the Corps or FERC must consult with the state historic preservation officer. Historic properties affected may range from newly exposed archaeological sites to the dam itself. The presence of a dam on the National Register of Historic Places (or eligibility for listing on the Register) does not automatically preclude removal. In many situations, proper documentation of the dam prior to removal may be sufficient to preserve its historical values of the dam (36 C.F.R. §800.1 *et seq*.).

**State Certifications.** The Corps and FERC decisions also trigger several federal statutes that require the state to issue certification that the actions are consistent with the state's implementation of federal law.

- *Water quality certification.* In order for the Corps to issue a CWA Section 404 permit or for FERC to issue a license surrender order or nonpower license, the state must issue water quality certification pursuant to CWA Section 401 (33 U.S.C. §1341). This certification states that the proposed activity will not result in the violation of state water quality standards. As part of its certification, the state may issue conditions related to how the dam is removed.
- *Coastal Zone Management Act certification.* If the dam is located in the coastal zone, the state must issue a certification pursuant to

the Coastal Zone Management Act (16 U.S.C. §§1451 *et seq.*) for the Corps or FERC to permit the dam removal. This certification states that the proposed activity is consistent with the state's approved coastal zone management program. Again, as part of its certification the state may issue conditions related to how the dam is removed.

## STATE PERMITTING REQUIREMENTS

**Waterways Development Permits.** Some states have laws that regulate the development of their waterways for hydropower, navigation, and other purposes. These laws are generally adopted to address construction of a new dam or alteration of an existing dam, but they also apply to dam removal.

**Dam Safety Permits.** Some states have regulations that require a permit for any activity that will affect the safety of a dam. Removal of a dam would require such a permit.

**State Environmental Policy Act Review.** Many states have an environmental impact review statute similar to the federal NEPA statute. The removal of a dam may trigger the state requirement to prepare an environmental impact document. Usually, the federal and state requirements can be met by preparing only one such document.

**Historic Preservation Review.** Most states require that before any state permit is issued historical and archaeological issues must be investigated and approved by the state historic preservation officer. This review can usually be done in conjunction with the federal historical preservation review described earlier.

**Resetting the Floodplain.** Most states require review of any activity that might change the 100-year floodplain. The applicant may be required to determine the new elevation for the 100-year floodplain once the dam is gone. The Federal Emergency Management Agency (FEMA) would then use the analysis to create new maps.

**State Certifications.** See the section on federal permits for state certification requirements pursuant to federal laws.

## MUNICIPAL PERMITTING REQUIREMENTS

**Demolition Permits.** The act of demolishing the dam's structure may require a demolition permit from the local municipality.

**Building Permit.** Construction of a cofferdam or restoration of the riverbank may require a building permit from the local municipality.

## THE PERMITTING PROCESS

Because dam removal is a relatively new phenomenon, the permitting process for a removal can be difficult. Most state and federal agencies have little experience with moving a restoration project such as dam removal through their permitting process. For the most part, the relevant permitting requirements were designed for more destructive activities, and thus dam removal does not fit easily into the requirements. Based on their considerable experience with dam removals, staff members at American Rivers, Inc. (2000) offer the following tips for securing permits to remove a dam.

- Expect dam removal projects to take longer than other construction efforts from beginning to end. More lead time and effort than allotted to other projects should be scheduled into the permitting process to avoid delays and frustrations.
- Because dam removal will likely not fit easily into the permitting requirements, be honest and up-front with the permitting agencies about the removal plan. Also, seek the input and assistance of the key permitting agencies. One of the most critical elements of successful permitting is a preapplication meeting with key agency staff, held in the field, at the project site, or in their office as soon as the project is well thought out.
- Even though dam removal may not fit easily into the permitting requirements, recognize that permitting is a process with an established procedure. Do not attempt to circumvent the process, and do not deviate from the process that is laid out (unless you and the agency determine that a deviation is necessary). Understand the permitting timeline and stay within it.
- Be especially careful to maintain good relationships with agency staff and a positive attitude. Do not provide inconsistent

information. Remember that the people who issue permits are professionals who review permit applications every day. The different permitting agencies work closely with each other and are likely to be discussing your application. Have a single point of contact for your organization to help avoid confusion and maintain consistency of communication

- Create clear and simple descriptions and drawings (to scale) of the proposed project. Be certain to identify complicating conditions, schedules, seasonal constraints, and so forth. Remember that these documents will be faxed from office to office for the review process.
- Provide and discuss alternatives even though they are not your choice of approach. Make it clear why your approach was chosen. Remember that financial considerations will be only a minor consideration of the people conducting the review.
- Assume the reviewers know nothing about the project. You deal with the details of the project day to day, but for them, it is just another project; they likely are working on an enormous backlog of permits.

