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Dam Removal in the United States: Emerging Needs for Science and Policy

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The aging of America's dams, coupled with increasing awareness of their environmental costs, has brought dam decommissioning and removal to the attention of the scientific community, management agencies, and the general public. Over the past two years, dam removal has been the focus of special sessions at the annual meetings of numerous scientific societies (e.g., American Association for the Advancement of Science, American Geophysical Union, Ecological Society of America, Association of American Geographers), as well as groups focused on bridging science and policy [*Heinz Center*, 2002].

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Here we briefly examine why dam removal has emerged as a critical issue, the realities of ongoing dam removal efforts and the current policy vacuum, and the need for expanded scientific research to support policy development.

Causes for Considering Dam Removal

In the golden age of U.S. dam building, thousands of large and small dams were built to supply power, reduce flood hazard, improve navigation, and impound water for irrigation and urban water supply (Figure 1). Outside of safety issues, little thought was given to the environmental impacts, long-term fate, inevitable aging, and need for continued maintenance, renovation, or even removal of dams. Although the issue of dam removal has surfaced intermittently over the decades [*Miles*, 1978], it is only within the past five years that it has become a hotly debated topic nationally, due to a convergence of economic, environmental, and regulatory concerns.

For a growing number of small dams (small dams impound reservoirs < 100 acre-feet (12 x 10^4 m^3), physical deterioration, risk of failure, and a loss of economic viability have created a financial liability for owners, such that removal is often less expensive than continued maintenance and operation. The magnitude of the aging problem is reflected in the estimate that 85% of the dams in the U.S. will be near the end of their operational lives by the year 2020 [*FEMA*, 1999]. Beyond economic and safety issues, scientific and public awareness of the social and environmental costs of dams has increased substantially over the past two decades, prompting numerous calls for dam removal [*World Commission on Dams*, 2000]. A particularly high-profile example has been the debate over the fate of the four lowest dams on the Snake River in Idaho, where dam removal has been considered as an option to improve threatened anadromous fish runs [*Kareiva et al.*, 2000].

The current intensification of economic and environmental concerns are coinciding with a policy window in which many private dams are coming up for regulatory re-licensing under the aegis of the Federal Energy Regulatory Commission (FERC), and operational guidelines for publicly-operated dams are being reviewed [*National Research Council*, 2002]. This has opened the door for re-evaluation of existing dams and their operation, and raised the prospect of dam removal as a potential strategy for addressing dam-related impacts.

The subject of dam removal often conjures up images of dismantling large structures, such as the Hoover Dam. However, the vast majority of removals to date have been of small, privately-owned structures [*Heinz Center*, 2002]. Large dams store a disproportionately large amount of water and sediment, and often have profound effects on riverine ecosystems at both local and watershed scales; but in most cases, still serve their original, or at least modified, purposes. The time and cost to remove a large dam are substantial [*Wik*, 1995], and removal may cause unanticipated environmental damage, with uncertain long-term benefits.

In contrast to their larger counterparts, smaller dams are typically older, no longer serve their original purpose, have deteriorated, and many (though not all) have reservoirs filled with sediment. Although they store only small volumes of water and sediment, they may impose other ecological impacts on rivers, including blocking migration routes and impounding unique habitats. Removal of these structures is often a cost-effective alternative to repair and maintenance; recent studies show removals of small dams can have limited negative environmental impacts while restoring riverine functions [*Kanehl et al.*, 1997; *Stanley et al.*, 2002].

Most dams removed to date in the U.S. have been small, and this trend is likely to continue. Issues surrounding small dam removals are thus the most critical focus for new science and policy.

The Science and Policy Vacuum

There are few policies and a dearth of systematic technical studies to guide considerations of dam removal among government agencies. On the policy side, prior to 1994, the FERC had no dam removal policy. The Federal Power Act of 1920 is silent on the issue of dam decommissioning and implicitly assumes that continued operation of dams is in the public interest. The FERC, responding to Congress and to pressure from environmental groups and some dam owners, developed a comprehensive decommissioning policy in 1994. This policy was implemented for the first time (and to date, only) in 1999, with the refusal to recommission the Edwards Dam in Maine, which was subsequently removed.

