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The Changing Role of Dams in Water Resources Management

William L. Graf

University of South Carolina

The river system of the United States is a once-natural system dramatically transformed through the application of technology. The construction of river control works, dams, diversions, levees, pilot channels, water treatment plants, hydropower generators, and navigation structures has resulted in a national river system that is partly natural and partly artificial. Among the most important artificialities introduced by technology have been the fragmentation of watersheds and segmentation of rivers by dams (Figure 1). There are about 80,000 dams in the United States that are either 6 ft (2m) or greater in height with storage capacities of 50 ac ft (61,000m^3) or more, or 25 ft (7.5m) or greater in height with storage capacities of 15 ac ft (18,500m^3) or more (USACE, 1996 and subsequent unpublished revisions by the National Dam Safety office provide the total estimate; federal legislation provides the definition of "dam" used in the inventory). Although the oldest surviving dam was built in 1677 (Mill Pond Dam in Newington, Connecticut), a quarter of all American dams date from a single decade: the 1960s.

These structures exert substantial control on the flows of water, sediment, and nutrients, and they have altered most aquatic and riparian habitats in the nation. Large dams and storage reservoirs have the greatest effects (Figure 2). In some large river basins, dams are capable of storing almost four years' total runoff (the Upper Colorado Basin and the Rio Grande Basin), though in some water-rich regions they store as little as a quarter year's runoff (Pacific Northwest and Great Lakes areas). Overall, the dams of the nation have a storage capacity that is only slightly less than a full year's worth of runoff from the nation's area, and their effects far exceed any effects likely to occur from global climate change over a period of several centuries (Graf, 1999). Smaller run-of-river structures that have little storage and simply serve to raise water levels (for mill operations or navigation) have lesser effects on the hydrology of their host streams, but they physically separate upstream reaches from those downstream. Because of their ability to store water and to disrupt the continuity of rivers, dams affect river hydrology, geomorphology, and biological systems related to the streams.

Dams are a critical component of the nation's water-control infrastructure. They store water for redistribution during dry periods, provide flood suppression, allow long-term navigation, generate hydropower, and serve the general public by creating flat-water recreation areas. In limited areas, dams

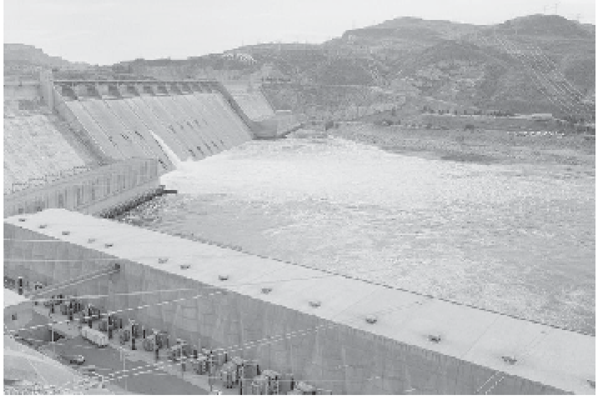

Figure 1. Grand Coulee Dam, one of the largest dams in the country, segments the Columbia River in Washington state. June 21, 2001. Source: U.S. Library of Congress, Historic American. Buildings Survey, Historic American Engineering Record.

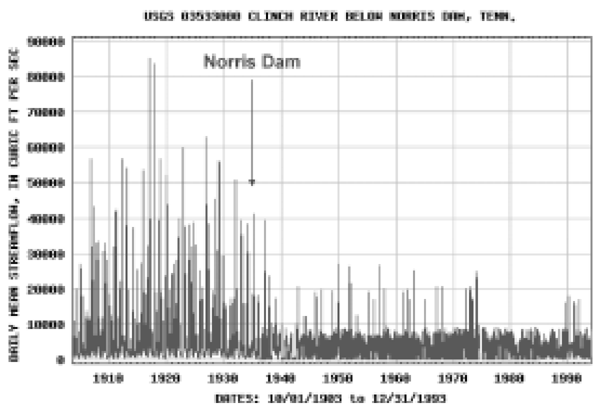

Figure 2. Daily mean discharge record for the Clinch River downstream from the site of Norris Dam, the first major Tennessee Valley Authority project. Note the flood control effects of the dam, which was completed in 1936. Source: U.S. Geological Survey data and graph. Dam label added by author.

create suitable conditions for wildlife, particularly introduced species. Some dams create reservoirs for waste disposal, especially in mining and agricultural areas. The largest dams in the nation serve multiple purposes and are connected through distribution systems to the lives of millions of citizens. The Colorado River Storage Project, which includes Hoover and Glen Canyon dams, serves 20 million people in the Southwest, and 8 million New Yorkers depend on an extensive dam and aqueduct system stretching more than 100 miles from the city.

