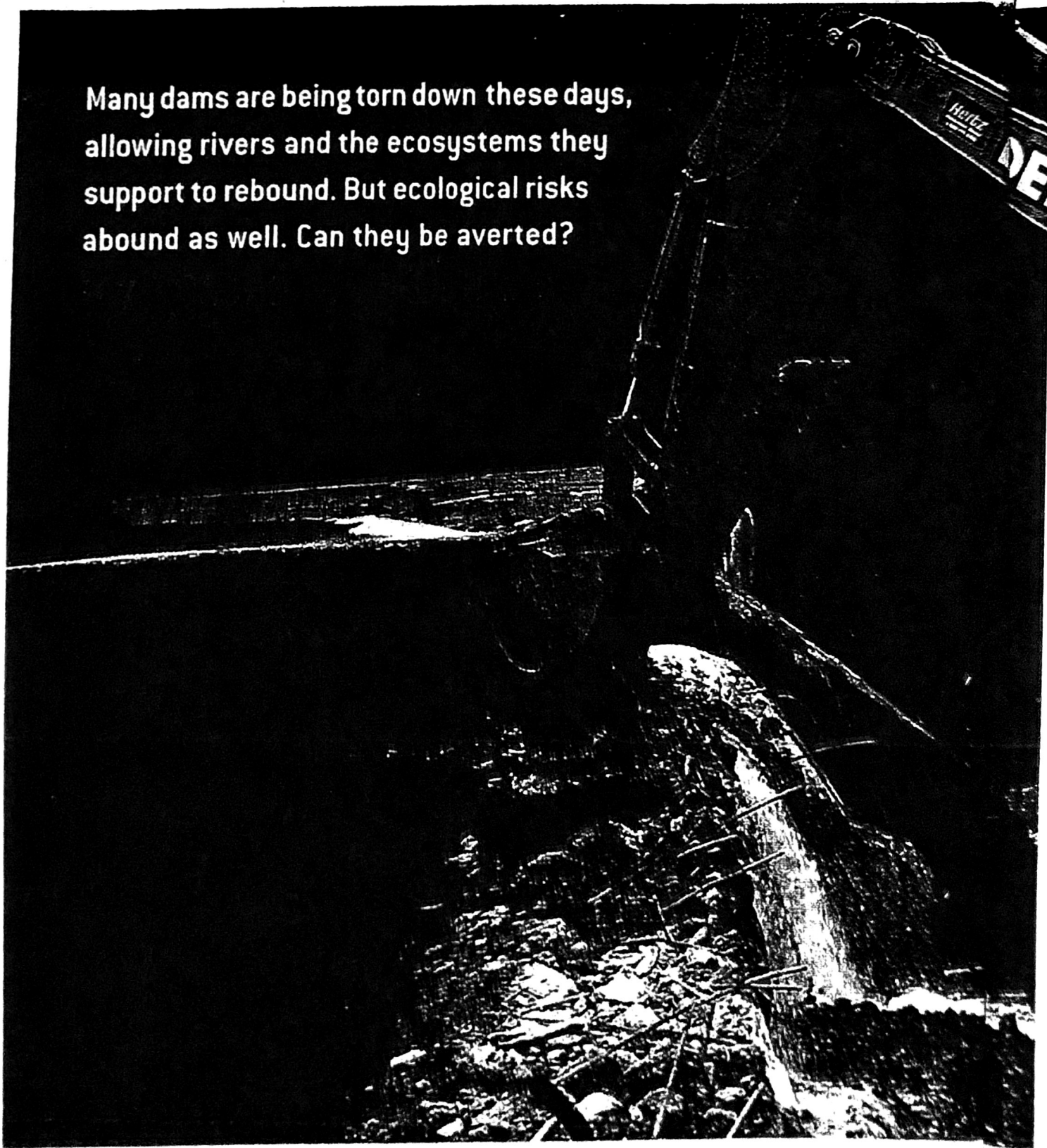
