Engineering and Ecological Aspects of Dam Removal—An Overview

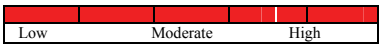
September 2006

By Jock Conyngham[1], J. Craig Fischenich[1], and Kathleen D. White[2]
[1]*Environmental Laboratory*
[2]*Cold Regions Research & Engineering Laboratory*
Engineer Research and Development Center, U.S. Army Corps of Engineers

Complexity

Environmental Value

Cost



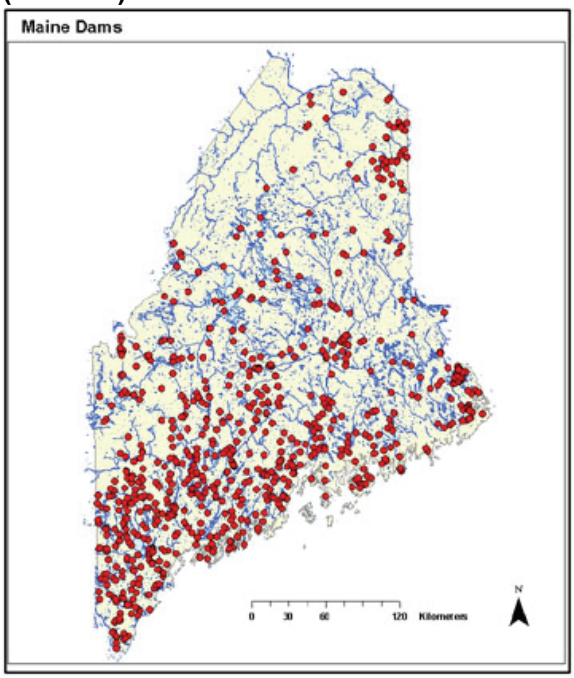
OVERVIEW

Decommissioning and removing dams has emerged as one of the central foci of the new millennium for infrastructure management, river conservation, and the restoration of fisheries populations (American Institute of Biological Sciences (AIBS) 2002; Heinz Center 2002). Anadromous, catadromous, and adfluvial species (Figure 1) are especially impacted by dam decommissioning and removal. It represents arguably the most powerful tool and largest opportunity for restoration of aquatic ecosystems and communities that currently exists. Several phenomena underlie this development:

- High dam densities and the aging of dam infrastructure. Of large dams, 85 percent will have exceeded their design lifespans by 2020 or soon thereafter (Federal Emergency Management Agency (FEMA) 2001). Though inventories are poor, dams exist at much higher densities than many realize (Figure 2).
- Threats or occurrences of dam failures (Figures 3, 4, 5). In 2000 and 2001, 520 dam incidents and 61 dam failures occurred; the American Society of Civil Engineers (ASCE) gave dam management and safety a grade of "D" in the last two editions of its "Report Card for America's Infrastructure" (ASCE 2002). Although inventories are incomplete (with 11 states having no inventory at all), 2,100 dams are categorized as unsafe and almost 10,000 as high hazard potential, and both categories show significant growth in recent years (ASCE 2002).
- Failure of traditional restoration.The mixed success or outright failure of expensive efforts to protect and recover various threatened and endangered species as well as critical prey populations, e.g. the herrings, has received much attention in recent years. The effect of dams on both upstream and downstream migration success is usually cited as a central factor.

Figure 1. Former Secretary of the Interior Bruce Babbitt helping remove Upper Falls Dam, Soudabscook River, ME, 2001

Figure 2. Inventoried dams of Maine, 2002. Courtesy Gulf of Maine Project (GOMP), U.S. Fish and Wildlife Service (USFWS)



- Improved knowledge of aquatic ecosystems and processes. Recent advances in knowledge and/or awareness of geomorphology and the ecology of regulated rivers have increased attention on the effects dams have on sediment budgets, hydrology, water chemistry, and life history needs.
- Economics. Dam removal often costs far less than the restoration of deteriorating or sub-standard structures. One review of 30 case studies in Wisconsin indicated that removal cost about one third the price of dam repair (Born et al. 1998). In addition, many of the values that dams have historically provided, such as hydropower, have been superceded by the direct or opportunity costs of values now considered important (liability, recreational values, large populations of important recreational or commercial fish, etc.).

