USDA United States Department of Agriculture
Forest Service

PNW Pacific Northwest Research Station

Science FINDINGS

issue one hundred ninety three / february 2017

"Science affects the way we think together."
Lewis Thomas

Liberated Rivers: Lessons From 40 Years of Dam Removal

Kate Benkert, USFWS/Flickr

The removal of Elwha Dam (above) and the Glines Canyon Dam on the Elwha River in Washington is the Nation's largest such project to date. Science on the geomorphic response of a river as accumulated reservoir sediment is suddenly released is being used to recognize and avoid potential problems.

IN SUMMARY

In recent decades, dam removal has emerged as a viable national and international strategy for river restoration. According to American Rivers, a river conservation organization, more than 1,100 dams have been removed in the United States in the past 40 years, and more than half of these were demolished in the past decade. This trend is likely to continue as dams age, no longer serve useful purposes, or limit ecological functions. Factors such as dam size, landscape and channel features, and reservoir sediment characteristics differ widely, so dam removal projects must be evaluated individually to determine the best approach. Stakeholders need trusted empirical findings to help them make critical decisions about removal methods, how to recognize and avoid potential problems, and what to expect in terms of geomorphic and ecological recovery.

Gordon Grant, a research hydrologist with the Pacific Northwest Research Station, in partnership with a U.S. Geological Survey working group, extracted key lessons from studies of dam removals to help guide future removals and predict geomorphic and ecological outcomes. The combined findings provide evidence that rivers are remarkably resilient, and when dam removal is well planned and executed, recovery is swift and few long-term problems have occurred. Although geomorphic responses are reasonably predictable, biological responses are less so, and in both cases dam owners and project managers would do well to plan for the unexpected. Numeric and physical models are proving to be valuable decisionmaking tools.

"Restoration is an acid test of our ecological understanding."
—Anthony D. Bradshaw, ecologist

More than 87,000 dams existed on America's waterways in 2013. About half of these dams were built during the post-World War II boom between 1950 and 1980. Astonishingly, these figures reflect only registered dams—it is estimated that there could easily be 10 times as many smaller dams, including those built by early pioneers to create mill and log ponds or to divert waterways for irrigation or minor flood control.

Today, many thousands of dams—most of which are privately owned—are aging. Many have outlived their usefulness or have become safety hazards. Many registered hydropower dams are coming up for relicensing, and owners must ensure that their infrastructure meets environmental regulations that did not exist when the dams were built. As a result, increasing numbers of dam owners are making the

decision to demolish their dams rather than make financially unfeasible upgrades or risk leaving themselves open to potential litigation.

Additionally, scientific knowledge is growing about the detrimental effects that damming can have on river ecosystems. For example, dams block or severely limit fish passage or negatively affect habitat by trapping sediments and other natural debris from downstream reaches, and they can seriously degrade water quality by slowing rivers and raising water temperatures.

In the United States, this confluence of circumstances and knowledge has contributed to a shift in focus from building dams to removing them. Dam owners are seeking guidance from the scientific community about how to plan, execute, and monitor demolition processes without creating havoc on river channels and water-dependent species, or upsetting adjacent landowners.

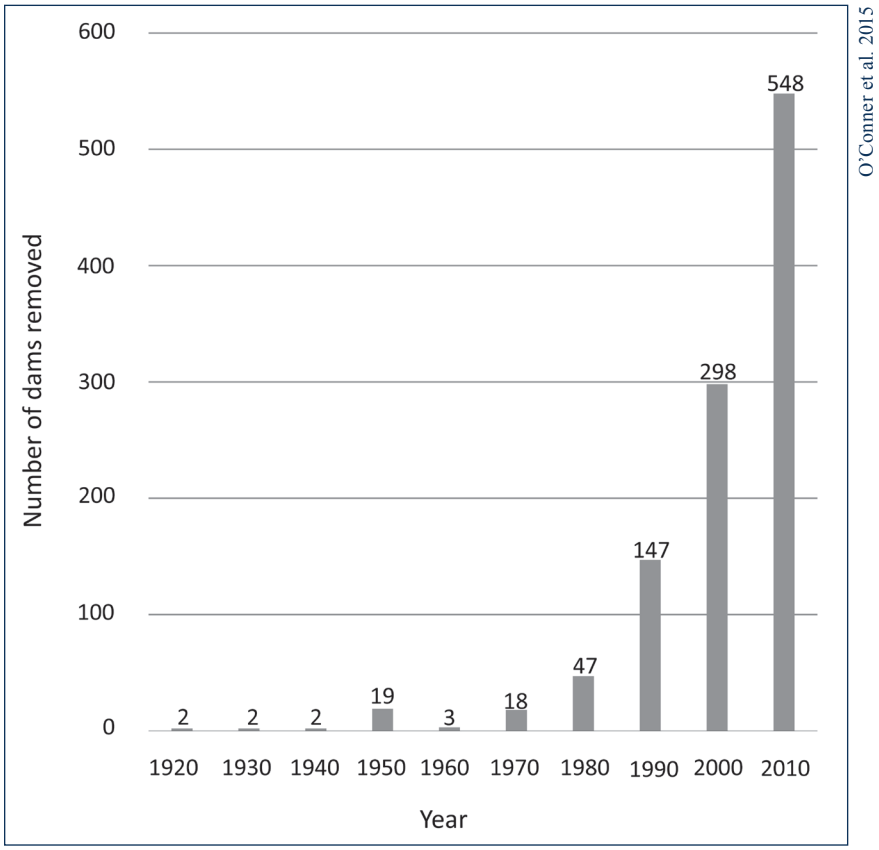
Only recently have enough empirical studies of dam removals been completed to give scientists confidence in their pre removal predictions. Scientists are now able to show how dam removal can improve fluvial connectivity, reduce environmental hazards associated with aging infrastructure, and promote recolonization of river reaches that have been blocked for decades.