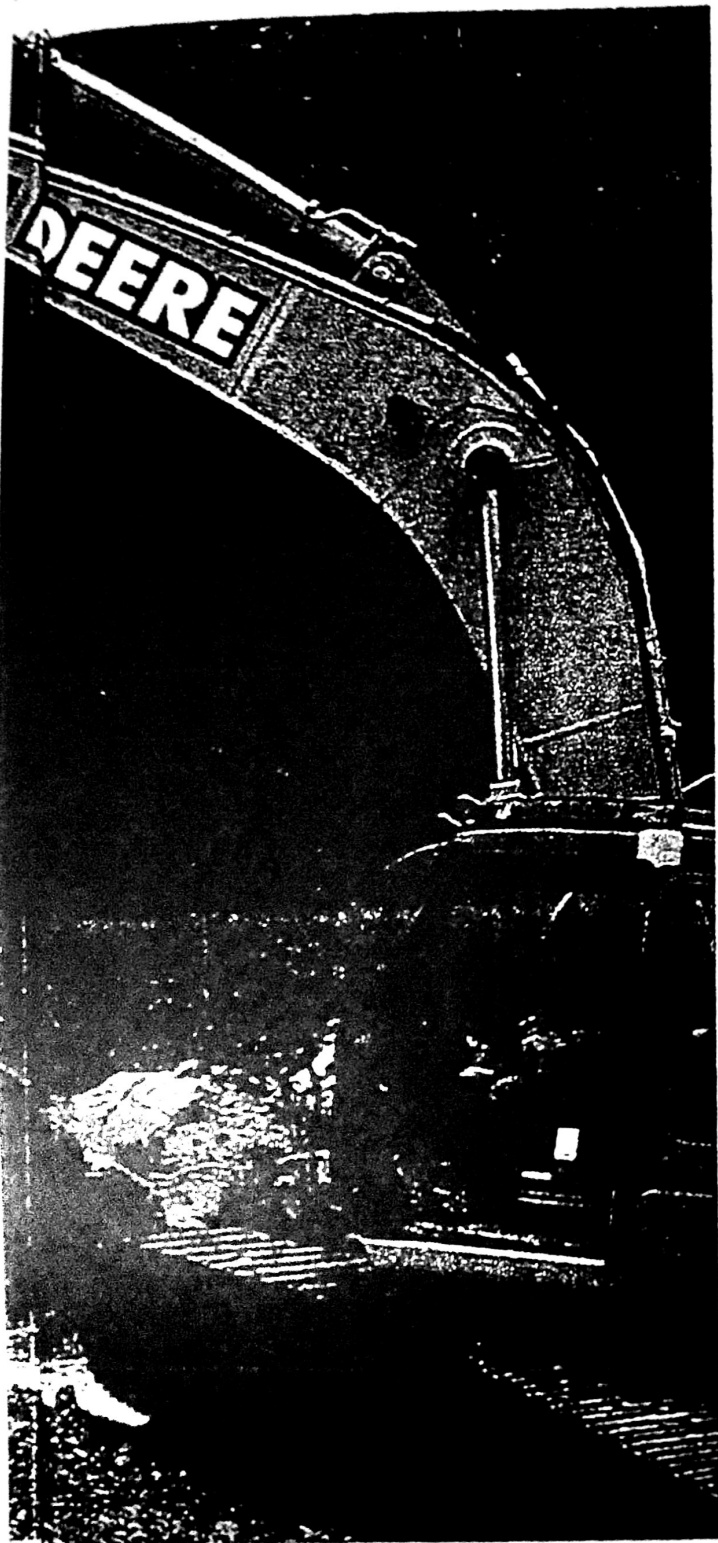