The beneficial role that dams have played in the economic development of the nation is clear, and their benefits affect almost everyone. The creators of dams, ranging from small private enterprises for mill and farm ponds to massive public works that produced icons of twentieth-century engineering, had specific beneficial uses in mind when they built the structures. Dam builders have often been seen as leading lights in the drive to control natural processes for human welfare, a perspective that was widely adopted in American culture during the early twentieth century.

During the last three decades, however, there has been a perceptible shift in how some of the general public views dams, and this shift has been reflected in federal legislation as well as state administration of rivers and water resources. By the end of the twentieth century, it became obvious that the benefits generated by dams were associated with environmental costs that planners had not foreseen. Aquatic habitats downstream from dams experienced changes in water quality, temperature, and sediment content, while riparian vegetation communities changed their species composition and aerial coverage. The 1977 Clean Water Act (with subsequent amendments) established as federal policy the restoration and maintenance of the physical, biological, and chemical integrity of the nation's water courses, thus launching massive efforts to reverse the degradation of water quality and the trends toward highly artificial streams. The 1973 Endangered Species Act established as federal policy the protection of species threatened with extinction as a result of human activities. The Endangered Species Act has turned out to be especially important to water managers because about half of all the species on the federal endangered list have been negatively affected by dams and diversions (Losos *et al.*, 1995).

This brief review both of dams and the shift in national attitudes toward a greater emphasis on environmental quality raises two questions that are explored in subsequent paragraphs:

- What new roles will dams play in the future of American rivers and water resources?
- Who will decide the role of dams in water resources management and river restoration?

New Roles for Dams

Paradoxically, dams are constructed to bring about beneficial changes in the hydrologic regime of rivers downstream, but those same changes cause damage to environmental systems. For example, structures created for irrigation storage contain most of the Spring high discharges in their reservoirs, therefore saving the water for later distribution to downstream users during dry growing seasons. The environmental cost, however, has been that downstream reaches experience flows in only a fraction of the former range of annual low and high flows. Aquatic habitats are, therefore, much less varied across and along the river channel, thus restricting the variety, number, and size of ecological niches. The simplified river offers a restricted and less-varied set of habitats, often to the detriment of native species of aquatic and riparian organisms (Figure 3). Flood control dams store enough water to allow them to suppress the damaging peak flows that might endanger life and property downstream

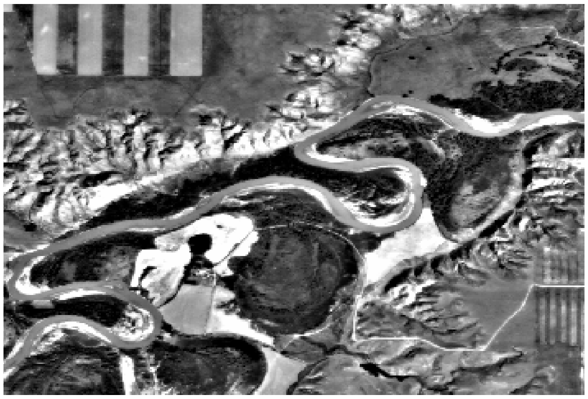

Figure 3. Aerial photograph of the Maria River, Montana, upstream from Tiber Dam, showing a complex assemblage of riparian ecosystems along the stream. Such complexity is often damped out downstream of dams. June 12, 1991. Source: U.S. Geological Survey photograph, EROS Data Center, Sioux Falls, South Dakota.

through over-bank flows. An ancillary cost, however, is that plant species that once flourished on periodically inundated flood plains cannot survive or reproduce with their pre-dam efficiency. Small run-of-river structures (Figure 4) permit navigation and diversion of water to off-stream uses, but they are amazingly effective barriers to fish passage, and they severely stress populations of anadromous species (those that spawn in freshwater rivers but live part of their life cycle in salt water oceans).

Most dams of all sizes are the result of a cultural view of water as a commodity. Depending on the region of the country, rights to the water in the channel belong either to property owners next to the river (generally Eastern areas) or to the person who first put the water to beneficial use (generally Western areas). Although extensive marketing of this commodity is not yet a widely accepted principle, water can usually be bought and sold within its basin of origin. Many other benefits of dams are easily quantified using standard economic principles: hydropower priced by the kilowatt, flood control evaluated by potential property losses averted, navigation assessed by ton-miles of freight transported, and recreation measured by person-days of boating activity.

The environmental costs of dams are not so easily molded to traditional economic analyses. While most citizens value wildlife, for example, the dollar value of a single sturgeon swimming in what is left of the coastal rivers of the Southeast is hard to assess, as is the value of a nesting pair of Southwestern willow flycatchers in the Colorado River Basin, a salmon in the Snake River of Idaho, or a Florida panther in the Everglades. Passage of the Endangered Species Act indicates that as a society we value these creatures, and direct observation shows that dams play a role in their demise. Managers and researchers now face the issue of learning what role dams can play in the survival of these species.