FERC's policy statement remains an exception, however. Regulation of small, privately-owned dams typically falls to state environmental agencies, and over one-third of all states in the nation do not have any statutes regarding dam removal (Figure 2). In most cases, statutes that do exist rarely go further than including removal along with repair or alteration as possible actions subject to regulation. In contrast, some states have adopted operational policies to expedite the process of approval for various permits needed for dam removal, and these states lead the nation in the numbers of dams removed (e.g., Wisconsin, Pennsylvania, Ohio, and Connecticut). The vast majority of resource agencies, however, have not yet come to terms with the realities of dam aging and the increasing likelihood that removal represents a viable alternative to continued maintenance and upgrading of deteriorating structures.

By Martin W. Doyle, Emily H. Stanley, Jon M. Harbor, and Gordon S. Grant

Appropriate policy must be driven in part by an understanding of the geomorphic, ecological, economic, and social impacts of dam removal. This is a rapidly emerging area of science, yet there are few well-documented scientific studies of dam removal, and the limited data that do exist are primarily for small dams.

Because dams and their reservoirs persist for decades, river channels typically adjust to the altered hydrologic and sediment transport regimes that dams impose. Dam removal itself therefore represents a geomorphic disturbance to a quasi-adjusted riverine system. The removal of a dam unleashes cascades of erosional and depositional processes that propagate both upstream and downstream, with the upstream response driving the downstream response.

Upstream of the dam, headcut retreat and channel incision erode reservoir sediment, but these processes vary in response to flow regime, deposit grain size and thickness, channel geometry, and method of dam removal, and are therefore difficult to predict [*Pizzuto*, 2002; *Doyle et al.*, 2003]. Flume experiments and dam drawdown studies, such as on the Elwha River [*Childers*, 2000], provide an empirical test for predicting rates and timing of sediment transport. The dynamics among sediment transport, transfer, and storage processes are poorly developed for dam removal applications, limiting accurate prediction of how long it will take for eroded sediments to be routed downstream and where they will be deposited.

More challenging to predict are the responses of aquatic ecosystems to elevated sediment loads and transformed channel morphology and hydrology. Because dam presence and operation are known to be detrimental to pre-existing aquatic ecosystems, dam removal is assumed to be beneficial, and emerging studies have supported ecological resiliency following removal [*Stanley et al.*, 2002], although projected recovery of salmon is not as optimistic [*Kareiva et al.*, 2000]. Dam removal may also wreak havoc on already highly-disturbed ecosystems. In the midwestern United States, reservoirs often provide a valuable, albeit unintentional, service as sinks for nutrients [*Stanley and Doyle*, 2002] within the already nutrient-laden Mississippi Basin. Further, the sediment released following a dam removal will inevitably be harmful to some downstream biota, which may include taxa of special interest, such as unionid mussels.

An additional wild card is the possibility that reservoirs may store high levels of contaminants, including heavy metals and other organic and inorganic compounds. Release of such materials following dam removal can create contaminant plumes with wide-ranging environmental consequences, as was observed in the release of polychlorinated biphenyls following removal of the Fort Edwards Dam along New York's Hudson River [*Shuman* 1995]. Addressing this issue will require spatial analyses targeted at identifying dams that lie downstream from industrial sites, active and abandoned mines, and other sources of pollution.