Despite current enthusiasm, the process of dam decommissioning and removal cannot be viewed as a simple environmental panacea but, rather, as a set of analyses, decisions, and trade-offs with both beneficial and adverse impacts across the spectrum of ecological, social, and economic concerns. Dam removal can require considerable technical expertise and carries potential risk of physical instability, ecological or economic impacts, and local backlash. Recent dam removals have caused occasional but significant occurrences of released toxins or nutrients, channel instability, downstream sediment impacts, invasive populations, and increased risk of ice damming, often despite demanding regulatory overview. Scientists and regulators have expressed concern about current removal practices and requested technical guidance to delineate determination of dam fate, the suite of relevant issues, and the appropriate selection and sequencing of tools for dam removal and associated restoration where indicated. Due to the poor condition of many dams as well as restoration mandates and goals, guidance on efficient and cost-effective project implementation stands out as a critical further need.

PLANNING CONSIDERATIONS

More than 68,000 large dams and an undetermined total number of dams, probably exceeding 2,500,000 structures, exist nationwide (National Research Council (NRC) 1992). With a large percentage of these structures, particularly the smaller ones, in undetermined but deteriorating shape and nearing the end of or having passed their design lifespan, the United States faces a pressing public policy need. Affected populations of threatened and endangered species as well as prey populations that enrich and drive entire freshwater and coastal ecosystems (such as various herring and shad species) add significant economic and ecological stakes to this problem.

Dam removals to date, however, have often been targets of opportunity or crisis. Born et al. (1998) suggest that public safety and

the desire to save costs of repair usually drive removals; only rarely is watershed or fisheries restoration a catalyst for dam removal. A number of projects, however well-intentioned, have resulted in adverse impacts and sometimes public reaction. Griffin (2001) describes one case of local backlash at a proposed removal in Maine that ultimately catalyzed unsuccessful attempts to pass legislation to slow removal efforts. Many removals to date have cost more money or taken more time than necessary, and the full costs are often unknown. Clearly, a proactive, planning-driven, and technically robust approach to a mounting problem is indicated.

Figure 3. Teton Dam failure, Idaho, 1976

BENEFITS AND COSTS OF DAMS

Dams have provided and continue to provide a diverse suite of services and values to owners and society. These include:

- Impoundment-based recreation
- Farm pond and firefighting water
- Flood control
- Water supply for irrigation, residential, and industrial uses
- Hydropower
- Protection from ice damming downstream of structure
- Management of tailings, toxic sediments, or excessive nutrient loading

Figure 4. Chase Brook Bridge collapse caused by private dam failure, NY, 1996 (*Walton Reporter)*

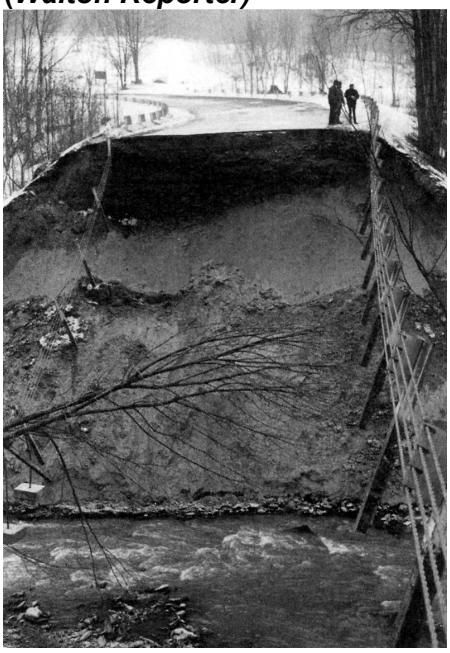


Figure 5. Rockfish Creek Dam failure, NC, 2003

- Historic and archaeological values of structure and/or associated buildings

As described earlier, dam removal advocates have on occasion catalyzed local backlashes, particularly in cases when economic interests came into play or where the process was relatively well-advanced when local stakeholders learned of the impending work. Effective analytic protocols, alternatives analyses, lucid metrics for decision-making, and clean lines

of communication are required for efficient project development and implementation.