Gordon Grant, a research hydrologist with the Pacific Northwest Research Station, is part of the vanguard in the emerging discipline of dam removal science. In 2014, he joined a working group at the U.S. Geological Survey's John Wesley Powell Center for Analysis and Synthesis, composed of 20 scientists representing a variety of disciplines at universities, government research and management agencies, and American Rivers, the leading nonprofit organization working on dam removals. The scientists came together to produce multiple synthesis publications about physical and ecological responses to dam removal and created the most detailed and wide-ranging analysis of dam removal science to date.

"As the most comprehensive cross-disciplinary 'big-data' synthesis of existing dam removal studies, the working group's output fundamentally redefines what scientists know—and don't know—about dam removals," says Grant. "We've looked beyond case studies to develop synthetic and analytical frameworks that have general applicability and can provide useful guidance as dam removals become more common, both nationally and internationally."

KEY FINDINGS

- Geomorphic responses to dam removal are rapid. Most sediment stored in reservoirs is evacuated within months to a few years following removal, and robust fish populations rapidly reestablish in previously blocked reaches.
- Geomorphic responses to dam removal are reasonably predictable. Key factors include dam size, removal method, and sediment volume and grain size. Numerical and physical models are useful for predicting rates and styles of response.
- Biological responses are less predictable. Rates of recolonization are influenced by interactions among species, the presence of other channel blockages, and the overall condition of the watershed.
- Surprises happen. Despite generally predictable response trajectories, unexpected events can occur. For example, rapid drawdown of reservoirs following removal has resulted in massive landslides and mudflows.



Many U.S. dams were built during the economic boom following World War II and are now due for relicensing. Some owners are choosing dam demolition rather than making costly upgrades to these aging infrastructures.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscriptions and change of address information to:

pnw_pnwpubs@fs.fed.us

Rhonda Mazza, editor; rmazza@fs.fed.us

Cheryl Jennings, layout; cjennings@fs.fed.us

Science Findings is online at: http://www.fs.fed.us/pnw/publications/scifi.shtml

To receive this publication electronically, change your delivery preference here:

http://www.fs.fed.us/pnw/publications/subscription.shtml

USDA United States Department of Agriculture

Forest Service

THE PRIMARY FACTOR: DAMMED SEDIMENT

River water carries all kinds of debris as it flows downhill on its journey to the ocean. When the water is dammed, much of the debris it carries gets trapped in the reservoir behind the dam. Depending on the landscape, rivers can carry fine-grained silt and clay, medium-grained sand and gravel, and large cobbles and boulders. Downed trees, branches, and other natural debris also get flushed downstream, and much of this debris gets deposited where the water slows.

This mixture of organic and inorganic materials settles to the bottom of reservoirs and gradually accumulates over the years. Depending on the size of the dam, and thus the size of the reservoir, tens to hundreds of millions of cubic feet of sediment can build up over 50 or 100 years. For example, the Marmot Dam on the Sandy River in Oregon, which was built in 1913 and demolished in 2007, was only 45 feet tall, but about 20 million cubic feet of sediment were estimated to have accumulated behind the dam prior to its destruction. Many dams are hundreds of feet tall, and thus have the capacity to store much larger volumes of sediment.