The adoption of a watershed perspective, couched in ecosystem terms, leads to a new view of dams, wherein these structures can be part of the resolution to their paradoxical benefits and costs. Dams should be viewed as opportunities both to affect environmental conditions in positive ways and to reverse some of their unintended adverse effects. Dams are control valves scattered throughout the nation's river systems, and though they lead to the segmentation of that system, they also exert some control over system flows. For example, in the Colorado River, Glen Canyon Dam had created undesirable effects along the river in Grand Canyon National Park (Carothers and Brown, 1991). The dam suppressed flood peaks and disrupted the movement of sediment through the canyon, which was dependent on flood peaks. The U.S. Bureau of Reclamation has experimented with artificial flood peaks, not as great as those that occurred naturally but much larger than flows allowed before considering ecosystem values. Whether these experimental flows will work as desired is unknown (Rubin *et al.*, 2002), but the use of the dam as a solution to some of the problems it created is an indication that new ecosystem values may yet be compatible with traditional commodity-based values.

The Everglades provides another example of how water control structures may be used in support of

Figure 4. Low-head run-of-river dam on the Savannah River near Augusta, Georgia, a significant blockage for fish passage. Source: U.S. Library of Congress, Historic American Buildings Survey, Historic American Engineering Record.

ecosystem values. The installation and operation of numerous low dams and water control gates in the region upstream from the Everglades deprived the area of much of its natural supply of water (McPherson and Halley, 1996). As a result, suitable habitat for the population of the endangered Cape Sable seaside sparrow shrank considerably. Water supply and flood control for the Miami area were major stimulants for the construction of the water infrastructure, but operating that structural system to benefit the sparrow may potentially expand its habitat or, at the very least, prevent further degradation. As with the Glen Canyon case, whether or not this experiment in the Everglades will work is not yet clear, but these experiences suggest that structures built for economic purposes may also serve to limit environmental damage.

The run-of-river dams that are barriers to fish passage pose different problems with regard to reconciling economic and ecosystem values. The installation of fish ladders has aided some fish populations, but more radical solutions are becoming common. Many run-of-river dams were built for mills or small hydroelectric projects that are no longer economically viable. In many cases in the Midwest and East, owners of these dams are unknown, or owners are saddled with unwanted liability for obsolete dams. The removal of such dams is an increasingly common solution (Heinz Center, 2002). Because the original economic incentive for the structures is now absent, the ecosystem values of dam removal and river restoration are great enough to justify public investment. Over the past decade, more than 500 dams have been removed from critical locations, thus restoring passage for endangered species.

The case of the Quaker Neck Dam, on the Nuese River of North Carolina, illustrates the utility of dam removal (American Rivers *et al.,* 1999). The dam, built in 1952 as a diversion structure, was only 7 ft (2 m) high, but it formed a sill across the river and blocked upstream migration of anadromous fishes, including the American shad and the endangered short-nosed Sturgeon. The dam was obsolete, and served no economic purpose. Removal of the dam in 1998 made more than 1000 mi (1600 km) of upstream river accessible from the ocean.

Who Will Decide the Future of Dams?

The adaptation of dams to new roles in water resources management means that some structures might be physically modified, others removed, and still others managed under adjusted operating rules. Decisions about these alternatives in planning and management are complex, involving not only the environmental outcomes, but also the economic and human social outcomes (Heinz Center, 2002). The structure of water policy and its execution in the United States insures that the answer to the question “who will decide the futures of dams?” is likely to be “almost everyone.” Federal, state, tribal, and local governments have direct policy connections to decisions about dams. Thus, it is necessary to consider all levels of government.

Dams are critical components of international agreements concerning water in North America. Agreements with Canada (particularly related to the Columbia River in the West and the Great Lakes in the East) depend partly on international approaches to dam operations. Similarly, water agreements with Mexico determine dam operations on the Colorado River and the Rio Grande. Adjustments in dam operations to account for endangered species in the United States, therefore, are not simple internal decisions. Rather, they must take into account issues related to water quality and quantity for delivery to or from other nations.

Federal involvement in decisions about dams derives from constitutionally mandated responsibilities for interstate commerce and the management of endangered species. States and other authorities do not have the right to infringe on interstate commercial activities related to water. Since almost all water-related commerce in the nation is interstate in some form another, the federal government has a regulatory responsibility that has been tested in Supreme Court cases. Moreover, the Endangered Species Act directs the U.S. Fish and Wildlife Service to review management plans for air, land, and water resources that might affect endangered species. A host of other laws assigns the federal government with responsibilities related to water. In fact, more than 25 separate federal agencies have some statutory responsibility for rivers and watershed management (National Research Council, 1999). It is particularly important that the

U.S. Army Corps of Engineers maintain the authority to regulate both physical alterations to channels as well as the introduction of sediment into them. These are both vital aspects of dam operations and modifications, and in some cases, removals.