Dam costs occur at various scales and must include consideration for:

- Risk of failure
- Ecological damage from alteration of hydrologic, thermal, and chemical regimes
- Ecological damage from significant alteration, in most cases, of sediment regimes, usually resulting in upstream aggradation and downstream incision (Collier et al. 1996). Dams that regulate the hydrologic regime or divert flows, however, can result in downstream aggradation because of the system's inability to route sediment supply from tributaries.
- Ecological damage to riparian zones from decoupling of the channel and floodplain by flow-regulating dams (Magilligan et al. 2003).
- Interruption of requisite upstream and downstream movements of populations, altered predation regimes, habitat fragmentation, and increased risk of exotic organisms due to mixing of lentic and lotic habitats. For instance, unobstructed stream and river reaches have been reduced 91 percent by large dams in the North Atlantic regions (Lary and Busch 1997).
- Chronic and high liability (related to both risk of failure and injuries or deaths due to the structure) and maintenance costs.

Dam removal itself has ecological and economic costs and impacts. These costs must be considered relative to the benefits of removal in alternatives assessments (Bednarek 2001; Schuman 1995, 2002). Examples of potential impacts include:

- Release of excessive sediments. A recent analysis of five removals in Wisconsin showed sediment loading from 170 to 1120 percent of normal sediment budgets (River Alliance of Wisconsin/University of Wisconsin-Madison 2002). Removal of the Elwha Dam was determined to have "major adverse short-term impacts on salmon" because sediment concentrations downstream of the dam would exceed lethal levels (National Park Service 1996).
- Release of toxic sediments. In an extreme and well-known case, removal of the deteriorating Fort Edward Dam on the Hudson River, New York in 1973 resulted in both biological and navigation impacts as several tons of PCB-contaminated sediments were released following removal (American Rivers et al. 1999).
- Release of nutrients. Gray and Ward (1982) found that the flushing of sediments from Guernsey Reservoir on the North Platte River caused a sixfold increase in downstream phosphorus concentrations, leading to the growth of large filamentous algal mats.
- Undesirable vegetation response. Though little empirical work has been done on vegetation and riparian response to removals, results may not be favorable and can include invasive exotics (Shafroth et al. 2002). Management is often necessary, though documented cases of unsuccessful active revegetation indicate that techniques need improvement (Drezner 2004).
- Physical instability and bank erosion (Figure 6). Depending on the volume and depth of stored sediments as well as project design choices, dam removals can lead to upstream channel incision, erosion and widening, with months and sometimes years of instability as the channel develops a new equilibrium. Transported sediments that deposit downstream can induce

local and systemic instabilities if the depositional features create large islands or bars (Wohl and Cenderelli 2000).

- Risk of downstream ice damming. Dam removals in ice-prone rivers have been observed to cause increased risk of ice jamming and damming (USACE 2001, White and Moore 2002). This should be compared to icing and ice transport dynamics of dam-affected downstream reaches. Incised and sometimes dewatered channels commonly observed below dams can produce large amounts of ice, which they are unable to route to floodplains during moderate flood events.
- Mobility of invasive organisms (e.g., sea lamprey). Dams serve as barriers to organism movement, which may prevent infestation from invasive species. Removal of the Marmot Dam in Oregon is being reconsidered, in part, because the dam not only restricts access by salmon to potential spawning sites, but also separates hatchery-reared and wild salmon, helping to maintain genetic integrity of the wild stocks (Oregon Department of Fish and Wildlife (ODFW) 2000).

Figure 6. Soudabscook River, ME channel instability after dam removal

Trade-off analyses must recognize that these costs and benefits are dynamic as knowledge grows and economies shift. Most of the potential ecosystem impacts of dam removal listed above can be eliminated or reduced when anticipated in effective project design and implementation using improved techniques. Few scientists and agencies recognized until recently that anadromous and adfluvial populations are critical sources of nutrients and trace minerals that support entire aquatic ecosystems. The former values of many dams have decreased, ceased, or been eclipsed by altered local and regional economies. In contrast, the role of dams in protecting infrastructure from flooding has increased with the widespread and often unmanaged development of floodplains.