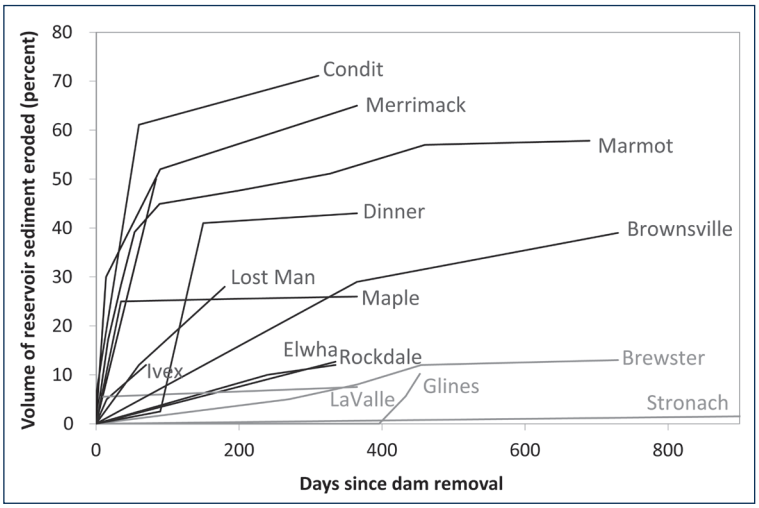
So what happens to all that sediment when the dam is removed? How long will it take to pass through the system? How will it affect the channel, both upstream and downstream of the dam? These are some of the questions Grant and his colleagues have made significant progress toward answering in the past few years.

One result of their studies, Grant says, is that geomorphic responses to dam removal are now relatively predictable.

"In general, sediment issues tend to drive both the decision as to whether a dam should come out or not, and also whether there will be significant consequences as a result of removing the dam," he says.

Jon Major, USGS

The 2007 breaching of the Marmot Dam on the Sandy River, Oregon, released about 20 million cubic feet of accumulated sediment. About 60 percent of it was deposited downstream within 2 years. Above, the knickpoint emerges in the earthen cofferdam that was built to allow workers to remove the concrete infrastructure.



Grant and Lewis 2015

Erosion rates of reservoir sediment for 12 recently removed dams. Several factors affect the rate of sediment erosion, including size of the sediment (rock, gravel, sand) and size of the dam, river, and reservoir.

PREDICTING A RIVER'S RESPONSE

Armed with data from dams removed in recent years, researchers have developed numerical models that can predict how an individual river system will respond during and after a dam removal. Key metrics used include the size of the dam, the method used to remove it, the estimated volume of sediment trapped in the reservoir, and the grain size of the sediment. Physical models of individual dams are also proving useful for predicting the rates and styles of response, and are especially useful when deciding which removal method would be best to apply in any given project.

"Compared to where we were 15 years ago, we have a much better understanding."

—Gordon Grant, research hydrologist, PNW Research Station

Just how the sediment comes into play in a dam removal is highly dependent on the removal method used. "You can take a dam out all at once, or you can take it out slowly, and the consequences for the way sediment is released are profoundly different depending on how you do it," says Grant.

If a dam is removed all at once, sediment is released very quickly, and this method is frequently chosen for smaller dams. A larger dam, or a dam where there is concern about the type of sediment stored in the reservoir, is best removed by breaching the dam in sections or stages.

The vertical height of the dam becomes important in these decisions because of something called the "knickpoint." A knickpoint is a sharp change in the slope of the river channel, such as the step that creates a waterfall. A dam represents a stationary knickpoint in the river's channel.

When a dam is removed quickly, the enormous energy of flowing water is focused at the former step and the knickpoint can move upstream rapidly, particularly if the reservoir is full of sediment. "You essentially get an upstream-migrating waterfall cutting its way backward up the channel," says Grant.

The rate at which the sediment comes out is driven largely by how quickly the knickpoint moves upstream, which in turn has to do with

the character of the sediment stored in the former reservoir, the sequence of flows, and the presence of buried obstructions and bedrock.

"We've been able to come up with some reasonably good ways of anticipating where the sediment is going to go," says Grant. "Our numerical models calculate how forces generated by the removal—the amount of water in the river, the gradient of the river, the shape of the channel, the roughness of the bed—act on those particles and transport them downstream."

Grant is quick to point out that the majority of dams removed to date fall into the small- to medium-size category—less than 50 feet high. "Unfortunately, we don't have enough examples of big dam removals to get a good sense of the full range of possible responses," he says. "But, compared to where we were 15 years ago, we have a much better understanding of geomorphic and biological responses."

Jon Major, USGS

Five years after the Marmot Dam removal. Native anadromous fish such as Chinook and coho salmon, and steelhead now have access to upstream spawning grounds previously blocked by the dam.

"SURPRISES HAPPEN"

What is less predictable is how long it will take for the sediment to disperse in the manner anticipated by the models. Weather is a big consideration when timing the release of a backed-up river. Scientists must rely on historical observations when predicting seasonal patterns, and although this data is certainly useful, the past is not always the best predictor of the future, particularly when climate change enters the picture.

"You never know what the existing flows will be," says Grant. "Is it going to be a wet winter or a dry winter? Will it flood just when you least want it? Or maybe you hope for high flows and you get drought instead. All these things affect the outcome."

