

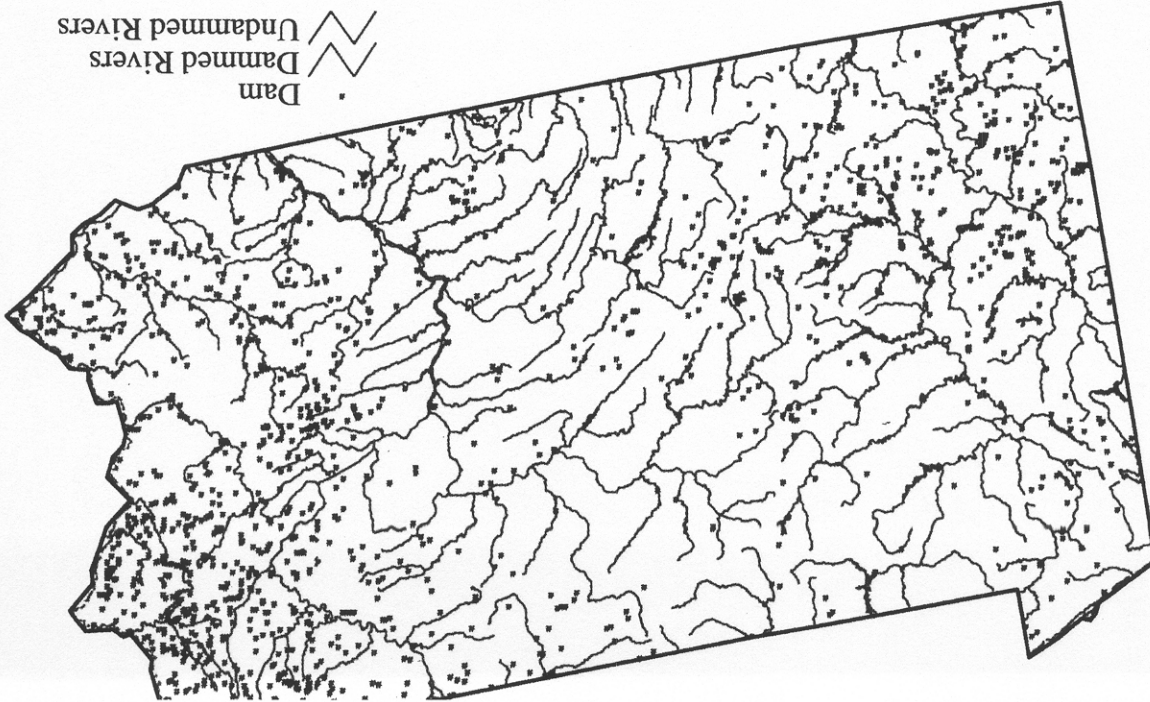
DAM REMOVAL

Science and Decision Making

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SCIENCE, ECONOMICS AND THE ENVIRONMENT

Plate 1 This map of Pennsylvania shows the statewide distribution of dams and major rivers. None of Pennsylvania's major rivers can be considered undammed or unchanneled. The map was compiled using data on 1,400 large and medium-sized dams from the National Inventory of Dams (NID). To be included in the NID, the dam must be either more than 6 ft (2 m) high with more than 50 acre-feet (61,000 cu m) of storage or 25 ft (8 m) high with more than 15 acre-feet (18,500 cu m) of storage. Pennsylvania also has many smaller dams that are not included in the NID and are therefore not represented on this map. (See page 102 for discussion.) *Sources:* Dam data from U.S. Army Corps of Engineers (2001); National Inventory of Dams (NID) river data from the National Atlas (2001).



PANEL ON ECONOMIC, ENVIRONMENTAL, AND SOCIAL OUTCOMES OF DAM REMOVAL

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CONTENTS

DEDICATION	iii
PREFACE	x
ACKNOWLEDGMENTS	xiv
SUMMARY	1
Background, 3	
Dam Removal Decisions, 4	
Physical Environmental Outcomes of Dam Removal, 6	
Biological Outcomes of Dam Removal, 8	
Economic Aspects of Dam Removal, 9	
Social Aspects of Dam Removal, 9	
Conclusions and Recommendations, 10	
<i>Making Decisions Today, 10; Data Needs, 11; Improving Tomorrow's Decision Making, 12</i>	
1. INTRODUCTION AND BACKGROUND	15
Purpose and Scope of the Heinz Center Study, 19	
Census of Dams in the United States, 22	
<i>Sizes of Dams, 23; Types of Dams, 23; Ownership, 29; Distribution, 31</i>	
Reasons for Dam Building, 32	
<i>Recreation, 34; Fire and Farm Ponds, 35; Flood Control, 35; Water Supply, 36; Irrigation, 37; Waste Disposal, 37; Waterpower, 38; Electricity Production, 38; Navigation, 39</i>	
Reasons for Dam Removals, 40	
<i>Structural Obsolescence, 41; Safety and Security Considerations, 42; Economic Obsolescence, 43; Recreational Opportunities, 45; Water Quality and Quantity Issues, 45; Ecosystem Restoration, 47;</i>	
Dams Removed in the United States, 49	
<i>Number of Dams Removed, 49; Sizes of Dams Removed, 50; Types of Dams Removed, 50; Ownership of Dams Removed, 51; Distribution of Removals, 52</i>	
Status of Scientific Research on Dam Removals, 53	
Conclusions and Recommendations, 58	

2. THE FEDERAL LEGAL CONTEXT AFFECTING DAM REMOVALS	60
Hydroelectric Dams, 61	
Dam Safety Programs, 64	
<i>National Dam Safety Program, 64; FERC Dam Safety Program, 65; Indian Dam Safety Act, 66</i>	
Protection of Natural Systems, 66	
<i>National Environmental Policy Act, 66; Clean Water Act, 68; Endangered Species Act, 68</i>	
Other Legislation Affecting Dam Removals, 69	
<i>National Historic Preservation Act, 69; Western Water Rights Law, 71; Tribal Governments and Water Rights, 72; Small Watersheds Rehabilitation Amendments, 74; Wild and Scenic Rivers Act, 75</i>	
3. DAM REMOVAL DECISIONS	76
The Economics of Dam Removal, 76	
Informed Decision making, 79	
<i>Step 1: Define the Goals and Objectives, 80</i>	
Is the dam meeting its legally or socially defined original purpose and need?, 81; Have additional issues or needs arisen that need to be added to the list of goals?, 82	
<i>Step 2: Identify Major Issues of Concern, 84</i>	
Safety and Security Issues, 84; Environmental Issues, 86; Legal and Administrative Issues, 86; Social Issues, 87; Economic Issues, 87; Management Issues, 88	
<i>Step 3: Data Collection and Assessment, 88; Step 4: Decision Making, 89; Step 5: Dam Removal, 94; Step 6: Data Collection, Assessment, and Monitoring, 94</i>	
Conclusions and Recommendations, 96	
4. PHYSICAL OUTCOMES OF DAM REMOVAL	98
Physical Integrity, 99	
Spatial and Temporal Contexts, 100	
Segmentation, 101	
Hydrology, 103	
Sediment, 109	
<i>Sediment Quantity, 109; Sediment Quality, 116</i>	
Geomorphology, 117	
Water Quality, 126	
Conclusions and Recommendations, 130	

5. BIOLOGICAL OUTCOMES OF DAM REMOVAL	133
Potential Impacts of Dam Removal on Aquatic Ecosystems, 135	
Aquatic Ecosystem Restoration Planning, 140	
<i>Spatial and Temporal Contexts, 142; Aquatic Ecosystem Indicators of Restoration, 145; Factors Affecting Restoration Rates, 147</i>	
Physical Habitat, 149; Restoration of Terrestrial and Riparian Vegetation, 150; Size of Disturbed Area and Upstream Sources of Drift, 150; Continued Disturbances, 150; Frequency of Previous Disturbances, 150; Presence and Proximity of Refugia, 151; Flushing Capacity and Persistence of Disturbance, 151; Watershed Characteristics and Land Use, 152; Timing of Disturbance and Life Cycles of the Biota, 152; Nutrient Input and Recycling, 152; Location of Disturbance in Stream Course and Stream Order, 153; Water Quality, 153	
Conclusion and Recommendations, 156	
6. ECONOMICS AND DAM REMOVAL	158
No-Action Alternative, 161	
Valuing the Outcomes of Dam Removal, 162	
<i>Market versus Nonmarket Goods, 162; Revealed Preference Valuation Approaches, 163; Stated Preference Valuation Approaches, 164</i>	
Beneficial Outcomes of Removal, 166	
<i>Restored Environmental Services, 166; Avoided Costs, 167</i>	
Adverse Outcomes of Removal, 168	
<i>Direct Costs of Removal, 168; Lost Dam Services, 170; External Costs of Removal, 170</i>	
Challenges for Economic Analysis of Dam Removals, 170	
Conclusion and Recommendations, 174	
7. SOCIAL ASPECTS OF DAM REMOVAL	175
Aesthetics and Social Values, 175	
Dams and Tribal Culture in the United States, 180	
Social Impact Assessments of Dam Removal Projects, 182	
Conclusion and Recommendations, 185	
THE FUTURE	188
APPENDICES	191
A USEFUL SOURCES OF INFORMATION ON THE WORLD WIDE WEB FOR DAM REMOVAL DECISION MAKERS	193
B GLOSSARY	197
C ABOUT THE CONTRIBUTING AUTHORS AND PROJECT STAFF	201
REFERENCES	207

PREFACE

DAMS are the most common and widespread form of direct human control on river and stream processes. The construction, maintenance, operation, and potential removal of dams are critical aspects of scientific and policy discussions about rivers. Until recently, the installation of dams has been a widely supported method of river management in the United States. American rivers are collectively the most closely controlled hydrologic system of its size in the world. The nation now has the capability to store almost a full year's runoff in reservoirs behind more than 76,000 dams (counting those 6 feet high or more). Many of these structures have contributed to the economic development of the nation and the social welfare of its citizens. Irrigation water diverted from streams and temporarily stored by dams has supported agriculture in western states, and lock and dam structures sustain an inland water transportation system for bulk commodities worth billions of dollars throughout the nation. Dams can reduce flooding and provide water for consumptive uses (e.g., drinking) and non-consumptive uses (e.g., for power plants and other industrial cooling operations). Hydroelectric power from dams provides about 10 percent of the total electrical power for the nation, and in many locales, it is the primary source. The reservoirs created by dams provide recreational opportunities and prime waterfront property locations, with benefits enjoyed by millions of citizens. Small dams, often only a few feet in height, have been an integral part of the industrial, mining, agricultural, and urban history of the country.

The installation of dams and reservoirs to provide the economic and social services related to water has transformed the natural, interconnected river system of the United States into a partly artificial, partly nat-

ural regulated and segmented system. The environmental changes brought about by dams include drowning of channels and valued floodplains, with more than 600,000 miles of the nation's waterways under reservoir waters. Dams have changed downstream conditions, altering the physical bases of ecosystems in every region of the country. In concert with other human-imposed changes, especially those realized through river engineering and land use alterations, dams have contributed to the loss or change of riparian and aquatic habitat, including ecological systems that support endangered or threatened species of plants, animals, birds, and fishes. As these changes have become more apparent, many small and medium-sized dams have aged beyond their expected useful life spans, and for their physical safety must be repaired. Urbanization and other developments downstream from them have created hazardous conditions in some places. Changing economic conditions combined with aging and safety issues have made some dams obsolete, and new regulatory requirements cloud the future of others. Some dams are orphans, abandoned by owners who no longer have use for them. As a remedy for all these problems, the option of dam removal recently has become more widely considered.

After more than two centuries of policy attention almost exclusively to the building of dams, public decisions about removing some structures have drawn increasing interest because of the expense of maintaining antiquated structures. Philosophically, the United States has supported the intensive use of rivers for economic development throughout its history, but over the last few decades, growing concern about environmental quality, endangered species, and aesthetic characteristics of rivers has become more prominent in the national discourse. In many cases, these new emphases have become part of national, regional, and local policies. From a scientific perspective, recent research conducted by hydrologists, geomorphologists, and ecologists has begun to detail the changes brought about by dams. This knowledge is emerging in the early twenty-first century because many large dams did not begin appearing on the American landscape until about 1960. It has taken two or three decades for the physical and ecological consequences of the structures to become apparent.

If it is true that Americans now have considerable experience in building dams and assessing their effects, it is equally true that even the most expert have relatively little experience in removing dams and assessing the outcomes of their removal. While national attention has been focused on a few highly visible dam removal issues involving large struc-

tures, such as the dams on the Snake River in the Pacific Northwest, the removal of numerous small dams and a few medium-sized ones has continued apace. Although the precise number of dams removed from the nation's rivers is unknown, it certainly is at least five hundred. The number of candidates for removal is certain to increase as the structures continue to age, and as further emphasis on river restoration stimulates more interest in removal as one of a series of management options.

When dam owners, governmental agencies, interest groups, and private citizens debate removal options for specific structures, the decision-making process often needs to be reinvented for each case, with no accounting for scientific understanding of the likely outcomes of the decision. This report, which focuses on the removal of small dams (defined as storing 1–100 acre-feet of water), seeks to assist the decision-making process regarding dam removal by providing information for use by dam owners; policymakers; interest groups; private citizens; and personnel in local, state, and federal agencies. After providing extensive background and contextual information, the authors of this report strive to

- Outline the nature of likely environmental, social, and economic outcomes of dam removal
- Define indicators for measuring or monitoring environmental, social, and economic outcomes of dam removal
- Indicate sources of environmental, social, and economic data that may help place each specific case in context for decision makers

This report emphasizes the potential environmental, economic, and social science aspects of dam removal rather than the details of the decision-making process itself. The treatment of these scientific aspects is necessarily uneven because there is more direct scientific research available on the environmental dimensions of the issue, and relatively less about the economic and social dimensions.

The authors of this report were brought together by The H. John Heinz III Center for Science, Economics and the Environment as the Panel on Economic, Environmental, and Social Outcomes of Dam Removal. The panel included specialists in geography, economics, engineering, environmental law, state and federal administration, environmental consulting, hydraulic engineering, dam safety, hydropower, and aquatic ecosystem management. The panel met three times over the course of the 18-month study period, twice in Washington, D.C., and once in Southern California to visit field sites. The panel hosted several

guests during its meetings to learn more about specific research activities related to dam removal and to receive the latest information about the subject. The Federal Emergency Management Agency, the Electric Power Research Institute, and The Heinz Center financially supported the activities of the panel.

The work creating this report was facilitated and coordinated by Sheila D. David, fellow and project manager for The Heinz Center. Her skillful planning, guidance, and management were critical to the successful completion of the project. She was a full and active partner along with panel members in the discussions and deliberations that went into the total effort. Sarah Baish, research associate for The Heinz Center, was a critical component of the project in managing the flow of ideas and paper, as well as writing case examples and making the essential arrangements for committee activities.

Individuals chosen for their expertise and diverse perspectives reviewed the report. Their independent review provided candid comments and suggestions that significantly improved the report. The panel wishes to thank the following individuals for their input during the review process: Syd Brown, California Department of Parks and Recreation; Charles C. Coutant, Oak Ridge National Laboratory; David Freyberg, Stanford University; Gordon E. Grant, U.S. Forest Service; Francis J. Magilligan, Dartmouth College; Larry Olmsted, Duke Power; A. Dan Tarlock, Chicago-Kent College of Law; and Chari Towne, Delaware Riverkeeper Network. Any errors or oversights in the final document are solely the responsibility of those who served on the panel.

This report does not advocate dam removal or retention in general or in any particular cases. There are numerous organizations and individuals who can speak to these viewpoints. Rather, this report is intended to be objective, and to offer the best science that is available in the belief that the best public policy decision is the one that is best informed.

WILLIAM L. GRAF
Chair

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SUMMARY

When one tugs at a single thing in nature, he finds it attached to the rest of the world.

—John Muir

DAMS ARE COMMON FEATURES of the American landscape and water-scape, forming an integral part of the nation's infrastructure that contributes to the collective economic and social welfare. The construction and operation of dams also have imposed environmental, economic, and social costs that only recently have become clear. Interest in dam removal is a recent outcome of the aging of many of the structures, evolving societal values, and increasing scientific knowledge about changes brought about by dams.

Throughout its history, the United States has supported the intensive use and development of rivers for economic gain. Americans traditionally have viewed rivers as water resource-related commodities to be used rather than as ecosystems to be protected. However, in the past few decades, growing concern over environmental quality, endangered species, and aesthetics of landscapes has become more prominent in the national discourse about rivers. Also evident are concerns about dam safety and security, downstream risks related to unsafe dams, and the future of structures that have become obsolete. The environmental and safety issues associated with dams have become components of local, regional, and national policies.

The majority of dams in the United States are small, storing less than 100 acre-feet of water. Private individuals, firms, or local entities own most of these small structures, although some orphan dams lack any

formal, established ownership. An unknown number of dams already have been removed, likely more than 500 mostly small, run-of-river structures. Many of these removals were the products of decisions by individual owners who sought a variety of economic benefits, although the environmental reasons for dam removal are numerous and often supported by local or state governments. The decision to remove a dam by its owner may not be made in the public arena. However, because of state and federal regulations, the decision to approve a removal becomes a public process.

The Heinz Center Panel on Economic, Environmental, and Social Outcomes of Dam Removal generated this report to assist dam owners, private citizens, and other decision makers. It outlines the current state of research and knowledge related to dam removal and recommends steps and indicators for decision making regarding dam removal. This report is a primer, designed to provide background information and basic principles derived from science and experience for decision-making processes. For the purposes of this report, the panel defined the following dam size categories based on reservoir storage rather than height or other measures because the size of the reservoir is related most directly to the magnitude of potential effects on river hydrology:

Small: reservoir storage of 1–100 acre-feet

Medium: reservoir storage of 100–10,000 acre-feet

Large: reservoir storage of 10,000–1,000,000 acre-feet

Very large: reservoir storage of greater than 1,000,000 acre-feet

This report focuses on small dams, because historically Americans have the most experience with the removal of such structures, and this size of dam is most likely to be considered for removal at present. The report addresses medium-sized structures but in less detail, because only a few are under consideration for removal. Lessons learned from the removal of small structures may provide useful input, with some modification, for decisions about larger dams, as owners/operators express interest in their removal. The report does not address the potential removal of large or very large multipurpose dams. The issue of removing large dams, such as the Snake River dams, is being considered in detail by the U.S. Army Corps of Engineers (2001) through an environmental impact statement process. A similar process exists under the Federal Energy Regulatory Commission for private hydropower dams. Within this context, the

panel sought to address a three-part task: (1) outline the nature of likely environmental, economic, and social outcomes of dam removal; (2) define indicators for measuring and monitoring outcomes; and (3) indicate sources of useful information for researchers and decisionmakers considering dam removal. The Heinz Center panel was charged with investigating the outcomes of dam removal and did not evaluate alternatives to removal. These potential alternatives include re-engineering the dam structures, changing operating rules, constructing fish passages, sediment management, and conducting other mitigation measures focused on habitat.