## A CASE STUDY IN OBTAINING A PERMIT FOR A DAM REMOVAL

When the state of New Hampshire initiated the process to remove the McGoldrick Dam from the Ashuelot River—the first dam removed in the state for river restoration purposes—one important agency partner was not initially consulted: the State Historic Preservation Office (SHPO). The state river restoration task force, established to explore opportunities for selective dam removal, had conducted the planning, raised all the necessary funds, obtained most of the required permits, and set a date for the removal. However, when the SHPO was consulted shortly before the scheduled removal date, all activities had to be put on hold.

Because the McGoldrick Dam and its associated power canal were over 150 years old, the structures were eligible for listing in the National Register of Historic Places. Although this finding did not prevent the removal of the dam, it did delay the removal for a year, potentially jeopardizing funding sources and creating other obstacles to removal. After the historic value of the site was recorded with photo documentation, biographies, and interpretive signage, the removal was completed in the summer of 2001. SHPO is now a member of New Hampshire's river restoration task force and is consulted at the initial stages of each dam removal project.

In any dam removal, regardless of a project's size or potential impact, the pertinent agencies and interested parties should be involved as early as possible in the permitting process (and, in general, in the removal process) to help minimize project impacts, costs, and timing delays. Although it is important to include all interested parties in a dam removal project, it can be hard to identify these parties up-front, and therefore critical players can be overlooked. Those agencies and individuals with experience in dam removal projects can often help to identify the entities that should be involved.

## VARIANCES IN STATE PERMITTING PROCESSES

To facilitate the removal of obsolete dams in Pennsylvania, the Pennsylvania Department of Environmental Protection, Division of Dam Safety, has instituted a process that waives state permit requirements (in general, see 25 Pa. Code §105.12[a][11] and [a][16] for more details). This waiver process is intended to make it easier and more affordable for dam owners to divest themselves of obsolete dams that could pose significant liabilities and safety hazards, as well as damage the environment. However, to qualify for the dam removal waiver, a dam removal project must restore the river to its natural, free-flowing condition. The waiver process includes placing notification about the project in the state bulletin, completing an environmental assessment, creating an engineering and design plan, coordinating with appropriate state and federal agencies, and conducting public hearings where deemed necessary. Since the institution of the dam removal waiver in Pennsylvania, the entire permitting process often takes just 12–18 weeks.

Just next door in Maryland, the dam removal permitting process is much different from Pennsylvania's. Maryland requires several permits for dam removal, the primary ones (for Alteration of Floodplains, Waterways, Tidal or Non-Tidal Wetlands and for Dam Safety) are handled through the joint application process, and several other permits (for Erosion and Sedimentation and for General Construction) must be applied for separately (see http://www.mde.state.md.us/Permits/WaterManagementPermits/

water2.asp for specific details). Because the state has no permit created specifically for dam removal projects—and limited experience with dam removal in general—the permitting requirements appear open to interpretation, and the permitting procedures that applicants must follow are not always clear.

On Octoraro Creek, a project has been under way for over two years to remove a small rubble dam that no longer serves a purpose, blocks access to migratory fish, and presents an ongoing liability and safety concern. Although the project has completed the testing and engineering design work as part of the permitting process and obtained funds for the removal, the permitting is not likely to be complete in the near future because of a discrepancy in the permitting process.

## CONCLUSIONS

The legal and regulatory requirements of dam removal are a critical aspect of the dam removal process both because particular permit requirements can play a significant role in determining the costs and conditions under which a dam can be removed and because permit requirements can help to ensure that each dam is removed in a manner that minimizes the short- and long-term effects on the river and surrounding communities. Numerous federal permits and consultations that may be required of a particular dam removal, but it is largely state permits that determine the stringency of the requirements applied to removal. In each dam removal effort, it is important to allow enough time to complete the permitting process, as well as to factor into the project budget all the costs associated with obtaining the necessary federal, state, and municipal permits.

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# APPENDIXES

# APPENDIX A

## AUTHOR AND STAFF BIOGRAPHIES

### THE AUTHORS

**KAREN L. BUSHAW-NEWTON** is an assistant professor of biology at American University. She also studies the biogeochemistry and the management and restoration of aquatic systems. Previously, she was a postdoctoral associate at the Patrick Center for Environmental Research at the Academy of Natural Sciences, where she conducted research on dammed stream systems, dam removal, and coastal marine ecosystems. When not in the laboratory, she can be found canoeing the waterways of the Mid-Atlantic region with her husband.

**JEFFREY J. CHAPLIN** is a hydrologist with the U.S. Geological Survey (USGS), Water Resources Division, in New Cumberland, Pennsylvania. His work for USGS includes characterizing mine discharge chemistry and stream water loss to underground mines, monitoring created wetland and riparian systems, and determining the effects of dam removal on water quality and channel morphology.