PROBLEM ANALYSIS AND RESTORATION ALTERNATIVES

Personnel addressing dam issues face an array of data demands that need clear and efficient articulation, development, consideration, and communication. For any given case, these can include:

Ecological

- Channel network analysis for habitat and life history needs in order to prioritize dam removal sequencing for species, community, and ecosystem restoration
- Site, reach, and system effects of altered and restored sediment and hydrologic regimes
- Threatened and endangered species, as well as other reference species or communities, e.g. recreationally or economically significant populations
- Wetlands values with or without removal
- Riparian characteristics and processes with and without removal

Policy contexts

- Dam purpose(s) and condition
- Repair alternatives and costs
- Removal alternatives (full, partial, sequenced over time, and sequential grade control for headpond maintenance, organism passage, or

channel stability) and associated costs
- In the event of continued operation or repair, dam maintenance needs
- Risk assessment of dam failure
- Dam mandates (e.g. licensing, fish passage) and liability
- Dam removal liability issues
- Dam and nearby property ownership and development
- Flood dynamics and mapping
- Flow rights and mandates
- Archaeological values
- Easements
- Public perceptions and stakeholder support for dams and dam removals
- Comprehensive cost-benefit analyses

Engineering and restoration implementation

- Sediment storage volumes, particle size analysis, contamination levels. Compare with upstream and downstream reaches
- Channel morphology downstream, through headpond, and upstream
- Icing and ice transport dynamics
- Hydrology and hydraulics
- Sediment transport capacity
- Bank stability
- Groundwater and well impact analyses
- Effects analyses on nearby infrastructure (water intakes, channel crossings, etc.)
- Restoration of upstream aggraded reaches and/or downstream incised reaches
- In the event of removal and the need for active sediment management, removal and disposal requirements (e.g., turbidity control, transport, disposal)
- Project sequencing and implementation
- Project effects monitoring (physical, hydrologic, biological, economic)
- In the event of repair or continued operations, determination of options for operational hydrology, fish passage, thermal regimes, riparian management, sediment amendments, or basin restoration for increased ecological integrity and productivity.

REGULATORY CONTEXTS AND AGENCY CONSIDERATIONS

There are few policies to guide government agencies on dam removal considerations. Federal Energy Regulatory Commission (FERC), under pressure from Congress, developed a decommissioning policy in 1994, but it has been applied only once (on Edwards Dam in Maine). Doyle and Stanley (2003) suggested that dam removal is at a stage of “organizational learning” wherein agencies should maintain an adaptive position and act less as an advocate of favored solutions and more as a participant in deliberating problems and potential new solutions. The experience of Wisconsin as a center of dam removal activity offers valuable lessons (Born et al. 1998, Trout Unlimited and River Alliance of Wisconsin 2001).

The regulatory and management contexts of dams are onerous. The federal government is the largest single owner of dams at approximately 3 percent of inventoried structures; by contrast, 58 percent of ownership is private, according to the USACE National Inventory of Dams. Ownership of small dams changes hands and, over the years, dams are often abandoned to state dam safety agencies. Concerns regarding a legacy of potentially contaminated sediments associated with many small dams is a disincentive for many owners to become involved in decommissioning actions.

Federal agencies including the Corps of Engineers, FERC, U.S. Environmental Protection Agency (EPA), National Marine Fisheries Service (NMFS), USFWS, and the Natural Resources Conservation Service (NRCS) all have an interest and role in dam removal actions, as do state and local governments and a wide variety of NGOs.

The diversity of interest, jurisdiction, and needs of these groups creates a multitude of opportunities for technical and funding collaboration.