The nation has many small dams that are abandoned or obsolete and whose owners may wish to consider removal as a viable option. Neither the panel nor this report advocates any particular position regarding the advisability of removal or retention of dams. The panel seeks to help resolve potential conflicts that are likely to develop in balancing societal and environmental needs with respect to dams. The report does not make recommendations about individual structures. Rather, this report recounts the lessons learned in previous dam removals and scientific investigations as an aid to informed, reasonable decision making. The panel believes that dam owners, private citizens, researchers, and other decision makers are more likely to reach conclusions that serve the best interests of all community members if they have the best available methods and information. The panel offers this report as a contribution to achieving the goal of informed, effective decision-making processes.

BACKGROUND

The National Inventory of Dams,* a database maintained by the Corps of Engineers and Federal Emergency Management Agency, catalogs more than 76,000 dams in the United States that are 6 feet high or more and impound at least 50 acre-feet of water, are 25 feet high and impound at least 15 acre-feet, or pose a serious hazard to people downstream. The potential storage behind these dams is almost equal to the nation's total annual runoff. About one-quarter of all dams were constructed during the

* The inventory is available online but the site was taken offline as a security precaution after the September 11, 2001, terrorist attacks. The site may be restored after further evaluation. The Web site is <http://crunch.tec.army.mil/nid/webpages/nid.cfm>.

1960s, and many structures now are half a century old. Reasons for building these dams included

- Water supply for domestic and industrial use
- Irrigation water supply for agriculture
- Flood suppression
- Waterpower (mills)
- Hydroelectric power
- Navigation
- Flat-water recreation
- Waste disposal

There is no completely accurate accounting of the number of dams removed in the United States, because accurate records of historical removals are rare. American Rivers Incorporated has documented the removal of almost 500 structures, though the actual total is likely to be much larger. Almost all dams removed so far have been small, privately owned ones that are most often of the run-of-river type, although a few medium-sized dams with some storage also have been removed. Reasons for dam removal include

- Economic obsolescence
- Structural obsolescence
- Safety considerations
- Legal and financial liability
- Dam site restoration
- Ecosystem and watershed restoration
- Restoration of habitat for riparian or aquatic species
- Unregulated flow recreation
- Water quality or quantity

DAM REMOVAL DECISIONS

A key premise of this study is that better decisions will be made about whether to retain or remove a dam if the process is logical, defensible, and organized. The decision to remove a dam by its owner may not be made in the public arena. However, because of state and federal regulations, the decision to approve a removal becomes a public process. Such a process would begin with the owner's desire to remove a dam. The next step

would be the identification of the specific goals that the owner and/or the communities involved with the dam hope to achieve. Public discussions about the advantages and disadvantages of retention versus removal are required, with freely available information, often assembled in map-based formats. Reliable maps and data about many of the environmental, social, and economic aspects of decisions related to dam removal are available from the World Wide Web (site addresses are given in Appendix A of this report).

The panel designed and advocates a systematic approach to decisions about dam retention or removal (Figure S.1). The steps include the following:

1. Establish the goals, objectives, and a basis for the decision, a task that includes the collection of information about the environmental, social, economic, regulatory, and policy contexts for the decision and its outcome.
2. Identify major issues of concern, ranging from the safety and security of a dam to those related to the cultural interests of the population involved.
3. Assess potential outcomes and gather data about the operations of the river; the dam; the legal regime; and the ecological, social, and economic systems associated with these elements. These assessments depend on the evaluation of a series of indicators that provide insight into present and likely future conditions.
4. Make decisions within a framework that encompasses available knowledge about the gains and losses, costs and benefits, public support and concerns, and private and public interests.

A key component of this step-by-step process is the gathering of data and assessment of outcomes, which not only provides a view of the present conditions, but that also may be useful in describing the likely future conditions once the dam is removed. Decision makers can use this information to assess the "with dam" and "without dam" future scenarios and consider what might happen in the short term (a few months), medium term (a few years), and long term (a few decades). The panel developed an extensive list of issues and associated indicators that can be measured in the present and predicted for the future (Box S.1). See Table 3.1 on pages 90–93 for an extended list of indicators.

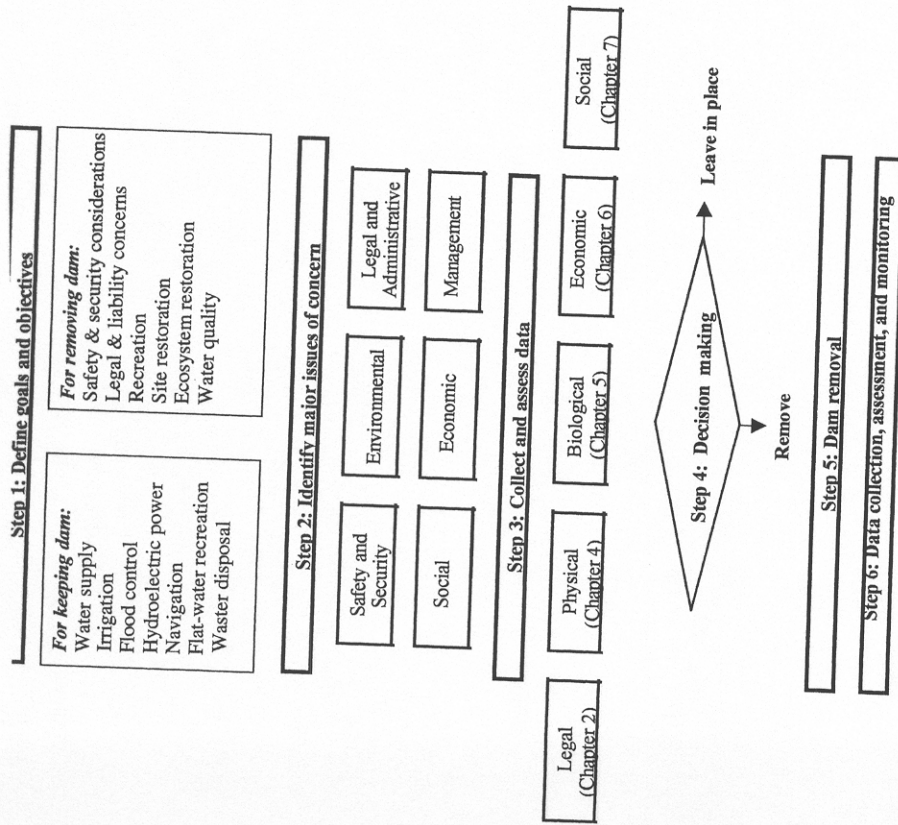


Figure S.1 A general method for dam removal decisions

PHYSICAL ENVIRONMENTAL OUTCOMES OF DAM REMOVAL

Dam removal can restore some but not all of the characteristics of the river that existed before the dam was built. Dam removal creates a more natural river than existed with the dam in place because some aspects of physical integrity* are restored to the river downstream from the dam site.

*The word integrity is especially apt when applied to rivers because it means unity, completeness, and the quality of state of being complete or undivided (Websters New Collegiate Dictionary, 1981).

Box S.1 Key Indicators for Dam Removal Decisions^a

Physical

- River network segmentation
- Watershed fragmentation
- Downstream hydrology
- Downstream sediment system
- Downstream channel geomorphology
- Floodplain geomorphology
- Reservoir geomorphology
- Upstream geomorphology

Chemical

- Water quality
- Sediment quality (reservoir area and downstream)
- Air quality

Ecological

- Aquatic ecosystems
- Riparian ecosystems
- Fishes
- Birds
- Terrestrial animals

Economic

- Dam-Site economics
- Economic values, river reach
- Regional economic values

Social

- Safety and security
- Aesthetic and cultural values
- Non-majority considerations

^a Ideally, these indicators would be used to measure or estimate today's conditions and forecast conditions one year, five years, and a decade or two into the future.

In addition to the effects of their reservoirs, which inundate terrain and ecosystems, dams affect physical integrity by fragmenting the lengths of rivers, changing their hydrologic characteristics (especially peak flows), and altering their sediment regimes by trapping most of the sediment entering the reservoirs. These effects cause downstream landscape changes, including channel shrinkage and deactivation of floodplains.

Dams also cause water quality changes that alter aquatic ecosystems. The removal of dams has the effect of reversing some undesirable changes, subject to the limits imposed by many other human influences on the watercourse. The most important positive outcome of dam removal is the reconnection of river reaches so that they can operate as an integrated system, which is the basis of a river with restored physical integrity. Productive, useful ecosystems can result from dam removal, but predictions of outcomes are sometimes difficult because of the many interrelated changes in physical and biological systems caused by placement of the dam and other physical stresses on the river. For example, dam removal may result in the remobilization of contaminated sediments once stored in reservoirs.

BIOLOGICAL OUTCOMES OF DAM REMOVAL

One way to learn about the potential effects of dam removal is to review what is known about the effects of dam installation on a river system. Although the changes brought about by installation may not be completely reversible, they do help to predict the various consequences of removal.

Changes in the physical system of a river imposed by a dam, and partly reversed by dam removal, cause associated adjustments in the biological components of the ecosystem. These biological changes, particularly among fish and macro-invertebrates, include altered movement patterns, residence times, and general habitat opportunities. These biological ecosystem changes are variable in time and space. The extent and intensity of the changes depend on the size of the dam (storage capacity), quantity and quality of sediment in the reservoir, timing of reservoir level fluctuations, limnological conditions in the reservoir, and stability of the downstream river reach. Non-native exotic species also affect native species in both rivers and reservoirs. Dam removal may, in some cases, increase the abundance and diversity of aquatic insect, fish, and other populations, but long-term data and numerous "before and after" tests of population trends are not available. Reservoirs create wetland areas in some cases; the removal of a dam and draining of a reservoir may create some wetlands downstream, but at the expense of some wetlands upstream. Dam removal often results in the replacement of one aquatic community with another that is, therefore, partly natural and partly artificial.

cial. The most significant biological effect of the removal of small structures is the increased accessibility of upstream habitat and spawning areas for migratory and anadromous fishes.

ECONOMIC ASPECTS OF DAM REMOVAL

From an economic standpoint, dam removal is not unambiguously good. Economic analysis can be helpful for setting priorities and facilitating communication among stakeholders and agencies. Benefit-cost analysis provides a process for identifying and measuring the outcomes of dam removal, whether they are perceived as positive or negative, and for clarifying trade-offs in the decision-making process. Traditional benefit-cost approaches are imperfect for dam removal, however, for several reasons. In traditional analyses, there is a "no action" alternative, which serves as an economic baseline that is the starting point for measuring beneficial and adverse effects. In many dam removal decisions, there is no such baseline, because "no action" (i.e., no project) is not possible. The owner of a dam may be compelled by safety or economic considerations to either remove the dam or repair it, and therefore a nontraditional reference case is required. Additionally, many environmental outcomes are uncertain or difficult to establish in monetary terms. Even so, they had best not be ignored, because they are among the primary concerns in public discourse and debate about dam retention or removal. Reasonable valuations of outcomes that are rooted as firmly as possible in economic theory and applications offer the best path to economically informed decisions.

SOCIAL ASPECTS OF DAM REMOVAL

Little research has been conducted to date on the social science aspects of dam removal. This is a serious shortcoming, because the social context of dam removal decisions is often as important as the environmental and economic contexts. Social outcomes of dam removal include, for example, the aesthetics of the dam site and adjacent river reaches. There may be a clash of values; some stakeholders may emphasize their desire for a partially restored environment, whereas others may warn against the loss of a historically significant structure or water body. On the other hand, the draining of a reservoir may restore a historical landscape. Cultural values

associated with human and natural landscape components are likely to be important in discussions related to potential dam removals. Water rights, property values, tribal rights, and the maintenance of storage capability are also likely to be issues, along with improved water quality and changed recreational opportunities.

CONCLUSIONS AND RECOMMENDATIONS

The Heinz Center panel identified conclusions and recommendations in three general categories: making decisions today, data needs, and improving tomorrow's decision making.

MAKING DECISIONS TODAY

Dam removal decisions require careful planning and review. To be effective and useful for managers, decision makers, and the public, a removal project needs to be scientifically based. Decisions about dam removal also take place in specific economic and social contexts that need to be taken into account. Decision-making processes for dam removal are, in most cases, more effective when they are systematic, open, and inclusive of the people in the affected communities.

■ **The panel recommends that participants in public decision-making processes use a multistep process similar to the one outlined in this report (Figure S.1), beginning with the establishment of goals as a basis for the process, and including the identification of the full range of interests and concerns of those likely to be involved, assessment of potential outcomes, and informed and open decision making.**

The assessment of potential outcomes of dam retention or removal requires measurable indicators that can be used to assess the present environmental, economic, and social conditions associated with the dam and to monitor future changes.

■ **The panel recommends that assessment of potential outcomes of a decision to retain or remove a dam include the evaluation of as many indicators as are applicable to the situation, with the assessment conducted for short-, medium-, and long-term periods,**

and for the "with dam" as well as "without dam" alternatives. The panel developed a list of measurable indicators (Box S.1 and Table 3.1) that can be used to support the decision-making process outlined in Figure S.1.

Decisions to remove dams in a complicated physical and biological system can have far-reaching implications both upstream and downstream. The consideration of a limited scope of outcomes is likely to have unforeseen consequences.

■ **The panel recommends that a dam removal decision take into account watershed and ecosystem perspectives as well as river-reach perspectives and the more limited focus on the dam site.**

DATA NEEDS

Data on dams that have been removed can be useful to decision makers considering the fate of existing structures, yet there is no centralized mechanism for collecting, archiving, and making available such information on a continually updated basis. The effects and effectiveness of any individual dam removal depend, in part, on the nature of the rest of the affected river system. There is an obvious need for a geospatial database that provides accurate, readily accessible data on the segmentation of the nation's river systems by dams and the quantity and quality of sediment discharged in the nation's rivers. In addition, monitoring after dam removal is essential to enable stakeholders to evaluate whether the goals and objectives of the removal have been met.

■ **When dams are removed, their entries in the National Inventory of Dams are deleted and the National Performance of Dams Program retains information about them. The panel recommends that federal agencies improve the availability of information about dam removal by making this database widely known and available to the public.**

■ **The panel recommends that the U.S. Geological Survey maintain and extend its network of sediment measurement statistics throughout the total national stream gauging system.**

■ The panel recommends that the U.S. Environmental Protection Agency and/or U.S. Geological Survey consider augmenting the existing national stream-reach geographical data to include the location of dams to allow better analysis and understanding of the segmented nature of the nation's streams and rivers.

■ The panel recommends that the U.S. EPA and/or appropriate state and local governmental agencies conduct a monitoring and evaluation program following dam removal. This program should be developed and implemented so that vital data on the natural and enhanced restoration of habitats is collected and made available in public datasets for use in adaptive management.

IMPROVING TOMORROW'S DECISION MAKING

Dams are a ubiquitous feature of the American landscape and watershed and form an integral part of the nation's economic infrastructure. The building of these structures has produced significant economic benefits, but the effort also has imposed environmental, economic, and social changes and costs. Science to support decisions about dam removal is progressing, but there is little cross-disciplinary communication, and research priorities have not been established to guide researchers or funding efforts.

■ The panel recommends that federal agencies and other organizations consider sponsoring a conference for researchers who currently focus on the scientific aspects of dam removal with the specific objectives of improving communication across disciplinary boundaries, identifying gaps in knowledge, and prioritizing research needs. The conference should not be a forum for debating whether dams should be removed but rather should focus on science and the state of knowledge available for decision makers.

Several fundamental technical aspects of dam removal are poorly understood. Dam removal may result in the remobilization of contaminated sediments once stored in reservoirs, yet understanding of sediment processes is poor. Sediment quality and quantity are the most important issues in considering biophysical outcomes of dam removal. Other issues include vegetation changes, bank erosion, channel change, and effects on

groundwater. Water quality is an important human health and environmental concern, yet outcomes of dam removal on water quality are poorly understood. One of the most important outcomes of dam removal is the reconnection of river reaches so that they operate as a free-flowing, unobstructed system—that is, restoring the physical integrity of the river system. However, empirical data are lacking on river channel changes downstream from removed structures.

■ The panel recommends that the scientific community of river researchers provide (1) improved understanding of sediment quality and dynamics to provide a scientific basis for evaluating contaminated sediments, (2) improved understanding of the roles that dams and their potential removal play in water quality, (3) empirically derived explanations of river channel change upstream and downstream from removed dams, and (4) a knowledge base of the likely fate of sediments and their contaminants downstream from removed dams.

Formal economic analyses can be very helpful in supporting the decision-making process for dam removal, in setting priorities, and, most of all, in facilitating communication among stakeholders and agencies. Nevertheless, significant challenges remain for those who would use methods such as benefit-cost analysis for this purpose. Dam removal has various environmental effects, including some that are highly uncertain and difficult to quantify. It may be tempting to ignore these issues, as often was done in the earlier building of dams. However, these nonquantified environmental effects are major issues for consideration when dealing with a possible dam removal and had best not be ignored. The science of economics does not yet offer decisionmakers considering dam removal a sufficient array of analytic tools and supporting data to assess adequately the economic outcomes of a decision in quantitative terms.

■ The panel recommends that the community of economics researchers provide (1) improved economics evaluation tools to enable the assignment of monetary valuations for outcomes of dam removal, and (2) empirical research on changes in property values associated with dam removals already accomplished.

The social outcomes of dam removal decisions are not yet well known, but standard social science, survey-based research can help stakeholders understand potential changes in individual and community

behavior related to such decisions. The adaptive management process for environmental systems could be extended to social systems so that river managers would be able to make informed adjustments to their plans.

- The panel recommends that agencies and organizations that fund social science research support investigations into the social and cultural dimensions of cases in which dams already have been removed, as a way of improving the predictability of outcomes.
- The panel recommends that decision makers in dam removal cases should undertake social impact studies modeled on the environmental impact studies that are a common feature of such decision-making processes. These social impact studies should address the cultural significance of the dam site (e.g., as a tribal sacred site), reservoir area, and river areas likely to be changed by the proposed removal.

Dams are important parts of the nation's economic and historical fabric, and their presence affects everyone's lives. Dams are also integral parts of the nation's riverine ecosystem, exerting wide-ranging changes in the physical and biological processes in rivers. A decision to remove or retain a dam has implications for a variety of community and national values, some of which may not be complementary. The surest route to a successful, informed decision is to explore the likely environmental, economic, and social outcomes before the decision to retain or remove a dam is made.