States also enter the decision-making arena for dams via their management of water rights, but of greater importance is the states' role in application of the Clean Water Act. This act empowers the federal government to set standards for water quality, for example, but the authority for monitoring and enforcement of the standards is usually exercised by state agencies.

Additionally, the state dam safety officers periodically inspect dams and approve their continued operations. A national Dam Safety Office coordinates standards and reporting, but most of the authority related to dam safety resides at the state level.

Tribal entities often have water rights that are central to the management of rivers and their dams. Tribal lands that may include dams have special considerations for Native Americans whose lands, waters, and wildlife may have religious significance. Many tribes are also concerned about maintaining their sovereignty over physical resources, and tribal approval is a necessity for changes to dams on reservations or that control water to which tribal rights are attached.

Local authorities also enter the decision-making process, because for those dams in county or city jurisdictions numerous codes for construction usually apply. In particular, removal of dams affects and is affected by local authorities. The removal of several dams from the Baraboo River in the town of Baraboo, Wisconsin, provides an example of a town landscape substantially altered by dam management. In South Bend, Wisconsin, the removal of Woolen Mills Dam on the Milwaukee River was accomplished in concert with local authorities who created a public park on the floor of the abandoned reservoir.

For about 2,300 dams in the country, a special local to national set of players take part in the decision-making process. These dams are privately owned and are licensed for operation by the Federal Energy Regulatory Commission (FERC), with licenses renewed every 30 to 50 years. The decisions on license renewal and on revisions to existing licenses are made by FERC which is a federal agency taking into account national interests, but participants in the decision process include all levels of government as well as non-governmental organizations. As a result, decisions on individual dams become entangled in issues ranging from local to national in scale.

This brief review of who is involved in decisions affecting dams shows that many levels of government, several types of agencies, and a wide range of stakeholders are included. Perhaps the complexity of dam management issues is illustrated by the length of time required to obtain a license renewal for a privately owned hydroelectric dam from FERC. Typical cases now require 8 to 10 years, while similar operating licenses of nuclear power stations require only 3 years on average.

Conclusion

Dams have played a pivotal role in the creation of an economic infrastructure for the United States. They have become important parts of the nation's landscape, and some of the largest ones are icons of American engineering prowess. Largely created during a period when American culture sought to control environmental resources and processes, these structures deal with water as a commodity and with geographic space as something to be protected from flood damage. During the last four decades, however, social values have expanded to include the naturalness of rivers and their associated features, especially valuing wildlife and endangered species. As a result, dams now play an expanded role, and they are key components of the restoration of aquatic and riparian habitats. Dams can be physically modified, alter operating rules, or be removed to achieve some of these expanded goals. In this new formulation, driven mostly by the Clean Water Act and especially by the Endangered Species Act, dams are becoming structures that deal with water as an ecosystem component, and with geographic space as patches, some of which are habitat for wildlife and others that are dominantly for human use. In this new view of the river as ecosystem rather than as merely a conduit for water to bought and sold, outdated simplistic notions of water resource management will have to be replaced by much more complicated approaches to integrating science and decision making across the entire spectrum of scales from local to international.

The themes of spatial analysis, movements and transfers of mass and energy, a dominant role for scale in analysese, and the over-arching perspective of nature-society interactions that are inherent in current research and policy for dams are also defining themes for geographers, who have a unique opportunity to contribute to the critical national issue of the changing role of dams in resource management.

Author Information

William L. Graf is Educational Foundation University Professor and Professor of Geography at the University of South Carolina. His specialties include fluvial geomorphology and hydrology, as well as policy for public land and water. His Ph.D. is from the University of Wisconsin, Madison, with a major in physical geography and a minor in water resources management. His research and teaching have focused on river channel change, human impacts on river processes, morphology, and ecology, along with contaminant transport and storage in river systems. In the arena of public policy, he has emphasized the interaction of science and decision making, and the resolution of conflicts among economic development, historical preservation, and environmental restoration for rivers. He has authored or edited 8 books, more than 120 scientific papers, book chapters, and reports, more than 60 successful grant proposals, and more than 90 public presentations. He is past President of the Association of American Geographers and has been an officer in the Geological Society of America. President Clinton appointed him to the Presidential Commission on American Heritage Rivers. His National Research Council service includes membership of the Water Science and Technology Board and the Board on Earth Sciences and Resources, chairing NRC committees to advise the U.S. Geological Survey, the White House Council on Sustainable Development, and on innovative watershed management, as well as committee membership on several water, earth, and ecosystem science topics. He is a National Associate of the National Academies.

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