DOWN GO THE

Many dams are being torn down these days, allowing rivers and the ecosystems they support to rebound. But ecological risks abound as well. Can they be averted?



DAMS



KEITH PLUMMER Courtesy of NOAA Restoration Center

At the start of the 20th century, Fossil Creek was a spring-fed waterway sustaining an oasis in the middle of the Arizona desert. The wild river and lush riparian ecosystem attracted fish and a host of animals and plants that could not survive in other environments. The river and its surrounds also attracted prospectors and settlers to the Southwest. By 1916 engineers had dammed Fossil Creek, redirecting water through flumes that wound along steep hillsides to two hydroelectric plants. Those plants powered the mining operations that fueled Arizona's economic growth and helped support the rapid expansion of the city of Phoenix. By 2001, however, the Fossil Creek generating stations were providing less than 0.1 percent of the state's power supply.

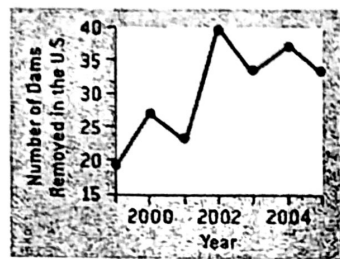
Nearly two years ago the plants were shut down, and an experiment began to unfold. In the summer of 2005 utility workers retired the dam and the flumes and in so doing restored most of the flow to the 22.5 kilometers of Fossil Creek riverbed that had not seen much water in nearly a century. Trickle became waterfall, and stagnant shallows became deep turquoise pools. Scientists are now monitoring the ecosystem to see whether it can recover after being partially sear for so long, to see whether native fish and plants can again take hold. They are also on the lookout for unintended ecological consequences of the project.

Decommissioning dams (particularly small ones, as is the case in Fossil Creek) is becoming a regular occurrence as structures age, provide an inconsequential share of a region's power, become unsafe or too costly to repair, or as communities decide they want their rivers wild and full of fish again. But simply removing a dam does not automatically mean a long-altered ecosystem will flourish once more. As with all things natural, reality often proves far more complex and intricate than people anticipate. Those of us who have witnessed many of the unexpected consequences of dam removals are now using that knowledge to try to minimize negative results in the future.

A Global Trend

TODAY ABOUT 800,000 dams operate worldwide, 45,000 of which are large—that is, greater than 15 meters tall. Most were built in the past century, primarily after World War II. Their benefits are clear. Hydroelectric power makes up 20 percent of the globe's electric supply, and the energy is largely clean and renewable, especially when contrasted with other sources. Dams control flooding, and their reservoirs provide a reliable supply of water for irrigation, drinking and recreation. Some serve to help navigation, by stabilizing flow.

SANDY RIVER DAM removal is part of the long-term restoration of Maine's Kennebec River. In 1999 the Edwards Dam on the Kennebec was taken down; soon after, many of the river's native fish returned and their populations grew dramatically. Unconstrained flow of the Sandy River, a tributary of the Kennebec, was restored last summer to ensure that no barriers prevent migratory fish from moving freely.



FOSSIL CREEK, which is fed by seven underground springs, went from merely a trickle [above] to a bubbling flow of 314 gallons a second after engineers redirected the water around an old hydropower dam [right]. Scientists are now studying the creek to see how the food chain changes and to determine whether native species flourish. The dam was one of more than 30 removed in the U.S. in 2005 (graph).

policymakers, conservationists, native peoples, researchers and the public—have fought to decommission aging dams.

In the U.S., where hydropower dams must be relicensed every 30 to 50 years, the rate of dam removal has exceeded the rate of construction for the past decade or so. In the previous two years alone, about 80 dams have fallen, and researchers following the trend expect that dams will continue to come down, especially small ones. Although the U.S. is currently leading the effort, it is not alone. France has dismantled dams in the Loire Valley; Australia, Canada and Japan have also removed, or are planning to remove, dams.