The Corps is involved in dam removal issues through a variety of authorities, including Regulatory, small Continuing Authorities Projects, and Support for Others. The Corps is almost always involved in dam removals through its regulatory authorities, which address permitting under Section 404 of the Clean Water Act. The Corps' jurisdiction requires that a public interest review be carried out, as well as a determination of the effects of the dam removal on wetlands, fish and wildlife, water quality, water supply, energy conservation, navigation, economics, and historic, cultural, scenic, conservation, and recreational values. Environmental benefits and detriments and mitigation measures are also considered as part of the permit process.

Other regulations that must be addressed in a dam removal plan include the National Environmental Policy Act; the Fish and Wildlife Coordination Act; the Historical and Archeological Preservation Act; the National Historic Preservation Act; the Endangered Species Act; the Coastal Zone Management Act; the Marine Protection, Research and Sanctuaries Act of 1972 as amended; the Clean Water Act; the Archeological Resources Act; and the American Indian Religious Freedom Act.

Both the benefits and the impacts of dam removal actions transcend the boundaries of ownership, political jurisdiction and agency missions. Given the diverse purposes and objectives of the many entities involved in dam removal decisions, coupled with limited but emerging technical knowledge on the subject, it is not surprising that dam removal is a contentious subject guided primarily by opportunism rather than by scientific consensus or public policy.

TECHNICAL GUIDANCE AND CASE STUDIES ANALYSES

Babbitt (2002) argued that, given the relative scientific ignorance of the consequences, current dam removal efforts are reminiscent of the dam-building era in the United States, and that we risk making decisions with similar costly long-term effects unless the ecological ramifications are better understood.

A literature of technical guidance for dam fate determination and removal is just emerging (ASCE 1997, USACE 2001, White and Moore 2002, this document). An early but excellent literature exists on social contexts and the process of dam removal (Aspen Institute 2002, American Rivers and Trout Unlimited 2006, Born et al. 1998, Heinz Center 2002). Useful listings and case history collections are also now available (American Rivers et al. 1999, Pohl 2001). The Water Resources Center Archives at University of California at Berkeley is creating a centralized clearinghouse for dam removal information and case studies.

The Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers, is currently planning and preparing a comprehensive list of publications that will assist practitioners in implementing dam removal projects. The ERDC is also initiating a three-year research effort to help overcome deficiencies in the state of knowledge regarding the removal of dams and the resultant ecosystem responses.

POINTS OF CONTACT

For additional information, contact the authors, Jock Conyngham (406-726-5002, Jock.N.Conyngham@erdc.usace.army.mil), Dr. J. Craig Fischenich, (601-634-3449, Craig.J.Fischenich@erdc.usace.army.mil), and Dr. Kathleen D. White, (603-646-4187, Kathleen.D.White@erdc.usace.army.mil) or the manager of the Ecosystem Management and Restoration Research

Program (EMRRP), Mr. Glenn Rhett (601-634-3717, Glenn.G.Rhett@erdc.usace.army.mil). Laura Wildman of American Rivers provided technical review of this document.

This technical note should be cited as follows:

> Conyngham, J., J.C. Fischenich, and K.D. White. 2006. *Ecological and engineering aspects of dam removal—An overview.* EMRRP Technical Notes Collection (ERDCTN-EMRRP-SR-80), Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/emrrp/

REFERENCES

American Institute of Biological Sciences. 2002. *BioScience—A special section on dam removal and river restoration* 52(8): 643-750.

American Rivers, Friends of the Earth, and Trout Unlimited. 1999. *Dam removal success stories: Restoring rivers through selective removal of dams that don't make sense.*

American Rivers. 2002. *The ecology of dam removal—A summary of benefits and impacts.* http://www.amrivers.org/damremovaltoolkit/ecologyofdamremoval.htm

American Rivers and Trout Unlimited. 2006. *Exploring dam removal—A decision-making guide*. http://www.amrivers.org/damremovaltoolkit/exploringdamremoval.htm

American Society of Civil Engineers. 1997. *Guidelines for retirement of dams and hydroelectric facilities.* New York: ASCE.

American Society of Civil Engineers. 2002. Report card for America's infrastructure, 2001, sams. http://www.asce.org/reportcard/.