As a follow-up on the activities related to this project, the Heinz Center proposes to host a conference for researchers on the science of dam removal with the objectives of clarifying the present state of knowledge in the various scientific disciplines addressing the issue, identifying topical areas in which one discipline can assist another in problem solving, and specifying the gaps in knowledge that require additional research to better support decision making. The Center also seeks to apply the concepts and procedures outlined in this report to several test cases in which dam removals are being considered. The Center also sees the need for a study and report that provides alternatives to dam removal, to aid owners of small dams and public decision makers, especially with cases of abandoned or orphaned dams.

INTRODUCTION AND BACKGROUND

DAMS ARE THE FULCRUMS of many of the increasingly important environmental quality decisions facing the nation's river managers and the public. The estimated 76,000 dams (counting those 6 feet high or more) constructed in the United States have transformed the nation's rivers and greatly influenced the economic development and social welfare of its citizens. Over the last 200 years, dams have been built and operated for a variety of purposes: to reduce flood flows, provide agricultural and urban water supply, control fires, improve navigation, offer recreational opportunities, and generate electricity. Dams also have created new habitats, such as nesting areas for riparian birds and migratory waterfowl on reservoir deltas, and lake fish habitat. However, some dams have created long-lasting changes in the quality of riparian and aquatic habitats and have contributed directly to the decline of some commercially important fish as well as endangered species. Increasingly, river management debates include discussions about dams and, in many cases, their removal or alteration.

The nation now has the capability to store the equivalent of almost one full year's runoff in reservoirs behind more than 80,000 structures. If the definition of "dam" includes the smallest structures, there may be as many as 2 million (Graf, 1993). At first glance, the long-term costs and benefits of dams seem straightforward, but they are actually difficult to determine. Dams have not completely controlled floods, but some have significantly reduced loss of life and provided property protection. Irrigation waters diverted from streams and temporarily stored by dams have stimulated the agricultural and economic development of western states. Lock and dam structures in the Mississippi basin have created an inland water transportation system for bulk commodities worth

billions of dollars. However, this system has relied on the continued maintenance of federally funded river engineering works. Dams generate more than 10 percent of the nation's electricity and more than 70 percent of the electricity in the Pacific Northwest.

Many U.S. dams were constructed during the late nineteenth century and early to mid-twentieth century. Dam building accelerated in the early 1930s, and, by 1945, Grand Coulee Dam and Hoover Dam were the two largest power sources in the world (Costenbader, 1998). Hydroelectric dams provide electricity that generates power with far fewer air emissions (little or no carbon dioxide) or solid and liquid wastes than do most other sources of energy. The installation of dams and reservoirs to provide electricity, recreation, and property protection from floods has transformed the natural, interconnected river system of the United States into a fragmented—and partly artificial, partly natural—system of river segments. The environmental changes associated with dams include the loss of channels and associated floodplains, with more than 600,000 miles of the nation's rivers under reservoir waters (Huntington and Echeverria 1991). Dams have resulted in changes in biology and biological processes, and they have altered the hydrologic and physical bases of ecosystems in every region of the nation. Dams are features of the landscape everywhere, with the greatest density of dams in the eastern and southeastern states, and the greatest influence on the hydrologic system in the interior areas of the West (where structures store almost four years' runoff).

The recent attention to the effects of dams stems from changing social values, dam safety issues associated with aging structures, and a general increase in the knowledge and scientific base of understanding of the long-term physical and ecosystem response. The nation previously supported the intensive use of rivers for economic development. In the last three decades, however, growing concern over environmental quality, mounting flood losses, endangered species, and aesthetic characteristics of landscapes have become more prominent in the national discourse about rivers. It also has taken two to three decades for some of the environmental changes caused by the larger structures, many built after 1960, to become apparent.

This report addresses downstream restoration and other changes that follow a dam removal. Restoration of the former reservoir is, of course, also a consideration. Frequently, the length of river involved in the reservoir area is short compared to the affected downstream areas. A relatively short reach of river upstream from the reservoir site is likely to be

affected first by the filling of the reservoir and then by its draining. Accumulated sediments in the reservoir area and immediate upstream reach may be eroded and removed with the dam, though some remaining sediments may become the site of a new channel and near-channel landforms.

The downstream alteration by dams of the physical operation of rivers has resulted in changes in river landscapes, loss of riparian and aquatic habitat, fragmentation of migration corridors (especially for salmon and shad), and endangerment of threatened native fishes and riparian birds. The recovery of these endangered species may depend on removing or re-engineering dams or changing their operating rules, measures that bring about unavoidable conflict with the objectives for which the dams originally were built.

Federal environmental legislation relevant to dam operations and removal include the Endangered Species Act of 1973 (P.L. 93-205), Clean Water Act (originally called the Federal Water Pollution Control Act [United States Code, Title 33, Section 1251 et seq.*] and amended a number of times), National Environmental Policy Act of 1969 (P.L. 91-190), Wild and Scenic Rivers Act of 1968 (P.L. 90-542), and tribal laws. These and other relevant laws are discussed in Chapter 2. The recovery of riverine endangered species and commercial fisheries may hinge on some actions involving dams, and the Clean Water Act stipulates that it is national policy to restore and maintain the biological, chemical, and physical integrity of rivers, a task that also engages dams. Actions involving dams are usually limited to the removal of structures, but they may be extensive in their effects. The removal of a single small dam in a key location may free many miles of newly accessible spawning reaches. For example, the removal of the 7-foot-high Quaker Neck Dam on North Carolina's Neuse River system opened 1,000 miles of upstream spawning reaches for migratory fish, and the removal of Columbia Falls Dam opened access to 28 miles of Maine's Pleasant River. Although the present debate seems to pit social and economic benefits against these types of environmental goals, it is likely that some dams can be operated to benefit both socioeconomic and environmental ends.

Very large dams (dam size categories are defined in the next section) are generally not targeted for removal and are largely owned by the federal government. Companies or cooperatives privately own most

* Henceforth, references to the *Code* will be abbreviated using the format 33 USC §1251.

medium sized dams used for irrigation, water supply, hydroelectric power, and direct hydropower (e.g., for mills). A small percentage of medium sized structures are nonfederal hydropower dams licensed by the Federal Energy Regulatory Commission (FERC) and are periodically considered for relicensing.

Almost all small dams are privately owned, although some are owned by state, federal, or local agencies. Some small dams are orphaned (or abandoned) and may be taken over eventually by the state or local community. Structures of this size were constructed primarily for water diversion and irrigation purposes, to generate locally marketed hydroelectric power, to improve navigation on small and medium-sized streams, or to power machinery directly. Other small dams were constructed for recreational purposes. Many of these structures are in poor condition and no longer perform their original functions because of the efficiency of competing regional power grids, changing transportation needs that eliminated water transport on small and medium sized streams, and the economic decline of water-powered industries. Private owners may seek to remove dams because of safety concerns, high insurance costs, and maintenance costs. The potential removal of small structures can be a key step in river and riparian restoration, improved recreational opportunities, increased access to spawning grounds for anadromous fishes, and resolution of safety issues. Privately owned off-stream tailings dams that impound mining waste pose special policy challenges.

Regardless of size, all dams encounter safety issues deriving from the 1972 National Inventory of Dams Act (P.L. 92-367), which requires periodic inspections of all dams in the country. State inspectors evaluate each dam to assess the potential for loss of life and damage to property should the dam fail or be operated improperly. Their reports to the U.S. Army Corps of Engineers (USACE) and Federal Emergency Management Agency (FEMA) show that 14 percent of all dams in the country are rated as "high hazard" (indicating the potential loss-of-life hazard to the downstream area resulting from failure or misoperation of the dam), with an additional 18 percent rated as "significant hazard." Concerns about dam safety are related to the structures, but if a dam is removed, new river safety and flood hazard issues need to become part of the decision making process. Dams are the most common and widespread direct human control on river processes in the United States, and as such, their management, operation, construction, maintenance, and potential removal are all critical aspects of any scientific or policy debate about the future of rivers.

PURPOSE AND SCOPE OF THE HEINZ CENTER STUDY

In the 1960s and 1970s, pioneering, multi-objective research was undertaken to ensure the economic efficiency and productivity of proposed dams. Despite this effort, relatively little work is available to guide decision makers who seek a balance among the social, economic, and environmental consequences of dam removal. Part of the problem with current discussions about dam removal is the lack of formal frameworks for such evaluations, the lack of general agreement on useful indicators or data, uncertainty with regard to the environmental benefits to be gained or lost, and limited knowledge of available alternatives. It is possible to measure the economic productivity derived from dams, particularly in terms of water delivery, hydroelectric power, recreation, and navigation. Non-use values, and values for wildlife and restored, more natural landscapes, are more elusive and difficult to quantify.

Discussions with experts on river restoration, hydropower, water supply, dam removal, and dam safety led the Heinz Center staff to believe that a review and study of potential outcomes, guidance to useful sources of information, and insights into current knowledge regarding dam removal would assist decision makers and help them to make more informed decisions. The Panel on Economic, Environmental, and Social Outcomes of Dam Removal was convened to conduct this study. *Neither the panel nor this report advocates any particular position regarding the advisability of removal or retention of dams. The report does not recommend decisions that should be made about dams collectively throughout the nation or about individual structures.* Rather, this report is intended to aid informed, reasonable decision making by recounting the lessons learned in previous dam removals and scientific investigations. The panel offers this report as a primer, a contribution to achieving the goal of informed, effective decision-making processes. This report builds the necessary informational foundation for researchers and decision makers by focusing on the following objectives:

1. *Outline the wide-ranging outcomes of dam removal, including potentially positive and negative effects, and a list of issues to be addressed in the decision-making process.* Examples of outcomes include the upstream and downstream geomorphic, hydrologic, and biological effects; changes in the economic infrastructure at the local level; and elimination of established recreational oppor-

tunities along with creation of new but different opportunities. The list of outcomes will be as specific and complete as possible, but it is unlikely that all effects will be important for every dam.

2. *Define indicators for measuring and monitoring environmental, economic, and social factors related to dam management and/or removal.* Examples include environmental indicators such as stream flow, water quality, sediment loads, and species diversity and abundance for aquatic and riparian terrestrial ecosystems. Economic indicators may include employment data, transportation planning issues, investment opportunities, and land parcel valuations. Social indicators might include recreational opportunities, population distribution, and quality of life measures. Indicators will be those most readily available and most easily measured; they will be informative for experts and understandable to educated laypersons.
3. *Provide available information sources for decision makers.* Information available to support decisions regarding whether or not to remove a dam is scattered among a variety of public agencies and private, nongovernmental organizations. This report provides a list of information sources and ongoing scientific research related to dam removal, and, if available, data sources such as World Wide Web sites and/or the names and locations of researchers and the topics of their research.

This report focuses on small dams because these structures are of most widespread interest now for possible removal. The size of dams can be defined in a number of ways, such as by height or width, but the most useful definition is reservoir storage capacity. The capability of a dam to store water (and, inadvertently, sediment) is a rough measure of its potential hydrologic impact. For the purposes of this study, dams are characterized as follows:

Small: reservoir storage of 1–100 acre-feet

Medium: reservoir storage of 100–10,000 acre-feet

Large: reservoir storage of 10,000–1,000,000 acre-feet

Very large: reservoir storage of more than 1,000,000 acre-feet

Another reason for focusing on small dams is that almost all dams removed so far have been small, and, therefore, almost all the present opportunities to evaluate the effects of dam removal scientifically

are limited to this size range. Although the majority of dams under consideration for removal are small, some medium-sized structures are under active consideration as well; Matilija Dam in California is being considered for dismantlement, and some others, such as Condit Dam in Washington, are in the advanced planning stages for removal. Lessons learned from the removal of small structures may be useful in the future, if more medium-sized structures are considered. Only two large dams are currently under active consideration for removal: Englebright Dam on the Yuba River in California and Glines Canyon Dam on the Elwha River of Washington. Additional large dams on the Snake River in the Pacific Northwest may be reconsidered for removal after a multi-year period for mitigation tests. The National Marine Fisheries Service and U.S. Fish and Wildlife Service will monitor fish runs and, if no improvement is seen, reconsider dam removal.

This report is aimed at decision makers and policymakers, dam owners, and planners at the federal, state, and local levels who are interested in learning how to make decisions that take into account the economic, environmental, and social aspects of dam removal in the United States. The audience includes legislators who establish broad policy and programs and local government officials who develop and implement policies regarding land use, endangered species, dam safety, and water power and supply. Citizens concerned about dam removal, and social and natural scientists, will find this report informative and helpful in determining new research needs.

The momentum of dam removal discussions is increasing, and other organizations were studying this subject at the same time as the Heinz Center. For example, American Rivers, Friends of the Earth, and Trout Unlimited (1999) issued a cooperative report outlining the experience of specific dam removal projects. The report is available as a paper-covered book and is on the Web at <http://www.americanrivers.org/damremovaltoolkit/successstoriesreport.htm>. The Aspen Institute began a dialogue on dams and rivers in September 2000; about 30 people have been convening every few months to consider and recommend guidelines for decisions regarding dam removal. The Aspen dialogue was expected to end by September 2002. In addition, the World Commission on Dams (2000) recently issued a major report on decision making regarding dams and economic development. The report is available as a paper-covered book and in digital form from the commission Web site: <http://www.dams.org/report>.

CENSUS OF DAMS IN THE UNITED STATES

Scientific research related to dam removal and the supporting decision-making process takes place in a historical and geographical context. As noted earlier, many U.S. dams were constructed during the late nineteenth or early to mid-twentieth century, and their presence has become commonplace. Rural and urban dwellers have come to rely on reservoirs for a constant supply of water and electricity. Because of the perceived permanence of dams, many people believe that existing dams will remain unchanged, despite the limited life expectancy of many small and medium-sized structures due to aging and reservoir sedimentation (some conceivably could last much longer if properly maintained). Information about the general background of dams that form the national infrastructure, and the reasons for past decisions that resulted in the present arrangement of dams, can be helpful to those seeking to understand the environmental, economic, and social implications.

The total number of dams that have been built on the rivers of the United States is unknown. Accurate records, especially for small structures, are lacking, and a national accounting would be an enormous undertaking in data collection and management. The best available data are in the National Inventory of Dams (NID), developed from the first broad-based effort to collate information about dams on a national basis as defined by the National Inventory of Dams Safety Act (P.L. 92-367) and signed into law by President Nixon in 1972. The collapse of Teton Dam on Idaho's Teton River in 1976, and the attendant loss of life and property, stimulated further interest in cataloging the nation's dams as potential hazards. In 1986, additional legislative emphasis on building a database appeared in the Water Resources Development Act (P.L. 99-662). The National Dam Safety Program Act of 1996 (P.L. 104-303) supports states in their regulation of dams. The result of these pieces of legislation was the NID, which is managed by the USACE and coordinated by the FEMA. These agencies published early digital versions of the database on CD-ROM (Federal Emergency Management Agency and U.S. Army Corps of Engineers 1994, 1996); more recent versions of the inventory are usually available on the World Wide Web. The following discussion is based largely on the 1996 CD-ROM version (subsequent revisions have been relatively minor, though there are continuing additions to the data, mostly for small dams).

The enabling legislation defined the dams eligible for inclusion in the NID as those structures whose collapse might pose a threat to life and

property downstream, those greater than 6 feet high with more than 50 acre-feet (61,000 cubic meters) of storage, and those that are 25 feet high with more than 15 acre-feet (18,500 cubic meters) of storage. In 1996, approximately 76,000 dams were included in the NID; that total has grown slowly since then, as more data have been made available by states. In addition to the structures included in the database, there are numerous small dams on the nation's small watercourses. A report by the National Research Council (1992) states that there are well over 2.5 million dams in the United States.

SIZES OF DAMS

From an engineering perspective, a most informative way of measuring the sizes of dams is to describe the physical dimensions: height, width, and thickness, for example. When considering dam removal, however, the storage volume behind the structure is a more useful measure of size because it is a direct measure of the hydrologic and sedimentary effects of the dam. The larger the storage volume, the greater the downstream effect of the structure on sediment throughput.

Many small dams have little or no storage, are informally designed, and age poorly. Medium-sized dams are often single-purpose structures erected with considerable investment, whereas large dams are multipurpose, large-scale engineering projects of regional or national significance. Taken together, the 76,000 dams in the NID have a storage capacity that is nearly equal to the nation's mean annual runoff, but the distribution of this storage volume among the various sizes is unequal (Graf, 1999). The majority of dams in the United States are in the small size range, but they store very little water and sediment. From a national perspective, the greatest proportion of the total volume of reservoir water is stored behind the large dams (Figure 1.1).

TYPES OF DAMS

From the standpoint of function, there are two general classes of dams: those that are designed to store water and those that are not. Storage*

* In this report, storage refers to the total volume of storage space available behind a dam at its completion. Some storage space may be occupied by sediment, and some by water; some space may be unoccupied at any given time in the history of the structure.

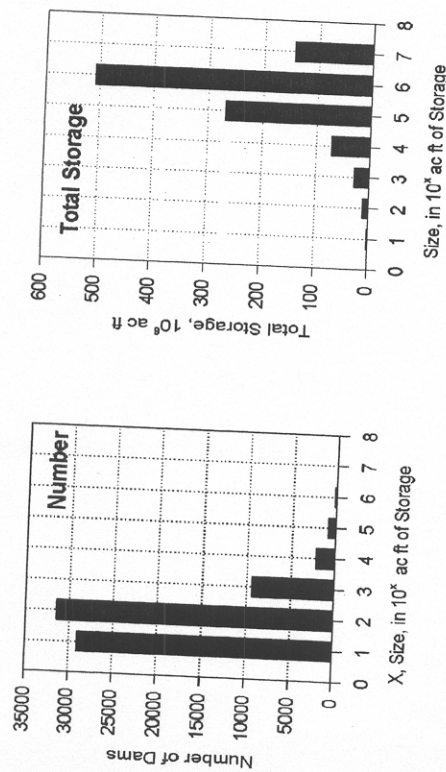


Figure 1.1 Most U.S. dams are small (chart on left), but the most storage volume is contained in reservoirs behind large dams (chart on right). Sources: Data from Federal Emergency Management Agency and U.S. Army Corps of Engineers (1996); calculations from Graf (1999).

structures create reservoirs or artificial lakes that impound water and release part of it through the dam on schedules determined by operators for various purposes (e.g., flood control, electric power generation). Reservoirs behind these dams experience large changes in water level annually. Dams that store no water or very little water are low structures across river channels designed either to raise the water level upstream for navigation purposes or divert flows into canal headings for distribution away from the stream (Figure 1.2). Some are run-of-river hydroelectric facilities. These low dams allow river discharges to flow over their crests, form reservoirs characterized by little fluctuation in water level, and do not generally affect moderate and high flows downstream. In dry land regions, diversion works often desiccate downstream areas by steering most or all of the low flows into canals. Some dams with storage reservoirs create a run-of-river downstream condition through operating releases, whereby the dam releases water at approximately the same rate as the reservoir receives it.