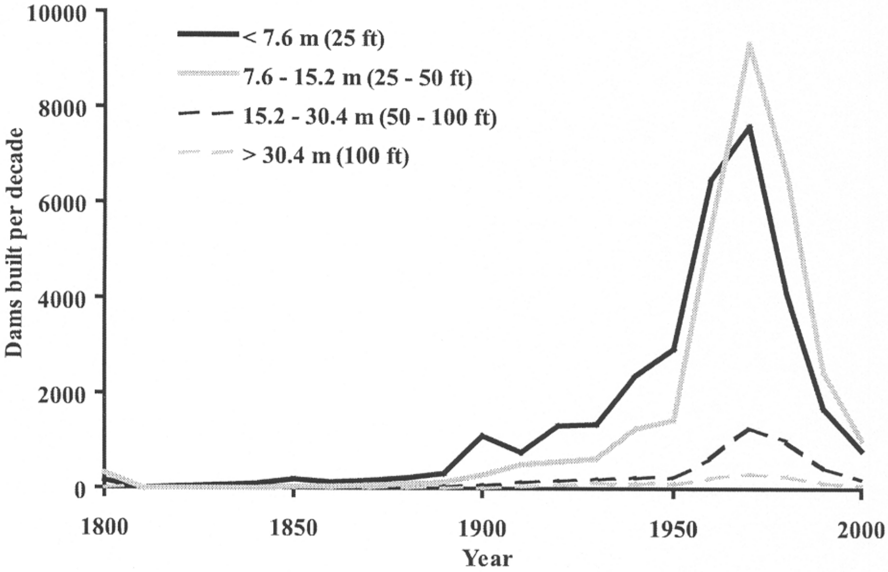

Fig. 1. Number of dams constructed over the past 200 years by decade and by National Inventory of Dams height class [FEMA, 1999]. The most active period of dam building occurred between 1950 and 1970, and has been called "the golden age of dam building."

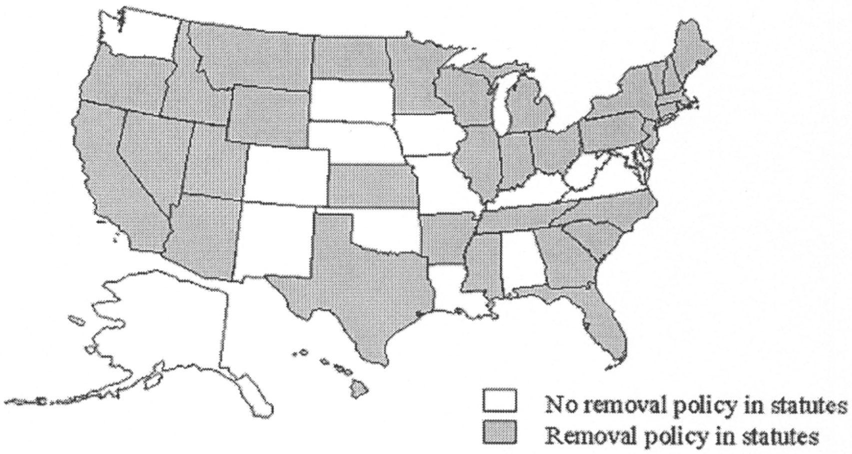

Fig. 2. Summary of state statutes dealing with dam removal. States with/without explicit mention of dam removal in statutes. Information on statutes was collected from reviews of state codes relevant to dams and waterways, and by contacting cognizant personnel in state agencies responsible for management of dams.

Opportunities and Needs for Expanded Research

Dams across America are continuing to age, and their management will become an even more pressing issue for environmental resource agencies, local communities, environmental groups, and dam owners. Given the scientific uncertainties, common sense would dictate that dam removal projects in the near term should be viewed as experiments, with adequate pre-, during, and post-removal monitoring built into removal schemes.

We suggest that the agency responsible for the removal decision fund such monitoring, as it is their responsibility to show the viability of dam removal as an alternative to dam repair. Yet this is not commonly done. In particular, removal of small dams should be viewed as opportunities to learn about the processes and impacts surrounding removal, before large-scale removals with potentially much greater environmental consequences are contemplated. As our scientific understanding of the issue improves through detailed studies of a small number of initial removal projects, we will be better equipped to develop the strategies needed to prioritize and implement dam removals that balance long-term environmental, economic, and societal goals.

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Author Information

Martin W. Doyle, University of North Carolina, Chapel Hill; Emily H. Stanley, University of Wisconsin, Madison; Jon M. Harbor, Purdue University, West Lafayette, Ind.; Gordon S. Grant, U.S. Forest Service, Corvallis, Ore.

New Array Monitors Seismic Activity near the Gulf of California in Mexico

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The Gulf of California rift forms a geologically young and active plate boundary that links the San Andreas strike-slip fault system in California to the oceanic spreading system of the East Pacific Rise. Although this is a classical example of a transform-rift plate boundary, the tectonic evolution of the Gulf of California and surrounding regions is complex and poorly understood due to a lack of geological and geophysical data. In 2002, the Network of Autonomously Recording Seismographs (NARS)-Baja network was installed. It consists of 19 broadband seismic stations deployed in the Baja-California and Sonora provinces of Mexico (Figure 1). Since NARS-Baja surrounds the Gulf of California rift system, it is ideal for constraining earthquake faulting processes and the crust-mantle structure of the region. Moreover, NARS-Baja, in combination with permanent Mexican and U.S. arrays, forms a unique linear array in excess of 4000 km that should lend itself ideally to seismological studies of the North American-Pacific plate boundary on a larger scale. NARS-Baja is planned to operate for at least 5 years. To promote involvement from the entire research community, the data collected from the stations will be made available immediately following routine data quality checks.

