



PERSPECTIVES

ECOLOGY

1000 dams down and counting

Dam removals are reconnecting rivers in the United States

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Forty years ago, the demolition of large dams was mostly fiction, notably plotted in Edward Abbey's novel *The Monkey Wrench Gang*. Its 1975 publication roughly coincided with the end of large-dam construction in the United States. Since then, dams have been taken down in increasing numbers as they have filled with sediment, become unsafe or inefficient, or otherwise outlived their usefulness (1) (see the figure, panel A). Last year's removals of the 64-m-high Glines Canyon Dam and the 32-m-high Elwha Dam in northwestern Washington State were among the largest yet, releasing over 10 million cubic meters of stored sediment. Published studies conducted in conjunction with about 100 U.S. dam removals and at least 26 removals outside the United States are now providing detailed insights into how rivers respond (2, 3).

A major finding is that rivers are resilient, with many responding quickly to dam removal. Most river channels stabilize within months or years, not decades (4), particularly when dams are removed rapidly; phased or incremental removals typically have longer response times. The rapid physical response is driven by the strong upstream/downstream coupling intrinsic to river systems. Reservoir erosion commonly begins at knickpoints, or short steep



Goodbye to a large dam. Elwha River passing through the remains of Glines Canyon Dam on 21 February 2015. The former Lake Mills can be seen in the background.

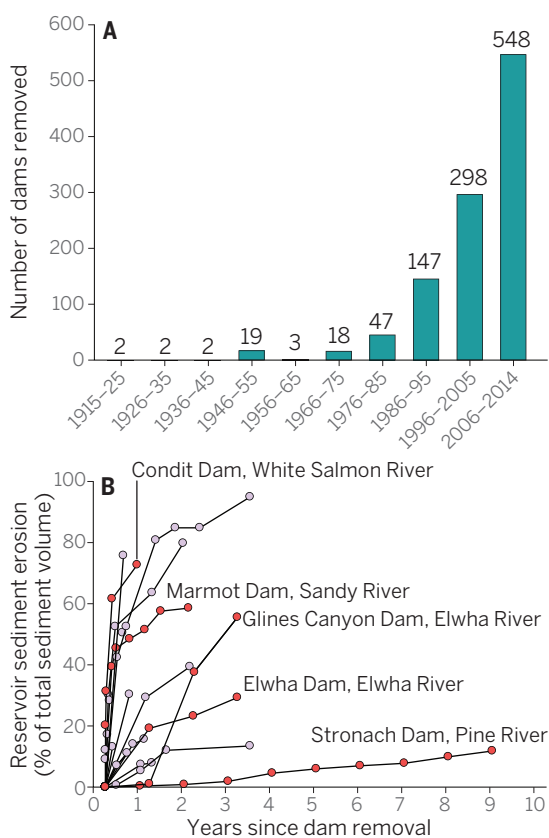
reaches of channel, that migrate upstream while cutting through reservoir sediment. Substantial fractions of stored reservoir sediment—50% or more—can be eroded within weeks or months of breaching (4) (see the figure, panel B). Sediment eroded from reservoirs rapidly moves downstream (5, 6). Some sediment is deposited downstream, but is often redistributed within months. Many rivers soon trend toward their pre-dam states (5, 7).

Migratory fish have also responded quickly to restored river connectivity. Removal of a dam on Virginia's Rappahannock River increased American eel populations in Shenandoah National Park, 150 km upstream (8). Similarly, following a small dam removal in Maine, sea lamprey recolonized newly accessible habitat, increasing abundance and nesting sites by a factor of 4 (9). Within days of the blast removing the last of Glines Canyon Dam, Elwha River Chinook salmon swam upstream past its rocky abutments. Responses have been mixed for less mobile bottom-dwelling plants and animals in former reservoirs and downstream channels (10, 11).

Dam size, river size, reservoir size and shape, and sediment volume and grain size all exert first-order controls on physical and ecological responses to dam removal. Larger dam removals have had longer-lasting and more widespread downstream effects than the much more common small-dam removals (4). Local environmental and habitat conditions and the dam's position in the watershed also affect physical and ecologic consequences. In the case of the Elwha River, both dams were near the river mouth, minimizing the extent of downstream effects while reconnecting large areas of high-quality fish habitat upstream in Olympic National Park.

Removals can also have additional consequences, some of them unintended. For example, changes to a headwater fish assemblage occurred when a removal allowed upstream colonization by reservoir species present behind a dam farther downstream (12). Watershed contaminants, organic accumulations, nutrients, once-inundated struc-

Dam removals in the United States



Coming down. (A) U.S. dam removals by decade. Data from (1). (B) Rates of reservoir sediment erosion for 16 recent U.S. dam removals. Condit, Marmot, Glines Canyon, and Elwha dams impounded sand-rich sediment accumulations and were removed over short periods ranging from hours to 3 years, leading to rapid reservoir sediment erosion. Stronach Dam was removed in several phases over 7 years, slowing reservoir erosion (15). Data from (4).

tures, and landforms from past land uses may be uncovered and sometimes mobilized by dam removal.

Numerical and physical models have guided removal and monitoring strategies, forecast broad-scale trends, and helped avoid negative outcomes (13), but cannot yet predict fine-scale changes driving many ecological processes. Quantitative models of species and ecosystem responses to dam removal lag even further behind.

Most dam-removal studies so far have been short-duration and opportunistic. Most dam-removal analyses are from the northern United States. Few removals have markedly altered flow and/or released large volumes of fine sediment. Furthermore, studies truly integrating biological and physical responses are rare. Common protocols, more coordination among disciplines, and longer, more systematic monitoring and research would benefit future syntheses (13).

In the United States, many dam removals have improved ecosystem function while avoiding catastrophic consequences to either ecosystems or human uses. The high pace of dam removal will likely continue. But the future is murky. As mostly small dams continue to come down, dam-removal advocates will gaze up at the many large and ecologically disruptive dams across the country that are decaying and filling with sediment. Decisions regarding these dams will require balancing risks, continued economic function, and the potential for ecologic restoration. Also clouding the future is climate change, which is likely to increase the demand for fresh-water storage, both as a low-carbon energy source and for consumptive use.

Dams are also being removed internationally; the 26 removals with published studies are just a sample from a total probably numbering in the hundreds. Like most of those in the United States, many are small structures at the end of their useful lives. And many removals, such as the ongoing one of Japan's Arase Dam, are motivated by economic and ecological considerations similar to those spurring U.S. dam removal.

The total number of U.S. and international removals are, however, more than offset by a renewed global boom in dam construction, chiefly for hydropower and in regions with emerging economies, such as Southeast Asia, South America, and Africa (14). But the dams of this ongoing boom will also age, just like those of the U.S. dam-building heyday. Dam removal looks like an activity with a long future ahead. ■

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ACKNOWLEDGMENTS

This Perspective is derived from discussions and analysis efforts conducted by the working group on *Dam removal: Synthesis of ecological and physical responses* of the U.S. Geological Survey John Wesley Powell Center for Analysis and Synthesis.

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Science **348**, 496 (2015);

DOI: 10.1126/science.aaa9204

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