Clear successes have driven much of this activity. In 1999 engineers took apart the Edwards Dam on Maine's Kennebec River after a long battle waged by environmentalists culminated in the Federal Energy Regulatory Commission's denial of a renewal permit. Within years, biologists observed with some surprise the return of scores of striped bass, alewives, American shad, Atlantic salmon, sturgeon, ospreys, kingfishers, cormorants and bald eagles. They also found that the water became well aerated and that populations of important food-chain insects such as mayflies, stoneflies and caddisflies grew.

Their costs are obvious as well. Dams displace people and as a result have become increasingly controversial in the developing world [see "The Himba and the Dam," by Carol Ezzell; *SCIENTIFIC AMERICAN*, June 2001]. The structures ruin vistas, trap sediments (needed for deltas, riverbanks and beaches), stymie migratory fish and destroy ecosystems in and around waterways. Conservation-

ists have a long history of opposing dams: John Muir tried to block the dam in Yosemite's Hetch Hetchy Valley; Edward Abbey's novel *The Monkey Wrench Gang* targeted Arizona's Glen Canyon Dam for guerrilla demolition. In recent years, as the downsides of dams have become more widely recognized, groups made up of several interested parties—utility officials, regulators,

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In the Loire Valley, the story is similar. Salmon were abundant in the 19th century—about 100,000 would migrate each year—but by 1997, only 389 were counted making the trip. Despite the incorporation of fish ladders and elevators, the eight dams along the Loire and its major tributaries—as well as their turbines and pumps—had decimated the salmon population. Nongovernmental organizations, including the European Rivers Network, led a campaign to bring the salmon back. In response, the French government decommissioned four of the dams—two in 1998, one in 2003 and one in 2005. Within a few months of each dam removal, five species of fish, Atlantic salmon and shad

Overview/Restoring River Flows

- Some 800,000 dams exist around the world, but small ones—and even some large ones—are increasingly being removed so rivers and streams can recover.
- Ecologists are learning, however, that removing or lowering dams takes a great deal of careful planning and active intervention because sometimes the dams confer environmental benefits, such as holding back toxic sediments or blocking the progress of invasive species.
- Before decommissioning a dam on Fossil Creek in Arizona, managers poisoned exotic fish and airlifted native species to safety. Such strategies could prove key to the success of future dam removal projects.

among them, began to reestablish their historic migratory pathways.

In most places where dams have been eliminated, the stories of the Kennebec and the Loire have been repeated. Water clarity and oxygen levels increase as flow comes back, and aquatic insects thrive again. Warm stagnant water runs from behind the dam along with the fish, such as nonnative carp, that love it. As the water moves freely, its temperature falls and cold-loving fish species, such as trout, proliferate or return. The carp population, which tends to squeeze out others, dwindles, sometimes disappearing completely. People, in addition to flora and fauna, return to enjoy the rivers. Biologists have observed these benefits from Wisconsin—one of the U.S. leaders in small dam removal—to New South Wales in Australia. Even restoring some water to rivers without removing a dam has had positive effects [see “Experimental Flooding in Grand Canyon,” by Michael P. Collier, Robert H. Webb and Edmund D. Andrews; SCIENTIFIC AMERICAN, January 1997].

The Downsides

BIOLOGISTS have also recorded unexpected problems. The release of sediments trapped behind a dam's walls can choke waterways, muddying the environment and wiping out insects and algae, which are important food for fish. This wave of turbidity can also eliminate habitat for sessile filter feeders, such as freshwater mussels. Sometimes the mud that had been held back by the structures is rife with contaminants. When engineers removed the Fort Edward Dam on the Hudson River in 1973, concentrations of PCBs rose in downstream fish and remained high for many years; even today the striped bass fishery remains closed because of high levels of PCBs.

Sediments that are not washed downstream can become problematic as well. As they dry out, they may provide fertile ground for potentially noxious exotic plants whose seeds they harbored. Eurasian reed canary grass—which homogenizes wetlands by outcompeting native plant species—grew explosively after Wisconsin's Oak Street Dam fell, even

though restoration scientists had seeded the area with native prairie plant species.