The difference between run-of-river structures and those that store significant and variable amounts of inflows from upstream is important from a physical and biological standpoint for reaches of the river downstream. If a dam is of the run-of-river type and does not divert a significant portion of the flow, then it does not alter the fundamental characteristics of



Figure 1.2 Forge Creek Dam in Cades Cove, in eastern Tennessee, is an example of a small, run-of-river structure. This view looks upstream from the west bank of the head-race and shows the main and diversion dams. A small diversion canal that supplied water to a mill is on the left. Courtesy of the Library of Congress, Prints and Photographs Division, Historic American Buildings Survey, Reproduction Number 5-CADCO, 1-24.

the flow of water downstream. Such a dam does not alter peak flows, mean flows, or low flows; does not change the timing or seasonality of peak or low flows; and does not alter the rate of change between high and low flows. Dams with storage reservoirs have the capability to effect such changes on downstream flow. Any problems in linking cause and effect become even more complex when attempting to predict the outcomes of dam removal. Because storage reservoirs have numerous and complicated effects when they are in place, their removal also is likely to produce complex changes in hydrology and downstream physical and biological systems.

From a design standpoint, the range of approaches to dam building seems endless. Local conditions, availability of building materials, and sophistication of the designers and builders are all highly variable, but there are a few standard types of structures that are most common: crib, earth fill, rock fill, concrete gravity, concrete arch, and concrete buttress dams (Jackson, 1988; U.S. Bureau of Reclamation, 1987).

Crib dams are especially common among older, small, run-of-the-river structures constructed as far back as colonial times in the United States. Cribbing constructed of timber forms an outer box for these low dams to create a linear barrier across the stream. The interior of the box often is filled with rocks for stability and sometimes further stabilized with wire or brush blankets (Figure 1.3). Because these dams often have constant

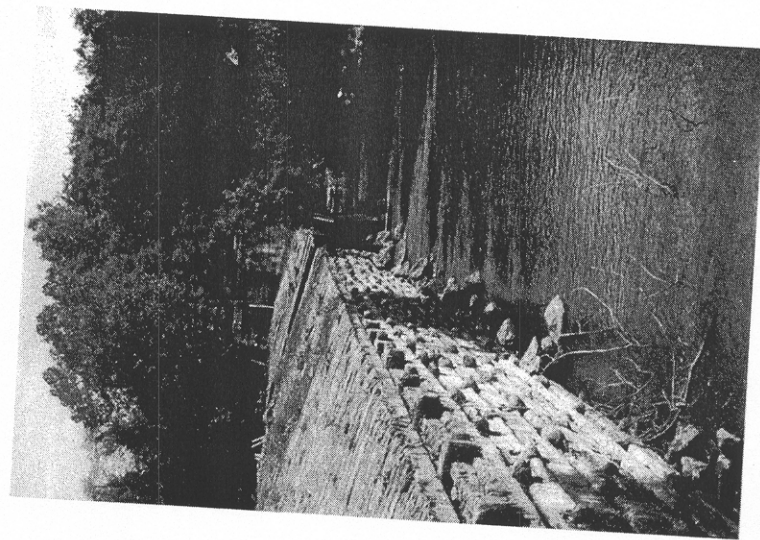


Figure 1.3 Felix Dam, shown here in 1995, is a timber crib dam on the Schuylkill River in Pennsylvania. This dam was partially breached during Tropical Storm Floyd in September 1999. Courtesy of the Pennsylvania Department of Environmental Protection.

overflow, they tend to deteriorate more rapidly than do some other types. As a result, many older crib dams have changed in form over the years, first built as wooden structures and later armored with a layer of concrete.

Earth fill dams, the most common general type of modern times, often are used as small storage structures. They are constructed from local earth materials that are shaped and rolled into a sill across the watercourse to be dammed. In cross section, along the alignment of the stream, the dam has a broad base with gradually sloping faces. All dams require spillway structures because, if the dam is overtopped by water flow, it is likely to be eroded and breached.

Rock fill dams use rock for weight and stability in association with a low-permeability membrane to provide watertightness. Like earth fill structures, rock fill dams are protected from destructive overflows by spillways, which drain off excess water when the reservoir approaches a full state (Figure 1.4).

Gravity dams consist of large masses of materials held in place by their own enormous weight (Figure 1.5). The construction material for modern gravity dams is usually concrete, but older structures often were

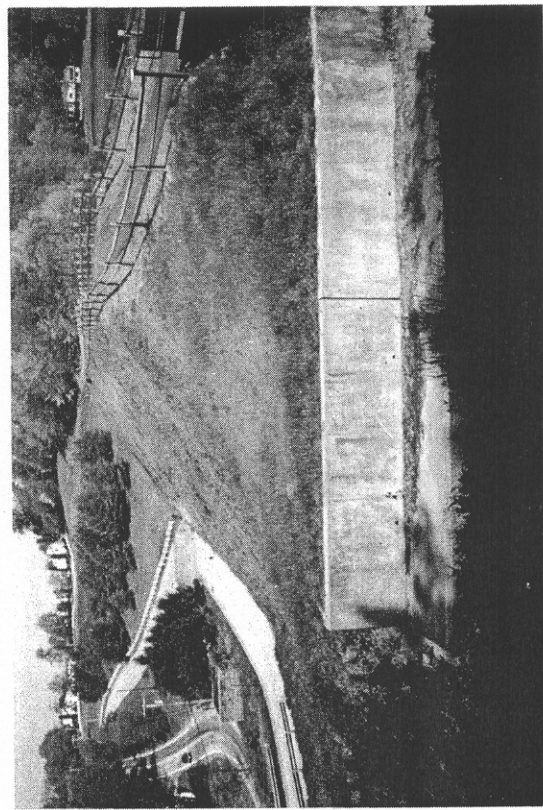


Figure 1.4 Township Line Dam, across Township Line Run in Pennsylvania, is an example of an earth fill dam. Courtesy of the Pennsylvania Department of Environmental Protection.

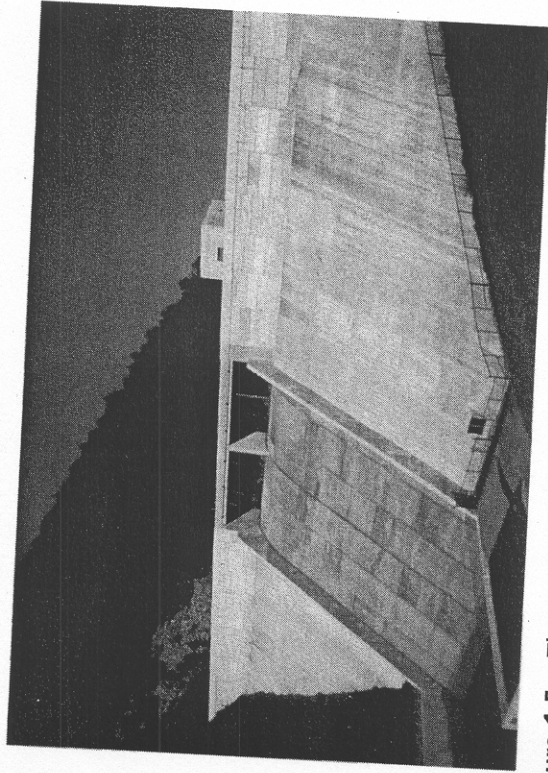


Figure 1.5. The Christian E. Siegrist Dam, constructed in 1993 across Mill Creek in Pennsylvania, is an example of a roller-compacted concrete gravity dam. Courtesy of the Pennsylvania Department of Environmental Protection.

built of masonry; cut and dressed stone blocks; or, in some eastern areas, brick. They usually are founded on a bedrock base and may be either linear or curved in plan. They are wider at the base than at the top to account for increased water pressure at the lower edges. Spillways or gates that permit the passage of water through, over, or around the structure to prevent overtopping often protect dams of this type.

Arch dams commonly are found where the dam site is a narrow constriction of the valley or canyon containing the stream. There are two subtypes: single and multiple. A single-arch dam spans the valley opening as one single structure and is anchored in the sidewalls by thrust blocks (Figure 1.6). In addition to a normal spillway, an emergency spillway is required to help prevent overtopping during high flows. A spillway may appear on the dam crest, gates in the structure may be used to drain excess water from the reservoir, or there may be bypass conduits that conduct water through the canyon or valley walls around the structure. The length of a single-arch dam usually is no more than about 10 times its height. Multiple-arch dams span valley openings that exceed this 10-to-1 ratio and have concrete arches connecting buttresses. A common design strategy in



Figure 1.6 Rindge Dam, built in the 1920s on Malibu Creek in California, is an example of a concrete arch dam. Courtesy of Sarah Baish.

the late 1800s and early 1900s was to make the connections between the buttresses with sloping, barrel-shaped arches of uniform thickness. Many water storage structures constructed at the turn of the twentieth century in western states are of this type. The majority of arch dams are concrete, although there are some masonry single-arch structures.

Buttress dams are made of flat decking that slopes from the crest to the base, usually with the decking inclined in the downstream direction (Figure 1.7). Numerous vertical buttresses anchored in bedrock support the decking, so the resulting structure is hollow rather than filled like a concrete or masonry gravity dam. Spillways are usually included to protect the basic structural integrity of the dams. Buttress dams commonly were constructed during the 1930s when labor costs were low relative to material costs; they were seldom built after World War II. The most common building material for buttress dams was concrete.

OWNERSHIP

The Federal Emergency Management Agency and USACE analyzed the NID to determine ownership of the 76,000 structures they recorded in

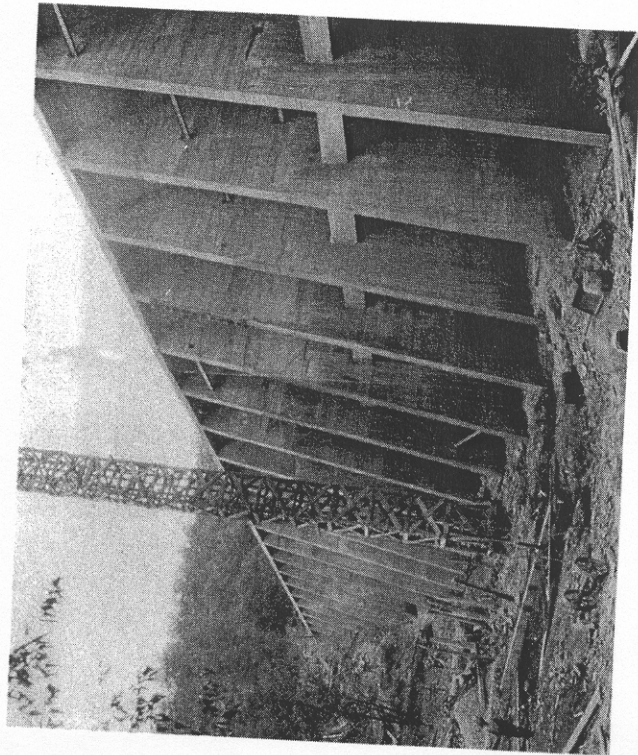


Figure 1.7 Bear Creek Dam in Pennsylvania, shown here under construction in 1915, is an example of a buttress dam. This dam was breached in 1999. Courtesy of the Pennsylvania Department of Environmental Protection.

the 1996 accounting. The analysis revealed that the majority of dams are privately owned (Table 1.1). Because there are many more small structures than other sizes, and because small structures are usually privately owned, private ownership is a major factor in the consideration of dam removal issues. Local government agencies own the next-largest share of the total inventory of U.S. dams, again largely concentrated in the small size range. Significantly, smaller proportions of the total inventory are the property of state agencies, the federal government, and public utilities.

The federal government owns only a small proportion of the total stock of dams in the nation, with its ownership concentrated among the largest structures. The significance of this observation is that the federal government owns the largest amount of storage capacity. Any removal decisions related to these very large structures would involve complex regional and national trade-offs among environmental, social, and economic concerns. Scientific issues and decision making are much more

Table 1.1 Ownership of American Dams

Owner	Number	Percentage of Total
Private	43,661	58.1
Local	12,859	17.1
State	3,680	4.9
Federal	2,209	2.9
Public utility	1,659	2.2
Undetermined ^a	11,119	14.8
Total	75,187	100.0

Source: Data from Federal Emergency Management Agency and U.S. Army Corps of Engineers (1996).
^a Abandoned or of questionable ownership.

complex and difficult to resolve for these large federal structures than for the smaller privately and locally owned ones.

DISTRIBUTION

Dams are a component of the American landscape. They appear in every major and minor river system of the lower 48 states and are found in every county and territory of the nation. Texas has the most dams of any state, almost 7,000, and Worcester County, Massachusetts, has the most of any county, 425 (Federal Emergency Management Agency and U.S. Army Corps of Engineers, 1996). The greatest concentration of dams is in the southern, midwestern, and Plains states (Graf, 1999). Fewer large dams are located in the interior western regions because of lower population density and lack of water (Figure 1.8).

A map of the water volume stored behind the dams would look different from the map of dam density because many of the large water-storage structures are in the West and Great Plains areas. Thus, the downstream effects from a disruption of the hydrologic system are likely to be greatest in those areas. Smaller, run-of-river structures with little or no storage are common in Atlantic coastal areas and the Midwest; the major environmental issues connected with dams in those regions are likely to be related to the disruption of fish passage rather than flow regulation.

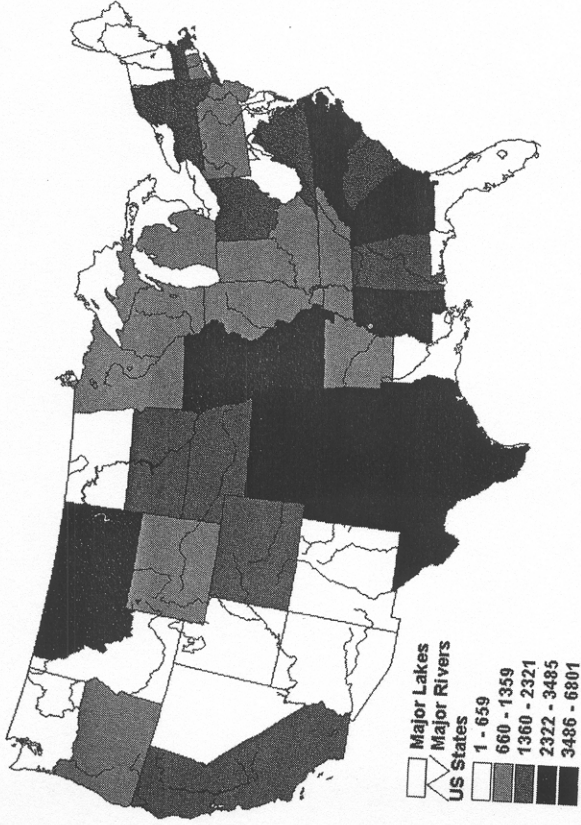


Figure 1.8 This map shows the distribution of existing American dams, with the higher densities indicated by the darker colors. Sources: Data from Federal Emergency Management Agency and U.S. Army Corps of Engineers (1996); map from Graf (2001a).

REASONS FOR DAM BUILDING

Dams have been part of the American infrastructure from prehistoric times.* In the eastern and midwestern regions and the Pacific Northwest, Native Americans constructed low dams and fish weirs. In drier western and southwestern areas, extensive irrigation works supported agriculture for the continent's first cities, pueblos with human populations numbering many thousands. It was European settlement and technology, however, that initiated the construction of permanent dams that exerted control over river hydrology. Dams diverted stream flow to power mills throughout the 13 original colonies and in southern coastal areas to water rice and indigo crops. The oldest surviving dam is Mill Pond Dam in

* The ideas expressed here were derived from research supported by a National Science Foundation Grant to W. L. Graf.

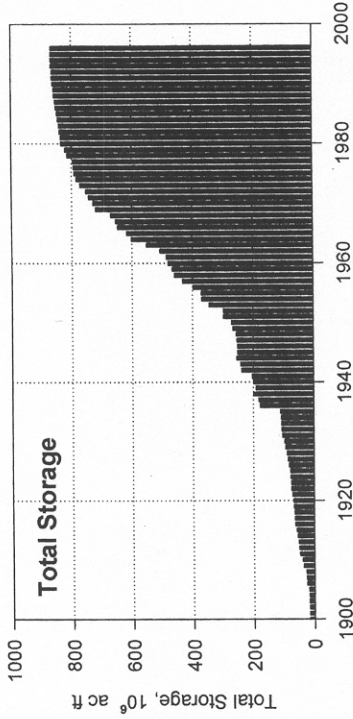


Figure 1.9 Reservoir storage behind American dams increased steadily during the twentieth century. Sources: Data from Federal Emergency Management Agency and U.S. Army Corps of Engineers (1996); calculations from Graf (1999).

Newington, Connecticut, built in 1677; nationally, more than 20 dams survive from the 1700s (Federal Emergency Management Agency and U.S. Army Corps of Engineers, 1996).

The twentieth century saw the construction of more than 80 percent of all the existing dams in the nation. As population growth, expanded agriculture, and industrialization increased the demand for water control infrastructure, the nation invested in building dams of all sizes. During the twentieth century, the amount of total storage behind dams grew from a relatively small amount to almost 1 billion acre-feet (Figure 1.9). Although some very large structures were products of New Deal or World War II construction, the great dam building era in the United States was from about 1950 to about 1970. The peak construction year was 1960, with more than 3,000 dams completed in a single year. The decade of the 1960s saw the construction of more than one-quarter of all the structures existing as of 1996 (Federal Emergency Management Agency and U.S. Army Corps of Engineers, 1996). After about 1980, the installation of new dams dramatically declined, partly because of increased public scrutiny and environmental concern, but also because almost all of the geotechnically desirable dam sites had been used.

This historical account of dam building is of more than academic interest. Because the majority of dams were built in the mid-twentieth century, they are of great technical, policy, and scientific importance now, 50 years later, for three reasons. First, many of the small and medium-

sized dams constructed during this period (the vast majority of all dams constructed then) have design lives of about 50 years, so many are now in need of repair. Second, some small, privately owned hydroelectric dams constructed on public waterways were constructed under licenses from FERC and its predecessors, and those licenses were for 50-year periods. At the end of the license term, a comprehensive reevaluation is to be performed of the environmental and developmental aspects of the project for an extended operating license. Third, in many cases it has taken decades for the environmental effects of the dams to become obvious. Significant time has been required for their influence on aquatic and riparian systems to play itself out and become manifested in changes in biological systems.

In current discussions about the removal of dams, considerable attention is given to the detrimental effects of the structures to the environment and/or costs that were either unknown or ignored when the dams were built. However, every dam was based on a perception that its benefits were real and tangible, and the resulting infrastructure provided by dams indeed has generated benefits for the nation. The question of whether individual structures need to be removed can be assessed most realistically based on an understanding of the reasons for the original dam building. The most common reasons for dam construction include recreation, water supply for fire control and farm ponds, flood control, water supply, irrigation, waste disposal, electricity production, and navigation (Table 1.2).