Aspen Institute. 2002. *Dam removal: A new option for a new century.* Queenstown, MD: Aspen Institute. http://www.aspeninstitute.org/AspenInstitute/files/CCLIBRARYFILES/FILENAME/0000000074/damremovaloption.pdf

Babbitt, B. 2002. What goes up, may come down. *BioScience* 52:656-658.

Bednarek, A. 2001. Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management* 27(6):803-814.

Born, S.M., K.D. Genskow, T.L. Filbert, N. Hernandez-Mora, M.L. Keefer, and K.A. White. 1998. Socioeconomic and institutional dimensions of dam removals: the Wisconsin experience. *Environmental Management* 22(3):359-370.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. *Dams and rivers—Primer on the downstream effects of dams.* U.S. Geological Survey, Circular 1126.

Doyle, M.W., and E.H. Stanley. 2003. Toward policies and decision-making for dam removal. *Environmental Management* Vol. 31, No. 4, 453-465.

Drezner, T.D. 2004. Few native species colonize on mud flats ten years after dam removal (Wisconsin). *Ecological Restoration* 22(1):50-51.

Federal Emergency Management Agency. 2001. National Dam Safety Program. http://www.fema.gov/fima/damsafe/.

Gray, L.J., and J.V. Ward. 1982. Effects of sediment release from a reservoir on stream macroinvertebrates. *Hydrobiologia* 96:177-184.

Griffin, W. 2001. Frankfort, Winterport united over removal of dams. *Bangor Daily News* 10/29/01.

Heinz Center. 2002. *Dam removal: Science and decision making.* Washington, D.C.: H. John Heinz III Center for Science, Economics and the Environment.

Lary, S.J., and W.-D.N. Busch. 1997. American eel (*Anguilla rostrata*) in Lake Ontario and its tributaries: Distribution, abundance, essential habitat and restoration requirements. Amherst, NY: Lower Great lakes Fishery Resources Office, USFWS.

Magilligan, F.J., K.H. Nislow, and B.E. Graber, 2003. Scale-independent assessment of discharge reduction and riparian disconnectivity following flow regulation by dams. *Geology* 31(7):569-572.

National Parks Service. 1996. Elwha River Ecosystem Restoration Implementation Summary Draft EIS. Olympic National Park, Washington. http:/www.nps.gov/planning/olym/drftsum/elwha.htm

National Research Council (NRC). 1992. *Restoration of aquatic ecosystems: Science, technology, and public policy.* Washington, DC: National Academy Press.

Oregon Department of Fish and Wildlife (ODFW). 2000. http://www.dfw.state.or.us/public/newsarc/2000news/January/021000news.htm

Pohl, M. 2001. Constructing knowledge on American dam removals. In: *The future of dams and their reservoirs.* Denver, CO: U.S. Society on Dams.

River Alliance of Wisconsin/University of Wisconsin-Madison. 2002. Sediment Management Research Project, #FAF-0119. April, 2002.

Schuman, J.R. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. *Regulated Rivers* 11:249-261.

Schuman, J.R. 2002. Environmental considerations for assessing decommissioning alternatives for large and small dams – sediment management. In *Dams—Innovations for sustainable water resources*. Denver, CO: U.S. Society on Dams, 485-496.

Shafroth, P.B., J.M Friedman, G.T. Auble, M.L. Scott, and J.H. Braatne. 2002. Potential responses of riparian vegetation to dam removal. *BioScience* 52(8): 703-712.

Trout Unlimited and River Alliance of Wisconsin. 2001. Restoring the flow: improving selective small dam removal understanding and practice in the Great Lake states. http://www.tu.org/pdf/newsstand/library/restoring.pdf

U.S. Army Corps of Engineers (USACE). 2001. Considerations for dam removal in ice-affected rivers. *Ice Engineering*, #27. Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers. http://www.crrel.usace.army.mil/ierd/tectran/27InDesign.pdf

White, K.D., and J.N. Moore. 2002. Impacts of dam removal on riverine ice regime. *Journal of Cold Regions Engineering* 16(1):3-16.

Wohl, E.E., and D.A. Cenderelli. 2000. Sediment deposition and transport patterns following a reservoir sediment release. *Water Resources Research* 36:319-333.