In some cases, dams have blocked invasive species from moving upriver and into zones above the dam. The dam at Fossil Creek, for example, halted the advance of exotic fish such as bass and sunfish, creating a sanctuary above the structure for imperiled southwestern fish, including headwater chub and speckled dace. The reservoir also provided habitat for a locally threatened species, the lowland leopard frog.

And dam removal can pose dangers for people living nearby. In places where flood control is crucial, government organizations have had to devise safety

reservoir-resident frogs. Ultimately engineers decided to reroute water around the dam, keeping it as a barrier to exotics and permitting the frogs to survive in the backwater.

In addition, biologists decided to actively manage the native fish. They caught as many as they could from the creek itself and airlifted them to a holding tank. They then doused the creek with fish poison to kill exotic species and returned the natives to the water once the poison had dissipated. The U.S. Bureau of Reclamation built a fish barrier 12 kilometers below the existing dam to further impede exotics. Now managers are waiting to see how the Fossil Creek species

Often a big issue facing managers is what to do with ACCUMULATIONS OF DIRT AND DEBRIS.

strategies before dams could come down. In the case of the Loire basin, the government computerized data on weather patterns, rainfall and river levels so flood warnings could be released at least four hours before danger arrived. Engineers also redesigned riverbeds to be wider and deeper, so the waters of the Loire Valley could move more freely without overflowing the banks.

Delicate Decommissioning

THE FOSSIL CREEK restoration project offers a prime example of the kind of planning that could help minimize the damaging effects of dam removal. Researchers carefully planned to control possible disadvantages of the operation. Their principal concerns were what to do with the accumulated sediments, whether to manage the fishery as a native one (which would mean removing exotic species) and how to protect the

do. The dam's fate will be decided in 2010: if the leopard frog becomes established downstream and exotic fish have not reinvaded the creek, the dam will come out. If not, it will be lowered but not eliminated.

Interestingly, restoring Fossil Creek involves the creation of many more dams—but these will be made of travertine, formed naturally as the calcium carbonate-rich water of the springs interacts with algae to form layers of limestone. These barriers create small, deep pools, the perfect habitat for a variety of fish and insects. They also trap leaf litter, a crucial food source for the river's denizens—one that the presence of man-made dams often eliminates by trapping it permanently behind the barrier.

Wrangling Sediment

SEDIMENTS STUCK behind dams are proving crucial variables when dams are

JANE C. MARKS owes her career as an ecologist to algae. After completing her undergraduate degree in English at the University of Michigan at Ann Arbor, Marks became fascinated with aquatic plants and earned an M.S. in biology from Bowling Green State University and then a doctorate from the University of California, Berkeley. In 1995 she began working for the U.S. Agency for International Development, advising the organization about conservation and resource management issues all over the world. In 1999 she joined the faculty at Northern Arizona University. Her work on Fossil Creek is being featured in a new documentary, *A River Reborn: The Restoration of Fossil Creek* (see www.riverreborn.org).

taken down. Often the biggest issue facing managers is how to contend with what can be a massive accumulation of dirt and debris. Because of the legacy of releasing PCBs downstream in the Hudson River, scientists now routinely test these materials for toxicity. If the sediments contain high levels of pollutants, the cost of removing them—especially from remote locations—has to be weighed against the ability of the waterway to wash them away. If the sediment load is very high and the river's flushing capacity low, engineers might opt to remove the dam in stages, allowing small amounts of sediment to be released at a time. Sometimes engineers build channels through reservoirs, planting vegetation to stabilize sediments or placing physical barriers such as rocks or temporary fencing to hold the dirt in place.

In Fossil Creek, where roughly 25,000 cubic yards of sediment are trapped behind the dam, geologists and others predicted that the river would naturally flush the sediments downstream within a decade, without any ad-

verse effects. So the project did not have to weigh the cost and negative environmental impacts of transporting heavy machinery into a wilderness area.