The need for a broadband seismic network surrounding the Gulf of California is clear from catalogues of the International Seismological Centre (ISC) and the National Earthquake Information Center (NEIC), which contain an unrealistically low number of earthquakes with magnitudes smaller than 4. Owing to a nearly complete station distribution achieved with NARS-Baja around the Gulf of California, an improved detection level should allow accurate earthquake locations and well-constrained focal mechanisms of moderate ($M > 3$–4) earthquakes to be determined. This will enable us to delineate active faults more accurately and improve our understanding of strain release and tectonic deformation in the region.

In addition, NARS-Baja data will be crucial for studying the crust and upper mantle structure beneath the entire Gulf. While global and continent-scale seismological models suggest that the seismic velocity structure in the mantle beneath the Gulf of California is as anomalous as that of the East Pacific Rise, NARS-Baja data will allow us to make models of the crust and mantle with unprecedented resolution. Resulting crustal and mantle models will provide new constraints on the nature of this young plate boundary and its transition from strike-slip faulting along the San Andreas Fault system, to

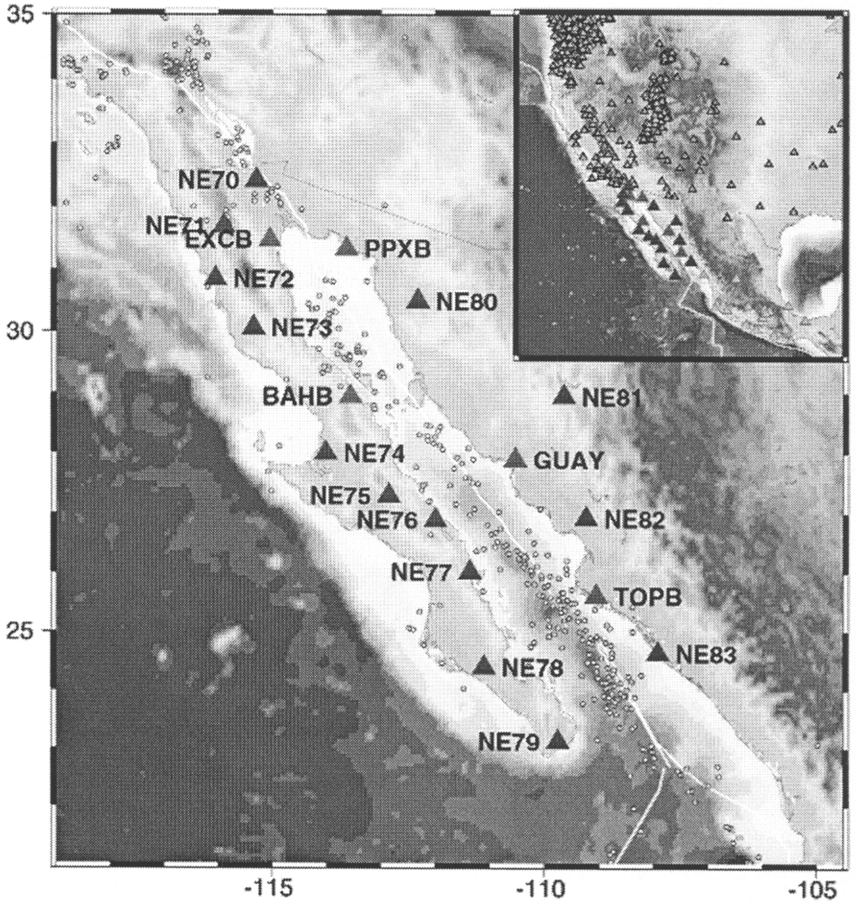

Fig. 1. This topographic map shows the station distribution of the NARS-Baja project. Dark red triangles are NARS stations. Lighter red triangles are CICESE stations. Earthquake hypocenters are indicated by red circles, and plate boundaries are plotted in white. The inset shows an enlarged area illustrating the gap filled by NARS-Baja between the U.S. stations (gray triangles) and the UNAM stations in Mexico (green triangles).