RECREATION

Many reservoirs were created for recreational reasons. Flat-water recreation is a significant component of regional economic activity, especially in the southeastern, midwestern, and Plains states. Nationwide, more than 27 million people are power-boaters, and their more than 16 million craft dot the nation's reservoirs (National Sporting Goods Association, 1998). Recreational boaters use reservoirs of all sizes as well as the elevated levels of rivers controlled for commercial rafting use. Fishing in reservoirs is very popular, a \$28 billion-a-year industry in the United States (American Sportfishing Association, 2001) (Figure 1.10). Releases of cold water from medium-sized and large reservoirs also support many trophy trout fisheries that otherwise would not exist.

Table 1.2 Primary Purposes of American Dams^a

Primary Purpose	Number of Dams
Recreation	26,817
Fire and farm ponds	12,532
Flood control	10,971
Water supply	7,293
Irrigation	7,223
Tailings and waste	6,756
Hydroelectric	2,259
Navigation	226
Undetermined	1,110
Total	75,187

Source: Data from Federal Emergency Management Agency and U.S. Army Corps of Engineers (1996).
^a Many structures are multipurpose.

FIRE AND FARM PONDS

Fire and farm ponds are common in rural areas across the United States. Since colonial times, farmers have been building dams and creating small reservoirs to impound water for livestock or agricultural uses (Forest Preserve District of Cook County, 1971). These ponds also traditionally have supplied water in case of fire. For the past two decades, a federal program run by the U.S. Soil Conservation Service (now the Natural Resources Conservation Service) has stimulated construction of these types of ponds (Forest Preserve District of Cook County, 1971). Today, most of these fire and farm ponds have multiple uses, including recreation such as swimming, fishing, and ice-skating. In Iowa alone, farm pond owners host 1.6 million fishing trips by licensed anglers each year (State of Iowa, Department of Natural Resources, 2002).

FLOOD CONTROL

Flood control is a major function of large, multipurpose dams in all parts of the nation, but especially in the East and Midwest. Medium-sized and large dams are used for flood control because large volumes of storage are

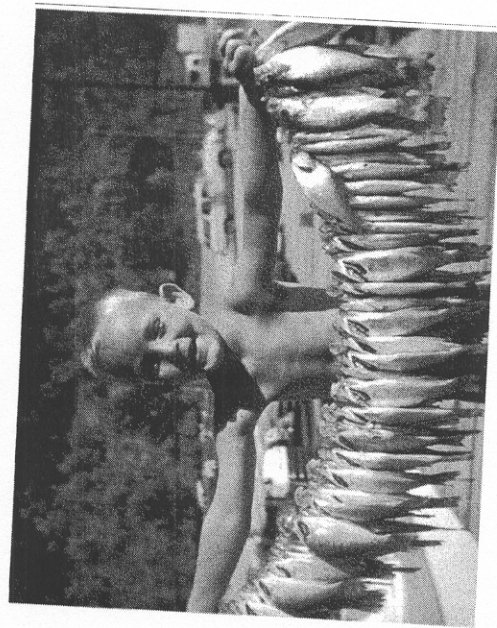


Figure 1.10 A young angler displays his catch taken at a lake located behind the Center Hill Dam on the Cumberland River in Tennessee. Recreational fishing is a benefit derived from most reservoirs. Courtesy of the U.S. Army Corps of Engineers.

required to capture potentially hazardous runoff and store it for subsequent gradual release. The large volumes of water involved are available only episodically, but this is sufficient to provide for needs such as drinking water supply and electric power production. The USACE is authorized by the U.S. Congress to construct dams largely for flood control purposes. The nation has invested more than \$3 billion in flood control works, yet annual losses from floods continue to increase (National Weather Service, 1999), and floods account for more loss of life than any other natural hazard in the United States (U.S. Census Bureau, 1999).

WATER SUPPLY

The need for water for urban, domestic, and industrial use spurred the construction of many dams, ranging from small, run-of-river structures diverting stream flow into distribution systems to medium-sized and large structures providing temporary storage. Withdrawals of water from the nation's streams and rivers amount to about 183 gallons per person per day, and industrial uses demand 24 billion gallons per day. About 60 percent of the domestic water and 80 percent of the industrial supply comes

from surface water in streams and rivers (Solley et al., 1998). Water is removed from the riverine part of the hydrologic cycle by diversion or storage in reservoirs. Some of this water is returned by wastewater and treatment plant discharges. These are significant diversions from an ecological perspective, disrupting the riverine part of the cycle and important components of the overall social and economic system. Economic development in the United States has caused water consumption to double in the past 40 years, and increases of this scale are likely to continue (Postel, 2000).

IRRIGATION

Irrigation diversions for agriculture are common functions of low dams in the plains and western states, where rainfall is not consistent enough for the production of crops. Medium-sized and large dams create storage reservoirs in the upper portions of watersheds, filling them with runoff and snowmelt in winter and spring and releasing water for downstream diversions into lateral distribution systems during the growing season. Irrigation systems withdraw 134 billion gallons per day from the nation's streams and rivers (Solley et al., 1999), and, unlike the consumptive process that occurs in many industrial uses, most is consumed by evapotranspiration. The U.S. Bureau of Reclamation was authorized by Congress to build large structures in western states for irrigation water supply; many smaller structures are the products of private investment.

WASTE DISPOSAL

The construction and maintenance of dams is required for waste disposal associated with several activities, particularly mining and industrial animal husbandry. The processing of mineral ores produces large quantities of liquid waste, slurry, and tailings, which contain water, acids, and sediment. The containment of these materials, usually by small dams, allows the water to evaporate, producing solids, which are more easily managed. Similarly, extensive industrialized production of chicken, pork, and beef results in the generation of large amounts of animal wastes, which often are retained in ponds by small dams before further treatment. Waste disposal ponds and their dams pose special problems because of the need for hazardous biomaterials management in their operation and removal.

WATERPOWER

Waterpower was the primary reason for the construction of many of the older dams in the United States. From colonial times until the late 1800s, and water diverted from streams hydraulically drove machinery to grind grain and produce goods ranging from textiles to sawn lumber. Most of these early structures were small, but they dotted coastal rivers, particularly in the eastern states bordering the Atlantic Ocean and in midwestern states. The advent of steam power made many of these structures obsolete for their original intended purpose, but some were refitted for other purposes, including the production of electricity. Only 3 percent of all dams (2,259) are hydroelectric (Table 1.2).

ELECTRICITY PRODUCTION

Hydroelectric dams use waterpower to turn turbines (Figure 1.11). Water may simply be passed through the structure of a dam to generate electricity, or it may be diverted through canals and pipes to off stream locations for this purpose. Electricity production therefore involves dams of all sizes, ranging from low-diversion works to large storage structures. Hydroelectric plants may produce base-load power by releasing consistent amounts of water to the turbines, or they may produce peak power by releasing water on a schedule to coincide with maximum demand. Dams produce about 10 percent of the nation's electricity and about 70 percent of electrical power in the Pacific Northwest (U.S. Census Bureau, 1999).

Recent problems with electricity production and distribution, notably in California during the winter of 2000–2001 and to a lesser degree in the summer of 2001, may influence decisions about hydroelectric dams. A heightened appreciation for electricity from such structures (inexpensive, reliable, low emissions) means that additional care needs to be taken when considering their removal. However, there are three reasons why increased concern about hydropower is not likely to change the current decision-making processes with respect to removal of some structures. First, as outlined in the next major section of this chapter, the majority of decisions to remove dams at present revolve around concerns over safety or obsolescence, and power production is only a minor consideration. Second, almost all of the dams being removed or likely to be con-

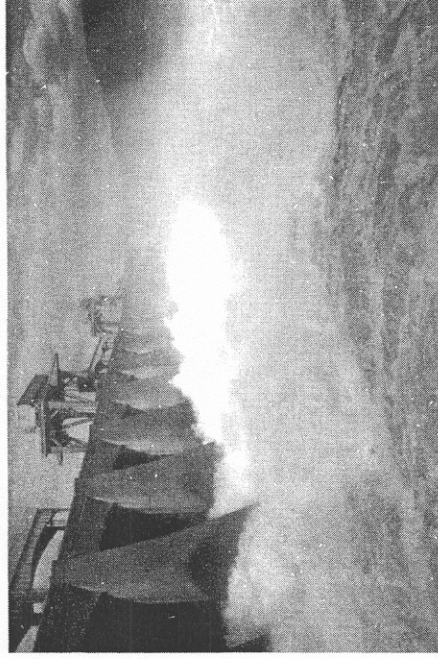


Figure 1.11 Bonneville Dam, on the Columbia River in Oregon, is an example of a large hydroelectric structure. It was completed in 1937 and produces 6 million megawatt-hours of electricity, enough for more than 500,000 homes. The dam may also contribute to declines in the salmon fishery. Courtesy of the U.S. Army Corps of Engineers.

sidered for removal in the near future are small, run-of-river structures, which generally produce little or no electricity. Third, medium-sized hydropower dams considered for removal are likely to be removed regardless of the electricity market, because of other factors driving the removal process. Condit Dam on the White Salmon River of Washington State, for example, has a reservoir that is filled largely with sediment, which reduces the effectiveness of the structure for power production.

NAVIGATION

Navigation on the nation's inland rivers depends on lock and dam systems that maintain pools of water deep enough to accommodate boat and barge traffic. About 25,000 miles of the nation's streams support transportation of goods, with their water levels regulated by dams. Small dams raise water elevations, with boat and barge passage to and from various sections provided by locks adjacent to the dams. In upper reaches of watersheds, large storage dams impound reservoirs that release water to sustain the downstream pools. Direct operating revenues of the system are

more than \$3 billion per year, accounting for the annual transport of 622 million tons of cargo (U.S. Department of Transportation, 2001). Although numerous industries depend on this transportation system, bulk cargos of grain, coal, and oil are most common.

REASONS FOR DAM REMOVALS

Just as Americans have been builders of dams, they have also torn some of them down. Some owners expected that the structures would not be permanent, and when the original purpose was served, they removed the dams. Dams built to serve sawmills in remote forests, for example, diverted stream flow to power the saws, and after the lumber was harvested, the mills and their dams disappeared from the landscape. The demise of many eighteenth-century gristmills in New England resulted in the removal of their diversion works; similarly, the waterworks associated with nineteenth-century mountain mining areas in the West also have disappeared. The removal of dams for purposes of restoring and maintaining some measure of environmental quality is a more recent phenomenon, but there is much national experience with the basic concept of dam removal.

Dam removal is one option for dealing with the effects of dams that are detrimental to environmental quality. However, progress has been made in the past two decades towards mitigating the undesirable physical and biological effects of dams while preserving the functional objectives (when still viable) of a dam and its impoundment. Most of these advances have resulted from actions related to the Federal Energy Regulatory Commission's licensing of privately owned hydropower projects and environmental assessments for federal projects done in response to NEPA requirements. FERC licensing procedures and NEPA environmental impact assessments embody some of the collaborative processes recommended in this report for evaluating dam removal (EPRI, 2000a; NHA, 1999; EPRI, 1996).

Advances to protect physical and biological processes have been made in the following areas:

- Fish passage (upstream and downstream) (Odeh, 1999 and 2000; EPRI, 1998; Clay, 1995; USDOE, 1994 and 1991; AFS, 1993; Mattice, 1991; AFS, 1985)

- Fish entrainment protection (EPRI, 2001; Coutant, 2001; Odeh, 2000 and 1999; EPRI, 1998; FERC, 1995; AFS, 1993)
- Instream flow protection (EPRI, 2001b; USDOE, 1991; AFS, 1985)
- Water quality protection (EPRI, 2002; USDOE, 1991; Mattice, 1991)
- Sediment management (EPRI, 2000c; White, 2001)
- Riparian area protection and management (EPA, 2001)

More information on mitigation measures at specific hydropower projects can be obtained from the FERC Library in Washington, D.C., or from the FERC Records and Information Management System (RIMS). RIMS can also be accessed via the World Wide Web at <http://rimsweb1.ferc.fed.uc/rims.q?rp2-intro>. This body of information is particularly important to owners, operators, and other stakeholders involved in dam removal decisions when alternatives to removal are preferred. In some cases, however, owners determine that dam removal is an appropriate option, and just as it is true that there were definable reasons for installing the dam, so there are definable reasons for removing it.

STRUCTURAL OBSOLESCENCE

A major expense associated with maintaining aging dams is the cost of structural repair required in the course of normal dam operations. Many dams have a useful life expectancy of about 50 years (River Alliance of Wisconsin and Trout Unlimited, 2000). This life expectancy typically is used in economic analyses related to dams. Maintenance and upgrading may extend this life span, and poor maintenance or abandonment may reduce it. Theoretically, dams could last forever if properly maintained. Of the entire formal list of dams maintained by the USACE, more than 22,000 (30 percent) are already more than 50 years old, and by 2020 more than 60,000 (80 percent) will be more than 50 years old (Federal Emergency Management Agency and U.S. Army Corps of Engineers, 1996). Because of concerns that "thousands of U.S. dams built in the 1930s and 1940s are nearing the end of their design life," the American Society of Civil Engineers developed a set of guidelines and principles for the retirement of dams, including their removal (Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities, 1997). The resulting guidance document contains descriptions of techniques, methods, and procedures for dam removal and includes numerous case studies.

Many dams require substantial overhaul after several decades of continuous operation. Run-of-river structures have water continually pouring over their crests, and erosion of exposed parts is inevitable. All dams leak to some degree, and the water passing through them often leaches calcium carbonate from the cement and mortar, resulting in reduced cohesion and disintegration. Erosion of the riverbed below some dams results in a gradual undermining of the structure; in some cases, weakened abutments and anchors require refurbishing. Without proper maintenance, structural deterioration can lead to a dam's collapse (Figure 1.12). Dams that were installed 50 or 100 years ago may require substantial investments to return them to safe, modern operating condition. In many cases, if the owner is an individual or small business, removal is the only reasonable, economical alternative. In other cases, the dam is abandoned or orphaned.

SAFETY AND SECURITY CONSIDERATIONS

Dam safety and security is a major issue in the consideration of dam removal. The legislation that established the National Dam Safety Pro-

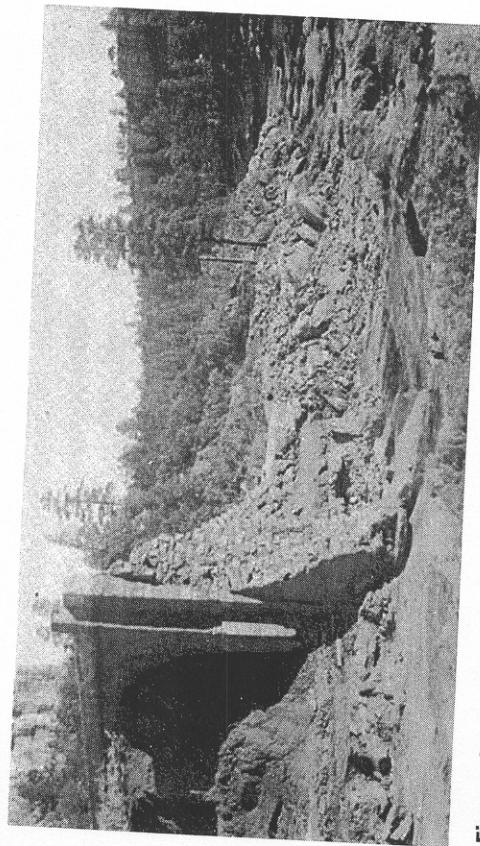


Figure 1.12 The 1933 collapse of Castlewood Dam on Cherry Creek in Colorado is an example of the result of unsafe dam construction and maintenance. Courtesy of the Denver Public Library, Western History Collection; photograph by Harry Rhoads.

gram and increased public concern about dam safety dictates due care by every dam owner in the country to ensure each dam's safe operation. Dam failures inundate downstream areas with unexpected floods and disastrous results. Historical dam failures in the United States include South Fork Dam upstream from Johnstown, Pennsylvania. The dam collapsed during an 1889 storm, and the ensuing flood killed 2,209 people (McCullough, 1968). The infamous Saint Francis Dam on the Santa Clara River of Southern California killed 525 people because of its collapse in 1928 (Garrison, 1973). In the 1970s, four dam collapses (Buffalo Creek, West Virginia; Canyon Lake, South Dakota; Teton, Idaho; and Kelly Barnes, Georgia) took 300 lives and initiated modern dam safety efforts.

Since 1980, the loss of life from dam failures has declined. However, environmental changes resulting from dam breaches continue to cause problems. In the southeastern states, hurricanes in the 1990s triggered river flooding that breached small waste retention dams and spread animal waste, primarily from hog farms, throughout downstream areas (Schwab, 2000). Breaching of mining tailings ponds during floods is also a problem that plagues some western states.

The downstream hazard posed by a dam depends on the physical condition of the dam, downstream river channel geomorphology, and distribution of the human population downstream. Dams in structural disrepair and populations living or working in flood-prone locations increase the hazard. Engineers have concluded that more than 13,000 dams in the NID pose significant hazards (a risk of property damage if the dam fails), and 10,700 are high hazard risks (with the potential for loss of life if the dam fails). Taken together, these dams constitute about 32 percent of all the dams in the inventory. In some cases, the owner of a dam in one of these risk categories may find it easier to simply remove the structure than to mitigate the risks from its continuing operation (Figure 1.13).

ECONOMIC OBSOLESCENCE

Most dams that have been removed from U.S. rivers have outlived their economic usefulness. In many cases, the reasons for their initial construction no longer apply. Many of the dams that diverted eastern streams for millraces or raised river levels to drive waterwheels lasted longer than the mills they served. In other cases, early hydroelectric facilities became antiquated with the development of regional power grids fed by larger, more

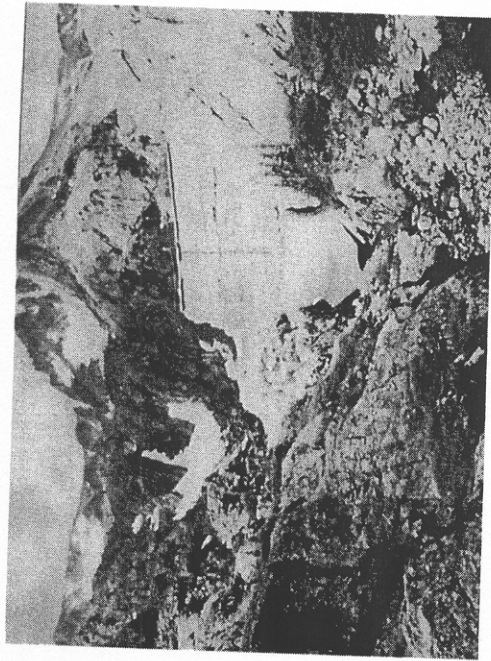


Figure 1.13 The 56-foot-high Bluebird Dam, located in Rocky Mountain National Park, Colorado, was removed in the summers of 1989 and 1990 after the collapse of a nearby dam killed three people and raised safety issues. Courtesy of Rocky Mountain National Park.

efficient sources of electrical energy. Even if the dam in question no longer produces income, expenses continue to accrue, including maintenance and insurance costs. The removal costs for small, run-of-river structures in the upper Midwest typically run about \$100,000 or less.* This may be much less expensive than retooling a dam for a new purpose or performing needed structural repairs.