Sediments pose a much bigger problem in many other places, however. Six million cubic yards of dirt lie behind the Matilija Dam on the Matilija Creek in southern California. (So much sediment, in fact, that the dam no longer serves to store water for irrigation or drinking.) At the same time, the downstream beaches are starved of sediment: they badly need dirt and sand to stave off ongoing erosion from wind and rain.

Matilija Dam is scheduled to be decommissioned in 2009, and managers have devised an elaborate sediment plan. They intend to transport fine sediments from behind the dam through a slurry pipe to sites five to 11 kilometers downstream. From there, the river will do the work by redistributing these materials during flood events to form beaches and sandbars. The larger, or coarse-grained, sediments that have accrued upstream of the dam will be left in place, but en-

gineers will regrade the river channel there into a more naturally sinuous one, which will better protect against flooding by allowing sediments to settle and rebuild the banks.

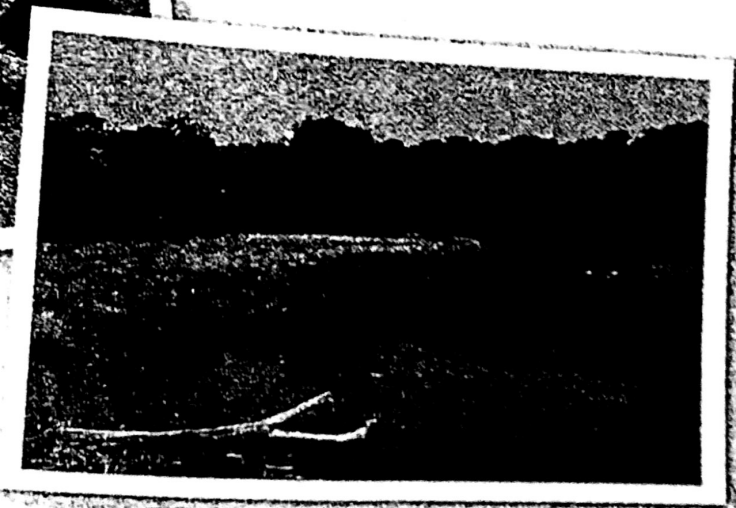
Going Forward

AT FOSSIL CREEK and elsewhere, managers and scientists are using all available information about dam removal and restoration ecology, as well as what they know of the entire watershed, to make decisions. But many gaps in our knowledge about ecosystems remain, and those working on decommissioning dams recognize they are conducting long-term experiments that may have unanticipated results. Fossil Creek, for example, was the first such project in which exotic fish were removed. If successful, this strategy could become routine, especially in smaller streams where chemical treatment is feasible.

At Fossil Creek our research team will now document how the river recovers. Among many unanswered questions we hope to focus on in the next five to 10 years are: Will native fish prosper without intervention? Will exotic fish come back? One interesting but problematic twist in the Fossil Creek story is that the chemical used to eliminate the exotic fish does not harm exotic crayfish, which are notorious for wreaking havoc on the food chain. The exotic fish had consumed crayfish, thereby keeping the crustacean's population down. Perhaps we will have exchanged one adverse situation for



NATIVE FISH return to Fossil Creek in buckets (above), after having been airlifted out and placed in holding tanks. Biologists treated the river with fish poison to get rid of the exotic species before returning the natives. Nonnative species were also a problem after engineers removed the Oak Street Dam on the Baraboo River in Wisconsin. Eurasian reed canary grass dominated the riverbanks, even though managers had planted native species (right).



CARRIE LEROY (left), FROM "TRADING OFF: THE ECOLOGICAL EFFECTS OF DAM REMOVAL," BY H. AND M. W. DOYLE, IN FRONTIERS IN ECOLOGY AND THE ENVIRONMENT, VOL. 1, PAGES 13-22, 2003; COURTESY OF CAILIN HUYCK ORR (right)

another. In addition, as Fossil Creek rebounds, so do the numbers of visitors to it. With more hiking trails in place along the river, managers now need to devise rules that can allow people access but also protect the fragile ecosystem.