**BRIAN GRABER** is a self-employed watershed restoration specialist based in Madison, Wisconsin. His background is in fluvial geomorphology, hydrology, and civil engineering. His current projects include several small dam removals and habitat rehabilitations in eastern Wisconsin, geomorphic assessments of five watersheds in northern Wisconsin for "coaster" brook trout habitat rehabilitation, and research on the downstream hydrologic impacts of large dams. He formerly worked for Trout Unlimited National, for whom he was the lead author of *Small Dam Removal: A Review of Potential Economic Benefits*.

**WILLIAM L. GRAF** is Educational Foundation Endowed University Professor and professor of geography at the University of South Carolina. His specialties include fluvial geomorphology and policy for public land and water. He has published several books and more than 125 scientific papers and is past president of the Association of American Geographers. He has served on the National Research Council (NRC) as a member of the Water Science and Technology Board, as a member of the Board on Earth Sciences and Resources, as chair or member of several NRC committees, and was appointed by President Bill Clinton to the Presidential Commission on American Heritage Rivers. Dr. Graf chaired the Heinz Center panel that produced *Dam Removal: Science and Decision Making.*

**David D. Hart** is vice president and director of the Patrick Center for Environmental Research at the Academy of Natural Sciences, where he leads a large team of watershed scientists. Current research programs at the Patrick Center include studies of dam removal, flow management, riparian restoration, invasive species, and the fate and effects of contaminants. He also is on the faculty at the University of Pennsylvania. He has served as a scientific adviser to numerous government agencies and conservation groups in the United States, United Kingdom, and Australia, and recently worked as a Fulbright Senior Scholar on river conservation issues with scientists and engineers in New Zealand.

**Richard J. Horwitz** is a senior biologist at the Patrick Center for Environmental Research at the Academy of Natural Sciences. His primary research area is the ecology of streams and rivers, with special interest in the relationships between watershed and riparian processes, hydrology, aquatic habitat, and fish communities. Recent projects include comparisons of fish communities in piedmont streams differing in riparian vegetation and watershed land use and studies of the effects of dams and dam removal on fish populations and communities. He has been involved in several ecological restoration projects, including master planning for natural land management in Fairmount Park, Philadelphia's 8,900-acre urban park.

**Sara E. Johnson** is a principal in G&G Associates, a consulting firm specializing in river restoration through dam removal. Her expertise is in the human dimensions of natural resource management and policy, and includes almost 10 years of practitioner experience with selective dam removal as a tool for river and fisheries restoration. In 1993 she cofounded and served five years as the executive director of the River Alliance of Wisconsin, a nonpartisan statewide citizen advocacy organization for rivers. She established the River Alliance's small dams program, and was a leader in collaborative efforts to restore Wisconsin's Baraboo River through removal of multiple low-head dams.

**Thomas E. Johnson** is a research scientist and watershed hydrology section leader at the Patrick Center for Environmental Research at the Academy of Natural

Sciences. His research interests include watershed hydrologic and biogeochemical processes, the influence of land cover type on stream ecosystems, the interaction of hydrologic and ecologic systems, and the management and restoration of streams and watersheds. His current projects are examining the influence of spatially heterogeneous riparian land cover on stream ecosystems, and the ecological effects of different size dams on stream ecosystems.

**Elizabeth Maclin** is the director of American Rivers, Inc.'s Rivers Unplugged campaign, which has field offices in the Northeast, Mid-Atlantic region, California, and the Pacific Northwest. She leads a staff of eight in restoring rivers by removing dams no longer of use. Before joining American Rivers, Inc., in 1999, she worked extensively on hydropower issues for both the University of Michigan and the Hydropower Reform Coalition.

**James E. Pizzuto** is chair of the Department of Geology at the University of Delaware. His current research in fluvial and coastal geomorphology focuses on developing new methods to understand how river channels adjust their morphology through time in response to changes in discharge, sediment supply, bank vegetation, and other factors; managing and restoring of streams and watersheds; and understanding how tidal wetlands in Delaware have evolved in response to changes in sea level, sediment supply, wave climate, subsidence, and other variables.

**Molly Marie Pohl** is assistant professor of geography at San Diego State University. A fluvial geomorphologist with an interest in spatial analysis of river channel change, she is currently investigating national trends in dam removal, as well as experience to date in sediment management of dam removals. Her specific interest is in modeling and measuring the geomorphic impacts of razing dams.

**Timothy J. Randle** is a hydraulic engineer who works for the U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, in Denver, Colorado. He has led sediment investigations associated with the removal of the Elwha and Glines Canyon Dams on the Elwha River in Washington, Savage Rapids Dam on the Rouge River in Oregon, and many other small dams in the western United States. He is currently working on geomorphic investigations of several rivers on the Olympic Peninsula of Washington State and the Platte River in Nebraska.