Dam owners may choose to remove a dam to eliminate their own potential liability. Small, run-of-river structures in humid regions of the country have river flow continually pouring over their crests, creating a hydraulic jump. The resulting turbulence and reverse eddies that sometimes result can be deadly traps for boaters and canoeists. People fishing from dams and related structures risk serious injury or drowning. The liability of the dam owner in such a case of injury or death is unclear, but some owners prefer to avoid the risk by removing the structure. In the upper Midwest, owners of small dams report insurance premiums of several thousand dollars per year, an expense that is eliminated

* This figure is based on reports by state officials at a December 2000 short course on dam removal at the University of Wisconsin.

by removal of the structure. The threat of liability for injuries or property damage following a dam collapse gives dam owners an economic incentive to repair or remove unsafe dams, and removal may be cheaper than repair.

In the wake of the terrorist attacks of September 11, 2001, FEMA expressed an increasing awareness of the vulnerability of dams to security threats. This event may provide new incentives for either more attention to the security of dams or renewed interest in their removal.

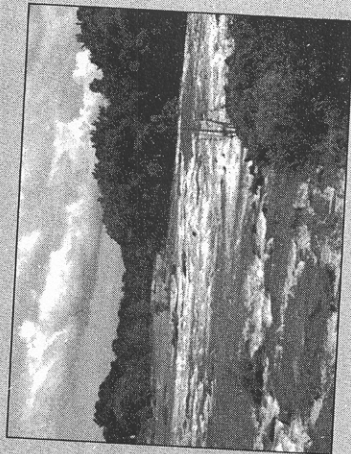
RECREATIONAL OPPORTUNITIES

Dams and their reservoirs make flat-water recreation possible; dam removal, although it eliminates reservoirs, often changes and sometimes improves recreational opportunities downstream. White-water boating in canyon rivers is enhanced by more natural river flows. Some dams operated as hydropower facilities create rapidly changing conditions for rafters as dam operators produce peak flows (Box 1.1). In flatland streams, canoeists and boaters seek continuous uninterrupted lengths of river, and campers and others enjoy stable streamside areas with natural forests. Sport fishing, especially for trout in eastern and midwestern streams, benefits from rivers without subdivision by dams. Such fishing also is enhanced by the wide variety of habitats that results from unregulated rivers and their flows. However, dams have supported trout fisheries that would not exist without the coldwater releases from reservoirs. In addition, reservoirs have provided habitat for largemouth bass, a fish prized by anglers.

WATER QUALITY AND QUANTITY ISSUES

Dam removal affects water quality and quantity because many reservoirs created by dams provide drinking water for human consumption. Given the importance of clean drinking water, the impact of dam removal needs to be considered carefully. A reservoir used for drinking water may be the pristine source of water for the region. If the dam is removed from such a reservoir, the nearby population may have to turn to groundwater supplies, which may be more contaminated and more expensive to obtain. On the other hand, the removal of a dam may improve water quality in at least two

Box 1.1 Long-Term, Unforeseen Outcomes of Dam Removal: Saluda River, South Carolina



Mill Race Rapids in 2001

Courtesy of William Graf

The need for extensive consideration of a variety of perspectives when considering a dam removal is illustrated by the experience on the lower Saluda River in South Carolina. A milldam was removed several decades ago using explosives. The remaining jagged bedrock, fractured by the removal process, contributes to the formation of rapids at the former dam site (Holleman, 2001). The rapids are situated on a ledge of metamorphic rock, and pieces of the former dam become exposed at the surface of the stream at low water levels. Uses of the river reach known as Mill Race Rapids include canoeing and kayaking, and the former dam site is a favored location for fishing, wading, and swimming.

Mill Race Rapids is about 9 miles downstream from Murray Lake Dam, a medium-sized structure that produces hydroelectricity. The Dam causes rapid fluctuations in discharge, and people often are stranded on the rocks by rapidly rising water levels. In 2001, a swimmer trying to rescue a stranded wader drowned after he was wedged into the rocks and submerged by rapidly rising waters. Kayakers describe the rapids as simply "dangerous all the time" (Holleman, 2001). The owners of Murray Lake Dam have installed warning lights and sirens to alert recreational users to impending rises in discharge, and the South Carolina Department of Natural Resources patrols the river. Despite these efforts, four people have died in the rapids of the lower river in the last seven years.

The experience of Mill Race Rapids provides a general lesson for decision makers in other dam removal cases. When the milldam was removed, the prospect of such problems was not publicly discussed. Given the pressure on river resources from recreational users, present-day plans for any dam removal need to account for use of the site by a variety of people long after the dam has disappeared.

important ways: by increasing the amount of dissolved oxygen and by returning water temperature to natural conditions. Water quality considerations in dam removal decisions are important from a regulatory standpoint because the stream that results from a dam removal is subject to evaluation against standards imposed by the Clean Water Act. Dam removal also may release accumulated sediment. This sediment, whether toxic or not, can reduce the quality of downstream water for human consumption, but may also restore stream habitat through deposition. However, this effect is usually temporary but can raise water supply treatment costs.

Dam removal also may affect groundwater supplies. For example, in central Vermont, FERC decided not to order dam removal in a voluntary surrender of a license. Instead, the commission allowed a local village to buy the dam. The village depended on this reservoir to maintain a high water table and previously had experienced a water shortage when another dam on the same river was removed (Pyle, 1995).

ECOSYSTEM RESTORATION

When a dam is removed, the river course once inundated by reservoir waters is restored. In addition, river reaches downstream from the removed dam also may be restored to a more natural condition. In their natural conditions, rivers are highly integrated ecological systems. Dams fragment the networks into isolated bits and pieces that are biologically and physically separated from each other. The principal removal efforts to date involve dams that fragment streams and block salmon spawning runs. Several Pacific Northwest dams are candidates for removal for this reason. This region is famous for severely depleted salmon runs and large hydroelectric projects that may be contributing to the declines. Even resident or native river fish often have wide annual ranges when not blocked by dams. Aquatic organisms often are prevented from reaching their original natural range in regulated and dammed rivers, so dam removal is an obvious method of reconnecting the system. The state of Wisconsin, for example, is removing four dams on the Baraboo River with the intention of restoring the connected system that once existed there (Figure 1.14), and many removals of small dams on Atlantic Seaboard streams seek to reestablish access to spawning areas for anadromous fishes.

The objectives of a dam removal need to be articulated before initiation of the project. To many, the recovery of a river implies that the



Figure 1.14 Waterworks Dam on the Baraboo River in Wisconsin was removed during the winter of 1997–1998. Courtesy of the River Alliance of Wisconsin.

physical and biological components will return to the same level that existed before the building of the dam. Rarely is this possible, because of the other impacts and changes that have taken place in the watershed. Rehabilitation implies that the physical and biological processes that define the river are returned to a functional level. This level is determined by the input from the upstream river, localized inputs, and location of the rehabilitated reach in reference to the rest of the watershed. The actions taken to achieve rehabilitation, and perhaps eventual recovery, of a rivers' ecosystem are known as restoration activities.

Similarly, many assume that the post-removal recovery of rivers and the species they support will be self-sustaining and not require additional actions by people. This may not be the case. Watersheds are dynamic and continuously respond to impacts and changes. The placement of a dam in a river fragments not only the river, but also the watershed. The removal of a dam will not automatically result in the full recovery of the river or the species that it once supported. It is essential to evaluate each dam removal in the context of other community issues and the location of the dam within the watershed.

Ecosystem restoration may be the most controversial rationale for dam removal. Many people view reservoirs as normal and natural components of the ecosystem and worry that any change back to the original natural river ecosystem will destroy existing wildlife and fish habitats. Many people prefer reservoirs to rivers, enjoy power boating more than

white-water rafting, and would rather fish for bass and catfish than salmon and trout. Such a bias in favor of existing, anthropogenic environments, combined with common personal recreational preferences, are conflicts that are often difficult to resolve. The importance of restoration to the public is subject to changing value systems. Fifty years ago, when many river dams were under construction, the restoration of aquatic ecosystems was virtually unheard of; now it is a national policy articulated by the preamble of the Clean Water Act.

DAMS REMOVED IN THE UNITED STATES

NUMBER OF DAMS REMOVED

Data on dams that have been removed are difficult to obtain. Many removal projects left little evidence of the former structure on the landscape, and even less documentation. Scientific evaluations of these removals are almost nonexistent. Research has been limited because the scientific community only recently has recognized such work as interesting from a scientific as well as policy standpoint. Additionally, funding for such research has not been readily available. The most extensive recent effort to collate information about dam removals was carried out by non-governmental organizations (American Rivers et al., 1999). Their accounting identified 467 structures that had been removed; the total continues to rise as more examples are identified. In another project, the National Performance of Dams Program at Stanford University is compiling a database on removed dams. In December 2000, officials of the Wisconsin Department of Natural Resources informed participants in a university short course that 50 dams had been confirmed as removed in that state. Further research has turned up data on 120 more, and Wisconsin officials suspect that as many as 500 dams have been removed in the state. Similar undercounting is likely throughout the nation.

The physical removal of dams can be undertaken using a variety of methods. Mechanical dismantling of the structure and physical removal of the debris usually begins with a breach to drain water stored behind the dam. For small, run-of-river structures, demolition of the remaining structure then can proceed while dealing with relatively shallow water conditions. For larger dams with significant storage, a systematic process of creating increasingly large notches in the structure

results in a gradual drawdown of stored water. Although different rates of notching, drawdown, and removal are likely to be reflected by different responses in downstream sediment dynamics, little is known about these issues. Experimental drawdowns can provide information about the redistribution of sediments and channel changes in the newly exposed reservoir areas upstream from the dam and associated changes downstream.

SIZES OF DAMS REMOVED

Almost all of the dams removed thus far have been small ones, with storage capacities less than 100 acre-feet, along with a few medium-sized structures with storage capacity measured in thousands of acre-feet. Many of the structures removed were less than 30 feet high, but there have been exceptions. Sweasey Dam, removed from the Mad River in Northern California, was 55 feet high; Mississippi River Lock and Dam Number 26 was 98 feet high; and several industrial dams removed from Tennessee streams were more than 100 feet high. Size is not necessarily an indicator of the impact of removal, however, because the removal of small dams, especially low-head, run-of-river dams, can have substantial environmental benefits in opening fish passage and restoring ecosystem function to extensive river networks. Although Quaker Neck Dam on the Neuse River of North Carolina was only 7 feet high, its removal in 1998 opened more than 1,000 miles of river habitats to anadromous fish.

TYPES OF DAMS REMOVED

Although there has been no strict accounting of the types of dams removed, a review of available evidence and discussions with state dam officials in many areas show that the majority of structures removed from American streams have been low head, run-of-river dams with crib or rock fill structures, sometimes with coverings of concrete. A few larger, concrete arch structures are being considered for removal, such as Matilija Dam on Matilija Creek in Southern California (Box 1.2). This structure is 163 feet high and 620 feet long and impounds 1,800 acre-feet of water.

Box 1.2 Removing Matilija Dam

Fifty-year-old Matilija Dam, located on a tributary of the Ventura River in Southern California, in the next few years may become the largest dam ever removed in the United States. Many local, state, federal, and private organizations are working together to complete various studies and find the financial support needed to remove the obsolete structure.

Several federal agencies have conducted or are studying various aspects of the dam's possible removal. The U.S. Bureau of Reclamation and U.S. Army Corps of Engineers, for instance, are studying the cost and feasibility of removing the dam. The U.S. Geological Survey is studying the impact the removal might have on sensitive species. Since June 1999, Ventura County officials have agreed to support Matilija's removal, and in 2000, they removed a chunk of concrete that was 8 feet high and 30 feet long during a dam demolition demonstration project (Matilija Coalition, 2000). Nonprofit environmental organizations also actively support the removal. Proponents of removing the Matilija Dam include: The American Fisheries Society, American Rivers, California Trout, Environmental Coalition of Ventura County, Environmental Defense Center, Friends of the River, Friends of the Ventura River, Patagonia Inc., Trout Unlimited, and the Ventura County Chapter of the Surfrider Foundation. These groups advocate removing the dam to restore the habitat of the endangered southern steelhead and to allow the river's flow to replenish the sand and sediment of southern California's beaches (Environmental Defense Center, 2000). In 2000, the Matilija Coalition was founded to increase public awareness and secure the funding and congressional support necessary to ensure that Matilija Dam will be removed. Prominent individuals, such as Ed Henke, a former San Francisco sports figure who grew up along the Ventura River in the 1930s and 1940s, are also particularly outspoken proponents of the removal.

OWNERSHIP OF DAMS REMOVED

Almost all the dams removed in recent decades have been privately owned. In some cases, such as Edwards Dam on the Kennebec River in Maine, the original owner reached an agreement with other legal entities, and the public assumed ownership for the express purpose of dam removal. This series of events also has taken place on occasion in Wisconsin, where it is easier administratively for the state to assume ownership of

the structures to be removed. In a considerable number of cases, dams that are targeted for removal by state game and fish departments as habitat restoration efforts do not have any known owner. These orphan dams truly become wards of the state, which then has to orchestrate their removal. In a similar example, Elwha and Glines Canyon dams on the Elwha River in the state of Washington started out as privately owned hydropower dams but now are owned by the federal government, and Congress has authorized their removal.

DISTRIBUTION OF REMOVALS

A geographical assessment of documented dam removals (Figure 1.15) as published by American Rivers et al. (1999) reveals a national pattern that is very different from the pattern of dam building (see Figure 1.8, p. 32). The states with the most dam removals are Pennsylvania, Ohio,

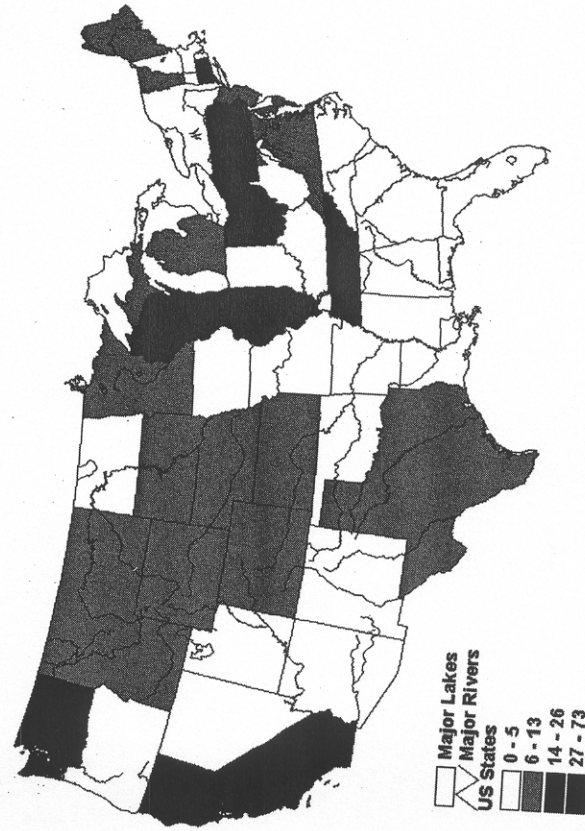


Figure 1.15 The map shows the distribution of dams removed in the United States, with the darker colors indicating the states where most removals occurred. Sources: Data courtesy of American Rivers et al. (1999); map designed by Graf (2001).

Wisconsin, and California. These are all states with some governmental commitment to providing administrative support for the activity.

Pennsylvania has an interest in reconnecting the Susquehanna River system, which drains into Chesapeake Bay. Because the state is part of a regional compact to enhance the bay's environmental quality, dam removal fits within a more general state policy goal. The criticality of connected river segments for the health of the bay provides an environmental incentive.

Wisconsin has a long history of fostering sport fishing, and in many cases the removal of antiquated crib and earth or rock fill dams that are small, run-of-river structures advances the state's general interest in improving aquatic habitat and supporting recreational fishing. Wisconsin also has paid considerable attention to reconstructing channels in previously inundated reservoir areas. California has environmental policies that stimulate the dam removal process. Some reservoirs are filled with sediment, so that the original purposes of the dams no longer can be served. In any case, the national distribution of dam removals is largely a function of local forces at work, combined with individual dam owners seeking to remove structures that they no longer want.

STATUS OF SCIENTIFIC RESEARCH ON DAM REMOVALS

Scientific research into the effects of dam removal is in its initial stages, and elaborate theories on the subject are not yet developed. Although investigations into the effects of dam installation have been ongoing for more than two decades, they are few in number and, as of late 2001, incomplete. In many cases, investigations of dam removal have not been reported in the refereed scientific literature. Examples include an evaluation of the possible removal of Searsville Dam in San Mateo County, California, being carried out by David Freyberg of Stanford University (Box 1.3). Matt Kondolf of the University of California at Berkeley is assessing the possible effects of removing Matilija Dam near Ventura, California. Employees of several federal agencies, including Brian Winter of the National Park Service and Tim Randle of the Bureau of Reclamation, are considering the outcomes of removing Elwha and Glines Canyon dams on the Elwha River in Washington State. Pat Shafroth and his associates in the Biological Resources Division of the U.S. Geological Survey (USGS) are involved in extensive investigations into the effects of dam

Box 1.3 Ongoing Management Studies and Research Projects: Searsville Dam and Lake Jasper Ridge Biological Preserve in California

Investigations at Searsville Dam near Menlo Park, California, illustrate the range of research initiated at the prospect of a dam removal decision. Searsville Dam was constructed in 1892 on San Francisco Creek to provide water for various purposes during the dry months (Softky, 2000). The dam, constructed of interlocking concrete blocks, is 68 feet high. The dam is a source of concern to Stanford University, which has owned the dam since 1919, and the nearby community because of its negative environmental effects on the watershed. Problems include a buildup of sediment in the reservoir, upstream flooding, presence of exotic species, and impaired migration for endangered steelhead trout.

Searsville Dam and the associated lake are the focus of a number of ongoing management studies and research projects. The management issues facing the university as it makes decisions about the operation of the reservoir and fate of the dam motivate some projects. Others are driven by scientific research questions but are also relevant to the current management challenges.