To supplement the in situ experiments such as the one at Fossil Creek, researchers are using computer simulations and are conducting indoor studies. The National Center for Earth-surface Dynamics in Minnesota has created a model ecosystem of miniature streams, dams and reservoirs. Investigators there use time-lapse photography to determine how sediments move downstream as dams are removed in different ways and to different extents.

Many engineers who were once dedicated to building dams now find themselves instead working on decommissioning them. U.S. government agencies such as the Bureau of Reclamation and the Army Corps of Engineers, as well as their European counterparts, are studying not only how to remove dams but also how to provide the benefits of the structures without their injurious effects—for instance, how to extract water from rivers without building blockades. In response to a 2000 report by the World Commission on Dams, engineers are also trying to incorporate decommissioning into the original designs of future dams.

Societies will continue to balance the pros and cons of dams, weighing their utility and benefits against their destructive costs. And scientists must continue to learn about how best to remove dams so natural ecosystems and human communities both can thrive. In the next few years the decommissioning of several large dams will provide further important knowledge. In 2009 two dams will be removed from Washington State's Olympic National Park: the 210-foot-high Glines Canyon Dam and the 108-foot-high Elwha Dam. Scientists in both locations are now collecting baseline data about salmon and steelhead, as well as oxygen levels, insect populations and sediment loads. Japan's Arase Dam will come down in 2010 in response to a long campaign by citizen activists con-



RIVER MODEL at the National Center for Earth-surface Dynamics in Minnesota provides scientists with a way to study how sediments move. This research can help experts plan what to do with the dirt and other material that accumulates behind dams.

cerned about poor water quality and a decline in fisheries. Australia will transform the 19,500-acre Lake Mokoan into a wetlands again when its dam is removed, while France contemplates the fall of a fifth Loire Valley dam.

In most cases, controversy about decommissioning arises—and sometimes the debate is unexpected. In the Loire Valley, a father and son ended up on different sides of the divide. The father remembered the wild rivers and the salmon runs; the son had grown up swimming and boating in the reservoir. In the case of Fossil Creek, the local community wanted to preserve components of the generating station, the Childs-Irving facility. Built by one of the few female engineers of that era, Iva Tutt, and main-

tained by generations of engineers who lived at the site with their families, the plant was culturally significant, and, accordingly, its preservation became part of the restoration plan.

The same proved true of the Wellington Dam in New South Wales, Australia. In 2002 the State Water Corporation ensured that a one-meter-high footprint of the structure remained (minus one gap for flow) across Bushrangers Creek so the public could still appreciate the dam that was built in 1898. With compromises such as these, along with further ecological insights and more flexible engineering, it seems possible to think of the world's waterways as ultimately fulfilling their promise for all parties—from plants to people. ■

READ TO ENLIGHTEN

Undamming Rivers: A Review of the Ecological Impacts of Dam Removal. A. T. Bednarek in *Environmental Management*, Vol. 27, No. 6, pages 803–814; June 2001.

Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration. D. D. Hart et al. in *BioScience*, Vol. 52, No. 8, pages 669–681; August 1, 2002.

Dam Removal Research: Status and Prospects. Heinz Center, 2003. Available at www.heinzcenter.org/NEW_WEB/PDF/Dam_Research_Full_Report.pdf

Trading Off: The Ecological Effects of Dam Removal. Emily H. Stanley and Martin W. Doyle in *Frontiers in Ecology and the Environment*, Vol. 1, No. 1, pages 15–22; 2003.

Interactions between Geomorphology and Ecosystem Processes in Travertine Streams: Implications for Decommissioning a Dam on Fossil Creek, Arizona. Jane C. Marks et al. in *Geomorphology*, Vol. 77, Nos. 3–4, pages 299–307; July 2006.

American Rivers: www.americanrivers.org