DAM REMOVAL

Science and Decision Making

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About the Study on Economic, Environmental, and Social Outcomes of Dam Removal

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

Dedication

The last meeting of the Panel on Economic, Environmental, and Social Outcomes of Dam Removal was held in Washington, D.C., on September 11–12, 2001. The panel was in the midst of a discussion of the Manatawny Creek dam removal project when the first attack took place on the World Trade Center in New York City. As that morning unfolded, we learned of the second attack in New York, the attack on the Pentagon, and the plane crash in Pennsylvania. None of us will forget where we were on September 11, 2001, nor will we forget the thousands of lives lost as a result of such senseless and brutal acts. We dedicate this report to the victims and their families and to the courageous firefighters, police, and rescue teams in New York, Washington, D.C., and Pennsylvania.

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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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Many individuals assisted the panel in its task by reviewing draft proposals for the project, recommending panel members, participating in panel meetings, providing data and background information to the panel, recommending individuals to be interviewed, or reviewing and editing drafts. The panel wishes to express its appreciation to the following people for their invaluable contributions to this project:

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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 waterscape, 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.

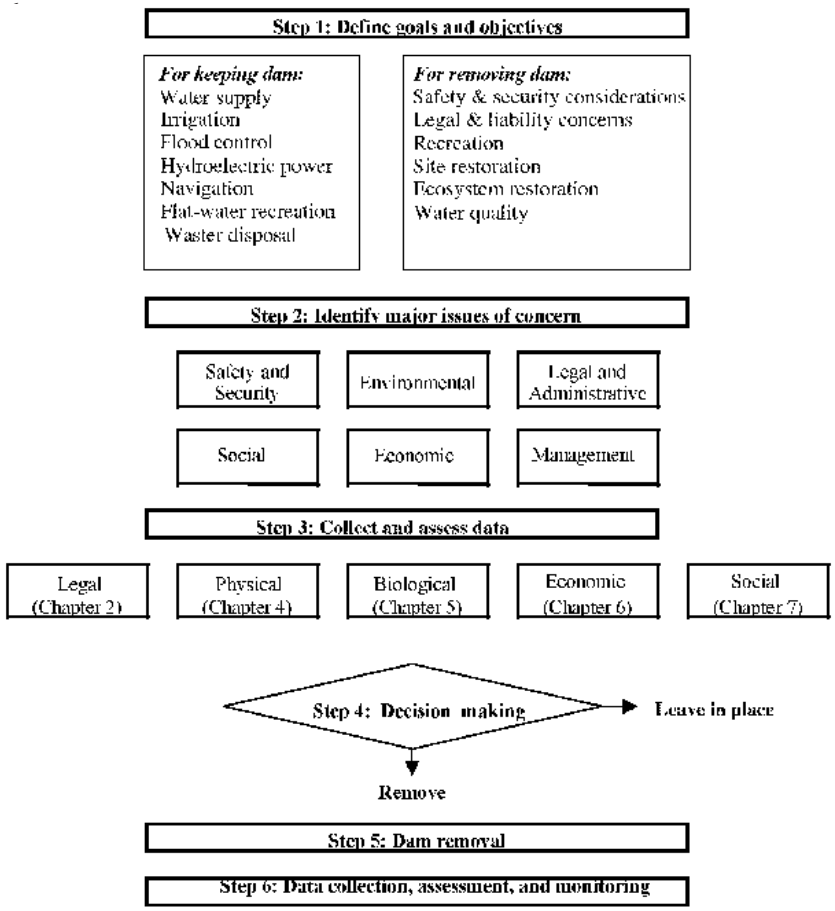

Figure S.1 A general method for dam removal decisions

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 artifi-

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 waterscape 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.