Because Searsville Dam and the lake are located on Stanford's Jasper Ridge Biological Preserve, a number of ongoing studies are investigating various aspects of ecosystem structure and health in environments affected by the lake. For example, Alan Launer of Stanford's Center for Conservation Biology is leading studies of the bullfrog population (an invasive exotic) around the lake and the aquatic ecology of San Francisco Creek below Searsville Dam. Philippe Cohen and David Freyberg recently completed a study examining the opportunities for maintaining some open water habitat at Searsville Lake under various possible dam management scenarios—

removal on riparian forests of the Great Plains. Emily Stanley of the University of Wisconsin and her associates are emphasizing the ecological ramifications of removal of low-head structures in Wisconsin. Randy Parker of the USGS is conducting physical experiments with dam removal scenarios using flumes in a laboratory setting. Formal publications on these efforts are not yet available.

Perhaps the most extensive investigation of the effects of dam removal is being undertaken by Karen Bushaw-Newton at the Patrick Center for Environmental Research of the Academy of Natural Sciences in Philadelphia (Box 1.4). The research is focused on the removal of a

Box 1.3 continued

dam lowering, dam removal, and no alterations to the dam. Several additional research projects are likely to begin in the near future in connection with the assessment of alternatives.

In addition, the university, through consultants, has completed several management studies focused on both short- and long-term decision-making. Several studies have examined alternative ways to minimize flooding in the Family Farm Road area caused by sediment aggradations at the delta of Corte Madera and Sausal creeks. The university has implemented some engineering measures (i.e., channel improvements and hardening, culvert replacement, berm construction), and has developed an ongoing channel maintenance program based on these studies. Another recently completed study examined the seismic safety of the dam. An important study nearing completion examines the consequences of increased sediment delivery below Searsville Dam on downstream habitat and flood risk.

Broader-scale research in the entire watershed is being conducted under a coordinated resources management plan (CRMP), as well as a joint powers authority (JPA). The CRMP (involving more than 30 stakeholder groups, including local and state governmental agencies, major landowners, and local and regional community organizations) has completed a biological resources inventory for the riparian corridor that has been incorporated into a geographical information system. The JPA (members include the Santa Clara Valley Water District, San Mateo County Flood Control District, and cities of Palo Alto, Menlo Park, and East Palo Alto) is seeking federal funding for a U.S. Army Corps of Engineers reconnaissance study for a federally funded flood control project.

For more information, contact David Freyberg, associate professor, Department of Civil and Environmental Engineering, Stanford University, at freyberg@cive.stanford.edu.

small, run-of-the-river dam across Manatawny Creek, a tributary of the Schuylkill River whose waters eventually flow into Delaware Bay, in southeastern Pennsylvania. This multidisciplinary effort is scheduled for completion in 2002.

Although there are few refereed journal articles on the effects of dam removal, some of the scientific investigations and results are beginning to be reported in oral presentations at scientific meetings. These preliminary reports provide an indication of the likely sorts of information and ideas that will emerge from the ongoing research. In the roughly two years prior to the publication of the present report in early 2002, a variety

Box 1.4 An Ecological Approach to Small Dam Removal: The Manatawny Creek Study

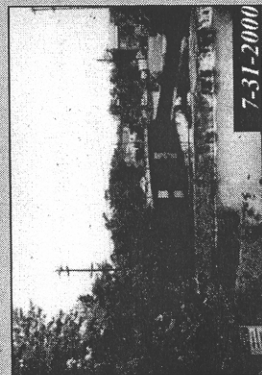
In late 1999, the Patrick Center for Environmental Research and University of Delaware, in collaboration with the Greater Pottstown Watershed Alliance (GPWA) and Delaware Riverkeeper Network (DRN), began an integrative study of the effects of dam removal on lower Manatawny Creek in Pennsylvania. A low-head, run-of-river dam was removed from Manatawny Creek in a two-stage process, with the first half of the dam removed in August 2000 and the remainder removed in November 2000. The orphan dam was removed because the local watershed organization, GPWA, and DRN were concerned about the integrity of the Manatawny Creek system and raised the funds to pay for the removal. Funds for the ongoing scientific and restoration studies have been provided through grants from the Pennsylvania Department of Environmental Protection.

At sites upstream and downstream from the dam, scientists have been monitoring several physical, chemical, and biological components of the stream system to document the spatial and temporal changes associated with the removal. These components include geomorphology, sediment and water chemistry, algae, macro invertebrates, freshwater mussels, fish, and riparian vegetation. In conjunction with the removal, the DRN has begun restoring the riparian corridor in the former impoundment. This project represents one of the first comprehensive studies attempting to document the large-scale physical, chemical, and biological changes in a river system following dam

removal. In August 1999, the American Fisheries Society hosted a special session on dam removal at its annual conference in Charlotte, North Carolina. The Geological Society of America hosted a special panel discussion at its national meetings in October 2000, at which participants tried to sort out the contributions of earth science to decision making regarding dam removal. In February 2001, the Association of American Geographers presented two sessions of papers and reports by researchers involved in dam removals. The topics emphasized the building of conceptual frameworks for the science. In August 2001, the Ecological Society of America hosted a special session on dam removal, which, like the sessions offered by the other organizations, extended the discussion beyond science to legal and policy dimensions. In June 2001, the North American Benthological Society hosted three special sessions on dam

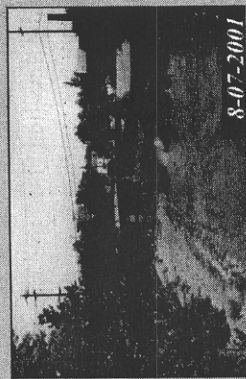
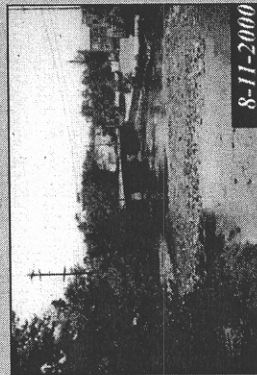
Box 1.4 continued

The results of this study will provide information to both scientific and management communities on the effectiveness of dam removal in the restoration of riverine ecosystems.



Visual documentation of the effects of dam removal on the Manatawny Creek system before, immediately following, and one year after removal.

Courtesy of the Patrick Center for Environmental Research



For more information on this project, see <http://www.acnatsci.org/research/pcer/manatawny/>.

removal that included wide-ranging assessments of the ecological results of removals.

Despite the early stage of development of the science of dam removal, structures *are* being removed, and short courses are beginning to appear to provide advice for decision makers, engineers, and scientists involved in the process. Exemplified by an annual course offered at the University of Wisconsin, Madison, these short courses show that the engineering community, in particular, is beginning to build a level of experience with the process of dam removal, and that there is considerable experience with the decision-making and political processes of removal.

An unfortunate disconnection occurs between the research pursued by the academic community and the research needed by decision makers. The majority of published research on the downstream impacts of dams, research that is likely to be informative about the potential out-

comes of dam removals, focuses on the effects of large and very large dams. The effects of these dams are more easily seen, more obvious, and more easily mapped or measured than is the case with smaller dams. For example, after the expenditure of about \$100 million by the federal government, more scientific literature, data, and understanding exists for the Colorado River downstream from Glen Canyon Dam than for any other location. However, at present and for the near future, decision makers are most concerned with small and (to a lesser degree) medium-sized structures. There is much less research available on the effects of these dams on physical and biological components of ecosystems. As a result, decisions must be made with relatively little scientific support. As shown by the preceding review of ongoing research on the outcomes of dam removal, the disconnection between scientific research supply and demand has begun to be rectified, but the gap between available and needed theory and knowledge is still substantial.

Another disconnection is apparent within the research base itself. High-quality research began to appear in 2001 and 2002 addressing questions about the effects of dam removal, but many projects are moving forward in isolation from similar work elsewhere. The questions and approaches that are most important to geologists may be very different from the questions and approaches significant to ecologists, whereas the issues faced by planners, legal experts, property owners, and dam owners call for answers to still other challenges.

The most pressing need is for much-improved integration of scientific efforts. Although groups of scientists from each discipline are beginning to present their work to colleagues working in the same discipline, there is little evidence of a truly broad-gauged, multi-science dialogue, despite the fact that the study of effects of dam removal is highly integrative. Decision makers in the public arena need to deal with the entirety of the effects of dam removal to reasonably assess a variety of trade-offs. Unless the various sciences are able to work across intellectual boundaries, their contributions to decision making will be diminished.

CONCLUSIONS AND RECOMMENDATIONS

Dams are a ubiquitous feature of the American landscape and waterscape, and they form an integral part of the nation's economic infrastructure. The building of many of these structures has produced significant eco-

nomic benefits, but the effort also has imposed environmental, economic, and social costs that are now becoming clear. The majority of structures are small, storing less than 100 ac ft of water, and most small dams in the nation are owned by private concerns or local entities. An unknown number of dams have been removed, but the total is probably at least 1,000. The removal of these structures, mostly small, run-of-river dams, typically has been the result of decisions by individual owners seeking a variety of largely economic benefits, although the environmental reasons for dam removal are numerous and often supported by local or state governments.

- **Conclusion:** Science to support decisions about dam removal is progressing, but there is little cross-disciplinary communication, and research priorities have not been established to guide researchers or funding efforts.
- **Recommendation:** The panel recommends that federal agencies and other organizations consider sponsoring a conference for researchers who are focusing on the scientific aspects of dam removal with the specific objectives of improving communication across disciplinary boundaries, identifying gaps in knowledge, and prioritizing research needs. The conference should not be a forum for debating whether dams should be removed, because other venues are available for bringing stakeholders together. The conference should focus on science and the state of knowledge available for decisionmakers, identify gaps, and assign priorities.
- **Conclusion:** Dam removal is a site-specific process, largely dependent on the owner and often in collaboration with local stakeholders and state and local government. These decision makers need more information and a framework for effective decision making. Data about dams that have been removed can be useful for decision makers considering the fate of existing structures, yet there is no centralized mechanism for collecting, archiving, and making available such information on a continually updated basis.
- **Recommendation:** When dams are removed, their entries in the National Inventory of Dams are deleted and the National Performance of Dam Program retains information about them. The panel recommends that federal agencies improve the availability of information about dam removal by making this database widely known and available to the public.

2

THE FEDERAL LEGAL CONTEXT AFFECTING DAM REMOVALS

FEDERAL, STATE, AND LOCAL laws and regulations at every step of the decision-making process influence dam removal decisions. In some instances, a law or regulation may stimulate the debate in the first place, such as when a dam removal is required to restore upstream habitat for a species of fish listed under the federal Endangered Species Act (ESA). The possible involvement of a wide range of laws and regulations needs to be considered when the decision to remove a dam is being made, as well as during the actual removal. For instance, the federal Clean Water Act (CWA) may apply if the dam's removal and release of sediment from the former impoundment would change pollutant-loading levels or affect temperatures downstream. This chapter focuses on the federal policy context of dam removal; it is outside the scope of this report to examine the context in all the states, which differ greatly in terms of the details of their laws, policies, and programs that may affect dam removal. In general, the removal of federally owned dams is governed by federal agencies and subject to the availability of appropriated funds. In contrast, the removal of privately owned dams are governed primarily by state and local rules, although many federal laws and regulations still could be relevant. State governments empower local governments to engage in land- and water-use planning, zoning, and taxation, and most states delegate authority to local governments to regulate subdivisions and provide local public infrastructure. Dam owners and others who may be evaluating possible dam removal need to seek guidance from their local jurisdiction and the state agency with jurisdiction.

There is no comprehensive, consistent national policy on the removal of dams, nor are there specific federal regulations or policies gov-

erning dam removal. However, the federal government plays various roles in the context of a dam removal. Many federal agencies can exercise jurisdiction in such a decision, including the Federal Energy Regulatory Commission (FERC), U.S. Department of the Interior, U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), and U.S. Department of Agriculture (USDA). In addition, numerous federal statutes and programs are relevant to the construction, alteration, and operation of dams and could be relevant to dam removal. The most important of these are the CWA, ESA, and National Environmental Policy Act (NEPA), all mentioned in the previous chapter; as well as the Federal Power Act of 1920 (P.L. 16 USC 791a), Electric Consumers Protection Act (ECPA) of 1986 (P.L. 99-495), National Historic Preservation Act (NHPA) of 1966 (P.L. 89-665), western water rights law, Small Watershed Rehabilitation Amendments of 2000 (P.L. 106-472), Indian Dam Safety Act of 1994 (P.L. 103-302), National Dam Safety Program, and FERC Dam Safety Program.

HYDROELECTRIC DAMS

The potential removal of any private, municipal, or state hydroelectric dams involves FERC, an independent regulatory agency that licenses and inspects hydroelectric projects. Federal hydroelectric dams, in contrast, are authorized by Congress and constructed by the U.S. Bureau of Reclamation, USACE, or Tennessee Valley Authority and subject to NEPA requirements.

An Act of Congress created FERC in 1977. At that time, FERC's predecessor, the Federal Power Commission, was abolished and FERC inherited most of the responsibilities that were first granted in the Federal Power Act of 1920.* The owners of hydroelectric dams must reapply to FERC for an operating license every 30 to 50 years. In the relicensing process, the dam owner must show that the dam operation continues to be in the public interest. Since 1986, when the Congress passed the Electric Consumers Protection Act (ECPA), FERC has been required to give the same level of consideration to nonpower values (e.g., the environment, recreation, fish and wildlife) that it gives to power and development

*The Federal Power Act can be reviewed online at <http://www.ferc.fed.us/intro/acts/fpa.htm>.

Box 2.1 The Removal of Edwards Dam on the Kennebec River in Maine

The 1999 removal of Edwards Dam in Maine marked the first time that the Federal Energy Regulatory Commission (FERC) ever ordered a dam to be removed against the wishes of its owner (American Rivers et al., 1999). In 1993, the 30-year license to operate Edwards Dam expired. The Edwards Manufacturing Company and city of Augusta, the dam's owners, applied to FERC for a new 30-year license that would allow them to continue to operate the 150-year-old hydroelectric dam. They also asked permission to increase the amount of electricity generated by the dam from 3.5 megawatts to 11 megawatts (American Rivers, 2001b). In return, the owners would install interim fish passage facilities to offset the environmental harm caused by the dam while FERC prepared its Environmental Impact Statement (EIS) as part of the relicensing process (American Rivers, 2001b). The National Environmental Policy Act requires an EIS. Since the passage of the Electric Consumers Protection Act in 1986, FERC has had to give the same level of consideration to non-power values (e.g., the environment, recreation, fish and wildlife) that it gives to power and development objectives.

In January 1996, FERC released its draft EIS recommending that the commissioners relicense the dam and require the owners to construct fish passage for seven target species. The Kennebec Coalition, a group of four nonprofit environmental groups that formed in 1993 when the original license expired, filed extensive comments with FERC, claiming that dam removal should have been chosen as the preferred alternative for both biological and economic reasons (American Rivers, 2001b). The FERC staff took a second look at the

objectives when deciding whether or not to relicense a project. The ECPA also increased opportunities for agencies, interested organizations, and the public to participate in the process and required FERC to base its recommendations for mitigating adverse effects of a licensing proposal on the recommendations of federal and state fish and wildlife agencies and to negotiate with the agencies if disagreements occur.

In 1992, the Congress further altered FERC's hydropower program under the National Energy Policy Act (P.L. 102-486). The Act prohibits licensees from using the right of eminent domain in parks, recreational areas, or wildlife refuges established under state law. It allows applicants for licenses to fund environmental impact statements—referred to as third-party contracting—and authorizes the commission to

Box 2.1 continued

issues, and when the final EIS was released in July 1997, they recommended that the commissioners deny the relicensing application and order the removal of the dam (Costenbader, 1998). The studies required by the EIS found that removing the dam would allow nine species of migratory fish access to 15 miles of historical spawning habitat and result in an overall increase in wetland habitat, recreational boating, and fishing opportunities; that installing fish passage facilities (required for the relicensing) would cost 1.7 times more than removal; and that customers paid twice as much for the dam's electricity as they would have for other sources of power (e.g., combustion turbine plants or natural gas) in the region (Federal Energy Regulatory Commission, 1997).

On November 25, 1997, the five FERC commissioners voted to deny the relicensing application and ordered Edwards Dam to be removed at the owners' expense. Subsequently, the owners filed a request with FERC for a new hearing and a stay of the order, which FERC granted (American Rivers, 2001b). The owners agreed to remove the dam but argued that they should not have to bear the full cost of removal. In May 1998, to avoid a lengthy court battle, all parties actively involved in the relicensing process signed a settlement that transferred the dam's ownership to the state of Maine. The costs of removal and fish restoration efforts were borne by upriver dam owners in exchange for a delay in their fish passage obligations, and a downriver shipbuilder in exchange for a permit to expand its shipyard operations (American Rivers et al., 1999). In 1999, Edwards Dam was removed. Currently, FERC's authority to order the removal of Edwards Dam is being debated in court because the cost of removal was not borne by the owner but rather by stakeholders who gave funds as in-kind mitigation for impacts at other water facilities in the area.

assess licensees for costs incurred by fish and wildlife agencies and other natural and cultural resource agencies for studies required under Part I of the Federal Power Act.

None of FERC's enabling legislation sets forth procedures for removing hydropower dams. In the absence of specific rules covering removal, one would expect relevant agencies to review a removal plan as they would a dam construction or modification program. FERC and other relevant agencies can be expected to develop appropriate policies as removal proposals are implemented. FERC also has the power to deny the relicensing of a hydroelectric dam, an action that could result in a dam being removed (Box 2.1). Typically, if FERC denies an application for a license renewal, another party can claim the license, and whatever prob-

lems led to the license denial may be mitigated. If no one claims the license, then the dam may be removed.

DAM SAFETY PROGRAMS

The average life expectancy of a dam is 50 years, and a full 25 percent of all U.S. dams are now more than 50 years old. By 2020, that figure will reach 80 percent (American Rivers et al., 1999). Often, safety is a factor in a decision about whether or not to remove a dam. As dams age, concern over their safety grows, and oversight and a regular inspection program are extremely important. Moreover, the issue of potential removal of these older dams is likely to become more significant in the future. Many agencies are involved: FERC, FEMA, USACE, Bureau of Reclamation, Tennessee Valley Authority, Bureau of Land Management, Fish and Wildlife Service, National Resource Conservation Service, and Bureau of Indian Affairs all administer dam safety programs at the federal level.

NATIONAL DAM SAFETY PROGRAM

Section 215 of the Water Resources Development Act (WRDA) of 1996 (P.L. 104-303) established a National Dam Safety Program under the jurisdiction of FEMA. The purpose of the program is to "reduce the risks to life and property from dam failure in the United States through the establishment and maintenance of an effective national dam safety program to bring together the expertise and resources of the federal and non-federal communities in achieving national dam safety hazard reduction" (WRDA §215[a]). The National Dam Safety Program does not specifically govern or regulate dam removal. It is relevant, however, in addressing a variety of actions that modify dams.