**Sara L. Rathburn** is assistant professor in the Department of Earth Resources at Colorado State University. She is a fluvial geomorphologist with a special interest in hydraulics and sediment transport of bedrock rivers. Her current research includes sediment management within semiarid reservoirs, one- and two-dimensional hydraulic and sediment transport modeling of reservoir-released sediment, and the effects of dams and dam removal on downstream channel morphology and fish habitat.

**Helen Sarakinos** is small dams program manager at the River Alliance of Wisconsin. Holder of a master's degree in aquatic ecology from McGill University, she has worked on numerous river-related issues, including the effects of point source discharges and sedimentation on river ecosystems and issues of water quality and aquatic diversity in the San Joaquin River Valley, California. At the River Alliance, she is helping to improve the dam repair or removal decision-making process in communities by advocating that selective dam removal be considered on its merits and advocating a strong state policy that considers all the economic and environmental costs and benefits of dams. She also conducts research intended to help assign priority to ecologically beneficial dam removals in Wisconsin.

**William W. Stelle** heads the Endangered Species Act Practice Group at Preston Gates and Ellis. The firm advises large and small public and private clients locally and nationally on compliance issues related to the Endangered Species Act (ESA). Before joining Preston Gates and Ellis, he spent six years as the northwest regional director of the National Marine Fisheries Service and was the chief architect of the ESA program in the Pacific Northwest. He participated in all major consultations under ESA for salmonids during the 1990s governing federal dam operations, federal land management, federal highway and transit spending, and the aquatic-related activities of the U.S. Army Corps of Engineers. Before moving to the Northwest, he held a variety of policy positions dealing with a broad range of environmental and natural resource programs in Washington, D.C. These included serving as associate director for natural resources in the President's Office on Environmental Policy; special assistant to the secretary of the interior; and chief counsel and general counsel to the legislative committee and subcommittee in the U.S. Congress with responsibility for endangered species, clean water, the superfund, and the National Environmental Policy Act. He also served as staff council to several Senate committees and as an attorney-adviser to Environmental Protection Agency's Office of Pesticides and Toxic Substances.

**Ellen E. Wohl** is professor of earth resources at Colorado State's College of Natural Resources. Her current research interests include hydraulics, sediment transport, controls on channel morphology, anthropogenic impacts on bedrock channels and mountain channels, and the role of floods in shaping channel morphology.

## THE STAFF

**Sheila D. David** is a consultant and project director at The Heinz Center, where she is managing studies for the Sustainable Oceans, Coasts, and Waterways Program. At The Heinz Center, she has helped produce several studies: *The Hid-*

*den Costs of Coastal Hazards* (2001), *Evaluation of Erosion Hazards* (2001), *Integrated Management of the Tempisque River Basin, Costa Rica* (2001), *Dam Removal: Science and Decision Making* (2002), and *Human Links to Coastal Disasters* (2002). She is currently directing a National Oceanic and Atmospheric Administration study on sharing coastal zone management innovations. Before joining The Heinz Center in 1997, she served for 21 years as a senior program officer at the National Research Council's Water Science and Technology Board, where she was study director for some 30 committees that produced reports on topics such as managing coastal erosion, restoration of aquatic ecosystems, protection of groundwater, wetlands characteristics and boundaries, water quality and water reuse, natural resource protection in the Grand Canyon, and sustainable water supplies in the Middle East. Ms. David has served as an adviser and board member of the Association for Women in Science (AWIS) and as editor of *AWIS* magazine. She is also a founder of the National Academy of Sciences' annual program honoring women in science.

**ROBERT M. FRIEDMAN** was the vice president for research and senior fellow at The Heinz Center through March 17, 2002. He is currently the vice president for environment and energy at the Center for the Advancement of Genomics and the Institute for Biological Energy Alternatives Policy. Before joining The Heinz Center, he was a senior associate in the Office of Technology Assessment (OTA), U.S. Congress, where he advised congressional committees on issues involving environmental, energy, transportation, and natural resources policy. He directed major policy research efforts on acid deposition, urban ozone, and climate change, among other issues. Dr. Friedman received his Ph.D. from the University of Wisconsin, Madison, in ecological systems analysis. He is a fellow of the American Association for the Advancement of Science and a recipient of OTA's Distinguished Service Award.

**JUDY GOSS** is a research assistant for The Heinz Center's Sustainable Oceans, Coasts, and Waterways Program, where she has worked on two other studies, *Sharing Coastal Zone Management Innovations* and *Dam Removal: Science and Decision Making*. She graduated *cum laude* with a degree in political science from Mary Washington College in May 2001. She currently volunteers with Marshall-Brennan Urban Debate League in Washington, D.C., where she teaches high school students and teachers about policy debate. She is particularly interested in the intersection of gender and political communication, and she plans to pursue a graduate degree in communication studies.

# Appendix B

## WORKSHOP PARTICIPANTS

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