The law requires FEMA to establish an Interagency Committee on Dam Safety, which FEMA now chairs, and a National Dam Safety Review Board. It also requires FEMA to coordinate federal dam safety efforts in cooperation with state dam safety officials, transfer knowledge and technical information among federal and nonfederal agencies, and provide for public education in the hazards of dam failure and related matters. FEMA also is authorized to provide grants to states to establish and maintain dam safety programs and provide training for state dam

safety staff and inspectors. To the extent that safety issues encompass dam removals, FEMA addresses dam removal concerns under the National Dam Safety Program.

FERC DAM SAFETY PROGRAM

Dam safety is also an important part of FERC's hydropower program, although dam removal is not a topic on which the commission focuses its attention. In terms of number of dams inspected, the commission's dam safety program is the largest in the federal government. Of the approximately 2,600 hydroelectric dams that fall within FERC's domain, more than two-thirds are more than 50 years old.

Safety issues are present at every stage of a dam's life. Before dams are constructed, the FERC staff reviews and approves the designs, plans, and specifications of dams, powerhouses, and other structures. During construction, FERC staff engineers frequently inspect a dam. After construction is completed, FERC officials inspect the dam on a regular basis to verify the structural integrity, identify needed maintenance and remedial modifications, ensure proper maintenance, and verify that licensees comply with the terms and conditions of their licenses. Inspection visits are coordinated with resource agencies, state dam safety officials, and other interested agencies. The FERC staff also inspects dams on an unscheduled basis.

Every five years, an independent consulting engineer approved by FERC must inspect and evaluate dams higher than 32.8 feet (10 meters), or with a total storage capacity of more than 2,000 acre-feet (2.5 million cubic meters). The engineer identifies any actual or potential deficiencies that might endanger public safety and requires the dam owners to correct them.

The FERC staff also evaluates the effects of potential and actual seismic and large flood events on the safety of dams. The commission monitors and evaluates seismic research in geographical areas where there is concern over possible seismic activity. This information is applied in investigating and performing structural analyses of hydroelectric projects in these areas. During and following flood events, the staff visits dam sites; determines the extent of damage, if any; and directs any necessary studies or remedial measures that the licensee must undertake.

Lastly, FERC requires licensees to prepare emergency action plans and conducts training sessions on how to develop and test these plans.

The plans are designed to serve as an early warning system if there is a potential for, or sudden release of water from, a dam failure or accident involving the dam. The plans include operational procedures that may be used, such as reducing reservoir levels and reducing downstream flows, and procedures for notifying affected residents and agencies responsible for emergency management. These plans are updated and tested frequently.

INDIAN DAM SAFETY ACT

The Indian Dam Safety Act of 1994 established a dam safety maintenance and repair program within the Bureau of Indian Affairs to maintain identified dams on Indian land that, if they failed, would present a threat to human life. Potential dam removals on tribal lands need to be evaluated in the context of this program.

PROTECTION OF NATURAL SYSTEMS

NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 is a general statute that declares a national environmental policy and promotes the consideration of environmental concerns by federal agencies. NEPA has had a pervasive effect on the federal decision-making process and has influenced thousands of projects and activities of federal agencies as well as state and local governmental and private projects involving federal funding or other significant federal involvement.

NEPA establishes national environmental policy and goals, provides a method for accomplishing those goals, and includes guidance on the fundamental question of how NEPA relates to other federal laws. NEPA announces a commitment to use all practicable means to conduct federal activities in a way that will promote the general welfare and be in harmony with the environment. NEPA's goals are intended to assure safe, healthful, productive, and aesthetically and culturally pleasing surroundings for all generations of Americans. Because NEPA creates no new substantive rights, its importance stems almost entirely from procedural provisions designed to ensure that federal agencies consider the environmental consequences before taking an action.

NEPA requires that an environmental impact statement (EIS) be issued for certain "major Federal actions significantly affecting the quality of the human environment" (NEPA §4332[2][c]). An EIS is a lengthy document based on an exhaustive process of public hearings, interagency consultation, and environmental research and analysis, including evaluation of alternatives and selection of a preferred course of action.

Compliance with NEPA matters very much to private and non-federal government interests dependent on federal permit decisions, such as dredge-fill permits under Section 404 of the CWA. In addition, NEPA continues to be a primary basis for challenges to public or private land development decisions, most of which can be argued to have an environmental component. NEPA is important to environmentalists because it provides a statutory basis to force the review of federal decisions, regardless of whether the federal agency involved has distinct environmental responsibilities. The U.S. EPA also has a review role in NEPA under section 109 of the Clean Air Act.

NEPA created the Council on Environmental Quality (CEQ) as a part of the Executive Office of the President and defined its responsibilities. The CEQ has promulgated regulations that guide the NEPA process (*Code of Federal Regulations*, Title 40, Section 1500 et seq.). The CEQ is charged with monitoring progress toward achieving NEPA's national environmental goals and is required to assist and advise the President in the preparation of the environmental quality report. It is also the duty of the CEQ to gather environmental information and conduct studies on conditions and trends in environmental quality. In addition, the CEQ has been assigned the duty of providing guidance to other federal agencies on compliance with NEPA.

NEPA most likely will be a consideration in planning, designing, and carrying out a dam removal project, particularly if federal land is involved, federal funding is provided, or significant federal permits must be issued. Each of these factors could become a trigger establishing a "major federal action" requiring NEPA studies and reporting requirements.

For any proposal to remove a federal dam, NEPA applies, and in many cases, an EIS is required because of the significant alteration of the environment involved. When a proposed dam removal involves private or nonfederal government land and water resources, the NEPA process still could be triggered if there is sufficient federal involvement. For example, if federal funding is provided for the dam removal, or if the project cannot proceed without issuance of federal permits or other approvals, then NEPA applies.

CLEAN WATER ACT

The CWA is the principal law governing the quality of the nation's waterways. Its objective is to restore and maintain the chemical, physical and biological integrity of the nation's waterways. The Act has been amended numerous times and given a number of titles. The 1972 amendments (P.L. 92-500) gave the Act its current form.

Although there is no CWA provision or associated regulation that specifically addresses dam removal, federally approved standards and regulations promulgated under the Act could influence dam removal decisions. For example, if a dam removal changes pollutant-loading levels in rivers or streams, the U.S. Environmental Protection Agency's total maximum daily load (TMDL) requirements may apply. If temperatures change markedly, temperature standards may apply. The CWA also could become the basis for federal, state, or tribal involvement in dam removal. If dam removal, for instance, requires dredge and fill operations or destruction of wetlands in the reservoir, a permit from the USACE most likely would be required under Section 404 of the Act.

ENDANGERED SPECIES ACT

The purpose of the ESA is to protect endangered and threatened species in the United States. It establishes a policy that all federal departments and agencies must seek to conserve endangered and threatened species and use their authorities in furtherance of the purposes of the Act.*

The ESA requires all federal agencies, in consultation with, and using the assistance of, the departments of Interior or Commerce, ensure that any actions authorized, funded, or carried out by them do not jeopardize the continued existence of any endangered or threatened species, or result in the destruction or adverse modification of habitat of such species that is determined by the secretary of Interior or Commerce to be critical, unless an exception has been granted by the Endangered Species Committee (ESA §1536[a][2]).

The Act identifies prohibited actions related to endangered species and prohibits all persons, including all federal, state, and local govern-

*The text of the ESA can be found online at <http://www4.law.cornell.edu/uscode/unframed/16/ch35.html> or <http://endangered.fws.gov/whatwedo.html#General>.

ments, from "taking" listed species of fish and wildlife (ESA §1538), except as specified under the provisions for exemptions (ESA §1539). The verb "take" is defined as harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. The U.S. Supreme Court has defined "take" to include many forms of habitat modification that threaten the continued existence of species. Provisions include civil penalties, criminal violations, enforcement, and citizen lawsuits. Additional guidelines for the protection of marine mammals are established in the Marine Mammal Protection Act of 1972 (16 U.S.C. §1361 *et seq.*). Consultation procedures are administered by the Fish and Wildlife Service within the Department of the Interior, and the National Marine Fisheries Service within the Department of Commerce.

The ESA can be a catalyst for dam removal decisions. When habitat for a listed endangered or threatened species is believed by some to be jeopardized by the presence of a dam, a movement to modify or remove the dam can gather momentum. For example, listings of Snake River salmon have led to the evaluation of dam breaching alternatives for the four lower Snake River hydroelectric dams. Similarly, the listing of steelhead trout has fueled interest in the removal of Rindge Dam in California's Malibu Creek watershed; the dam is believed to interfere with steelhead spawning.

OTHER LEGISLATION AFFECTING DAM REMOVALS

NATIONAL HISTORIC PRESERVATION ACT

With the NHPA, Congress established a lead role for the federal government in promoting historical preservation and fostering conditions under which modern society and prehistoric and historical resources can exist in harmony. An underlying motivation in passage of the Act was to transform the federal government's position of indifference to historical sites into a role assuming responsibility for stewardship of historical areas for future generations. In the case of Rindge Dam, built in 1925-1926, for example, members of the Rindge family who support preservation of the dam argue that its historical significance needs to be considered in the federal decision-making process.

The NHPA requires federal agencies to assess the impact of proposed projects on historically or culturally important sites, structures, or

objects within the sites of proposed projects. It further requires federal agencies to assess all sites, buildings, and objects on a project site to determine if any qualify for inclusion in the National Register of Historic Places. The Act also establishes a procedure for archaeological activities and a system of civil and criminal penalties for unlawfully damaging or removing important artifacts.

The national register is an inventory of historical resources maintained by the National Park Service pursuant to the NHPA. The inventory includes buildings, structures, objects, sites, districts, and archeological resources. It also encompasses significant properties that have not yet been listed or formally determined to be eligible for listing.

Under the NHPA, agencies must establish preservation programs consistent with their missions and the effects of their activities on historical properties. Agencies also must consider historical properties and designate qualified federal preservation officers to coordinate their historical preservation activities.

The NHPA created the Advisory Council on Historic Preservation (ACHP), an independent federal agency, to advise the President and Congress on matters involving historical preservation. The advisory council is authorized to review and comment on all actions licensed by the federal government that will have an effect on properties listed in the national register or eligible for such listing. The Act requires that a federal agency involved in a proposed project or activity is responsible for consulting with the state historic preservation officer (an official appointed in each state or territory to administer NHPA programs) and the advisory council.

Federal actions and materials subject to historical protection consideration include, but are not limited to, construction, rehabilitation, and repair projects; demolition; licenses; permits; loans and loan guarantees; grants; and federal property transfers related to historical places. The agency sponsoring such an activity is obligated to seek comments from the advisory council.

The NHPA could be a consideration in a dam removal if the dam structures involved are found to have historical, prehistoric, or cultural importance; if valuable artifacts are found on the project site; or if the actions required to remove the dam may jeopardize historical, prehistoric, or cultural resources. Proposed federal actions involved in a dam removal that affects such artifacts must take into account the potential outcomes, and agencies must consult with the advisory council and document potential outcomes in environmental reports, such as a NEPA environ-

Box 2.2 Preserving the Tumwater Dam in Washington State

Tumwater Dam on the Wenatchee River in Washington State is a good example of a dam left in place for historical preservation reasons—even though it originally blocked salmon runs. This small dam, just 17 feet tall, produced electricity to power locomotives passing through a tunnel in the Cascade Mountains. Steam locomotion could not be used in the tunnel because of the smoke, and therefore electrical locomotives were needed. This little dam is historic for that reason; it is also located along a popular tourist highway, making a tour stop almost obligatory. After a debate over dam removal, officials decided to build a fish ladder and leave the dam in place. Now fish pass upstream, the historic structure is preserved, and tourists get a lesson in both fish and history.

mental assessment or EIS. If sites determined to be eligible for listing in the national register are to be disturbed during a proposed dam removal, then additional surveys, testing, and site characterization are likely to be required (Box 2.2).

WESTERN WATER RIGHTS LAW

In the western United States, the waters of a state are publicly owned. A state grants permission to use the water (e.g., a water right) but the holder of the right does not own the water. The water right is transferred with the property when the land is sold. A water right specifies a point of diversion, place of use, rate of withdrawal, total volume of water to be used, and season for the use. The rights to construct and remove a dam could be determined by these rights to ownership and use.

The original purpose of western water law was to resolve conflicts among users, not to protect the quantity or quality of water resources. According to the doctrine of "prior appropriation," the bedrock of western water law, the first person to take water from a stream for beneficial uses has priority over all subsequent users. The priority date determines who gets water when the quantity is restricted. Both appropriation and riparian rights have functioned to detach water from the watershed by promoting dams and diversions.

Currently, western water is over-appropriated, largely because states routinely grant water rights for more water than actually is found in a river or stream. The water is diverted for irrigation or municipal use, run through turbines, or stored in reservoirs.

In 1992, the Congress passed the Western Water Policy Review Act (P.L. 102-575).^{*} This Act authorized the U.S. Geological Survey and USACE to assist in a comprehensive review, in consultation with appropriate officials from the 19 western states, of the problems and potential solutions facing these states and the federal government in the increasing competition for the scarce water resources in the region. The Act authorized an advisory commission to

- Review present and anticipated water resource problems affecting the 19 western states
- Examine current and proposed federal programs affecting these states
- Review problems of rural communities relating to water supply, potable water treatment, and wastewater treatment
- Review the need and opportunities for additional storage or other means to augment existing water supplies, including, but not limited to, conservation
- Review the history, use, and effectiveness of various institutional arrangements to address problems of water allocation, water quality, planning, flood control and other aspects of water development and use
- Review the legal regime governing the development and use of water and the respective roles of both the federal government and the states over the allocation and use of water
- Review the activities, authorities, and responsibilities of the various federal agencies with direct water resources management responsibility

TRIBAL GOVERNMENTS AND WATER RIGHTS

Tribal governments are considered sovereign governments under the U.S. Constitution. Tribal governments expect to participate as sovereign nations

^{*} The text of this Act can be found online at <http://www.den.doi.gov/wwwpract/informat/act1.htm>.

in dam removal decisions and discussions that affect tribal resources. In addition to the constitutional status accorded tribal governments, the federal government holds a "trust responsibility" for tribes. The trust is a product of Chief Justice John Marshall's commitment to recognize the indigenous nations' and tribes' inherent sovereignty within the context of a wider national government. In three decisions, he rationalized the federal government's power and held that the purpose of the exercise of the power was to fulfill the government's duty to protect the tribes' treaty rights (*Johnson v. McIntosh* 21 US, 8 Wheat., 543 [1823]; *Cherokee Nation v. Georgia* 30 US, 5 Pet., 1 [1831]; and *Worcester v. Georgia* 31 US, 6 Pet., 515 [1832]).

As applied to water, the trust responsibility requires that the federal government protect the tribes' continued enjoyment of their existing water rights. The Supreme Court's opinion in the 1908 case *Winters v. United States* (207 US 564 [1908]) remains the foundation of tribal water rights. At issue was the claim to the use of water from the Milk River in Montana by the Gros Ventre and Assiniboine tribes on the Fort Belknap Indian Reservation as against upstream non-Indian appropriators. The court recognized the "command of the lands and the waters" held by the tribes and the concession they had made to stay within the limits of the reservation, exchanging their nomadic life for a pastoral one.

Consequently, the extent of tribal claims to water resources is substantial. In 1984, the Western States Water Council estimated that tribal-reserved water rights might extend to as much as 45 million acres-feet. In most cases, tribal rights are senior to other water rights established under state laws.

In many treaties with the U.S. government, tribes did not give up their rights to water, but rather "reserved" the rights to continue fishing, hunting, and gathering in "all usual and accustomed places." These reserved fishing and hunting rights have been construed in several court cases to include an implied reservation of the water necessary to fulfill them (*United States v. Winters* [1908] and *United States v. Adir 723F, 2d 1394, 1408-15* [9th Circuit (1983)]). Moreover, because these reserved rights had been exercised since "time immemorial," the priority date of the implicitly reserved water right has been interpreted to extend back beyond the reach of memory, record, or tradition.

Further, the U.S. Supreme Court has ruled that when the federal government created the Indian reservations, it implicitly reserved the amount of water necessary to support present and future homelands. This is true whether the reservation was created by treaty or executive order.

The priority date of these implied water rights is the date of the reservation (Cohen, 1982; Pisani, 1996).

Native fish species that are to be protected under the tribes' reserved fishing rights include both anadromous fish, such as salmon and sturgeon, and resident fish, such as trout, whitefish, and sucker. Because these species have different life cycles, their needs vary, too. The natural river system provided a wide range of habitats that supported the native fish. Many native plant species that are culturally important to the tribes for food, medicine, or other purposes also have water needs, especially if they are adapted to riparian areas or marshes.

SMALL WATERSHEDS REHABILITATION AMENDMENTS

To address concerns over the safety of small flood control dams built by local communities with federal assistance, the Congress recently amended the Watershed Protection and Flood Prevention Act. The Small Watersheds Rehabilitation Amendments of 2000 (P.L. 106-541 Section 313) authorizes \$90 million over five years to the Natural Resources Conservation Service (NRCS) to provide financial and technical assistance to organizations to cover a portion of the costs incurred for the rehabilitation of structural measures originally constructed as part of a covered water resources project. The FY 2002 Agricultural Appropriations Bill appropriated \$10 million to begin implementation of the program. Over the past two fiscal years, Congress appropriated \$16 million for pilot projects in four states. The NRCS will work with local community leaders and watershed project sponsors to address public health and safety concerns and environmental impacts of aging dams. The activities may include removing a structure if the sponsoring local organization requests it.

The amount of federal funds available is limited to 65 percent of the total rehabilitation costs and cannot exceed 100 percent of the actual construction costs incurred; none of this financial assistance can be used to perform operation and maintenance activities. The rehabilitation of structural measures must meet standards established by the Secretary of Agriculture and address other dam safety issues. The secretary also may provide technical assistance to a requesting organization in planning, designing, and implementing the rehabilitation projects.*

* For more information, see <http://www.ftw.nrcs.usda.gov/pl566/agingwater/infra.html>.

WILD AND SCENIC RIVERS ACT

The Wild and Scenic Rivers Act of 1968 (P.L. 90-542) protects U.S. rivers and their local environments that have remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values. The Act preserves them in a free-flowing condition and designates three classes: wild, scenic, and recreational. Wild rivers have no development and are the river equivalent of wilderness. Scenic rivers have some evidence of human activities and some access points along their lengths. Recreational rivers have numerous pieces of evidence of human activities and many access points, and they may have undergone some impoundment or diversion in the past (National Park Service, 2001). The Wild and Scenic Rivers Act could be used to protect free-flowing rivers with significant natural and cultural resources. Rivers and streams included or proposed for inclusion into the system must be considered during project planning, and project impacts must be identified in an EIS. If a dam is removed from the river, the river is eligible for inclusion as a recreational river under the Act. At present, approximately 10,500 miles of rivers are included in the national system (National Park Service, 2001). Many states also have such designations, with substantially more river miles included.