Laura Craig, director of science and economics and river restoration programs with American Rivers, worked alongside Grant as part of the Powell Center working group and has managed numerous dam removal projects. In October 2012, she was overseeing the Darby Creek Restoration Project—a series of three dam removals—in Delaware County, Pennsylvania, when the eye of Hurricane Sandy passed directly overhead. This, of course, was not part of the original plan.

"You do your modeling, and everything you plan for assumes typical conditions for that time of year," says Craig. "You might assume standard flow conditions for October, and you'll make assumptions about how quickly the sediment will flush out based on what the storm frequency is. But we're not often predicting a megastorm."

As it turned out, the amount of rainfall associated with the storm did not set any records, and the project had a positive outcome. A site-specific feature of one of the dams was that it tended to trap huge logs behind it, slowing the water and causing localized flooding. Fortunately, the crew had just removed the dam and debris before the storm hit, which most likely prevented what could have been serious flooding in a populated area.

"Removal created a better path for the floodwater to pass through without backing up into the neighborhood," says Craig. "It was a little scary, but we were really lucky. Having an understanding of what, for example, a huge amount of additional rainfall will do to a site is useful because knowing that helps us to adapt on the spot."

Another example of unexpected occurrences involved removal of the Elwha Dam on the Elwha River in Washington State. The dam, which was built in 1912 and removed in 2012, was 108 feet high and had an estimated 53 million cubic feet of sediment trapped behind it. Scientists had not anticipated the large amount of woody and organic debris that came down the channel, clogging a water treatment plant for the City of Port Angeles that had been specifically built to accommodate the dam removal.

In some instances, rapidly draining reservoirs have resulted in massive landslides and mudflows, or the unexpected release of contaminants. These are just some of the surprises that Grant believes can be avoided with thorough pre removal studies informed by the latest available science.

RAPID RECOVERY

Biological responses are less predictable than geomorphic recovery. The rates of recolonization are influenced by interactions among species, the presence of other dams or blockages along the river, and the overall condition of the watershed.

"You can't model critters as neatly with a numerical model," says Grant, "because they're not just responding to physical forces; they're responding to biological pressures like predation, community structure, habitat, and so forth."

But Grant and many of his colleagues were initially surprised at how quickly rivers and their inhabitants respond to their reclaimed freedom. Whether a dam comes down quickly or slowly, aquatic species seem to waste little time in taking advantage of restored habitat. Fish populations generally regenerate within a season or two. As a research area, however, biological response to restoration is in its infancy.

"While we've found that rivers get repopulated pretty quickly, it's not easy to predict what trajectory it will follow," says Grant.

John Esler, a project manager at Portland General Electric, was responsible for overseeing the removal of the Marmot Dam. He is extremely grateful to Grant and all the scientists and stakeholders who participated in evaluating pre-removal strategies and recommending a course of action.

"It was a real collaborative process," says Esler. "So by the end of the day, the federal and state agencies, the tribes, the environmental groups, and the local community all accepted the risk and said 'this is the right thing to do.' I'm a big believer in the value of these collaborative efforts with our public institutions to help us do the right thing. It's a great relationship that pushes science forward and actually has practical value on the ground."

"The measure of the restoration lies in the extent to which we apply social values more noble than mere monetary profits"

—Franklin D. Roosevelt

LAND MANAGEMENT IMPLICATIONS

- The findings provide a sound empirical basis for dam removal as a rational, workable strategy to improve fluvial connectivity, reduce environmental hazards associated with aging infrastructure, and promote recolonization by fish and other aquatic organisms in previously blocked reaches.
- Compared to large knowledge gaps 15 years ago, we now have a much better understanding of geomorphic and biological response trajectories that can provide guidance for future removals.
- Numerical and physical models that predict the evacuation rate of sediment, downstream sediment fluxes under a range of conditions, and the fate and consequences of downstream sediment can now be applied to specific removals.
- Because of the potential for unexpected outcomes and consequences, adequate pre-removal studies and post-removal monitoring are strongly recommended. This research can help focus these efforts.

Laura Craig, American Rivers

The Darby Borough Dam (above) was one of three dams removed during the Darby Creek Restoration Project in Pennsylvania.

Laura Craig, American Rivers

Three years after removal of the Darby Borough Dam. During Hurricane Sandy, the benefit of the restored flood plain was readily apparent: floodwaters were able to spread out rather than back up behind the dam and flood upstream communities, as had happened during heavy rains when the dam was intact.

FOR FURTHUR READING

O'Connor, J.E.; Duda, J. Grant, G.E. 2015. 1000 dams down and counting. Science. 348(6234): 496–497.

Grant, G.E.; Lewis, S.L. 2015. The remains of the dam: What have we learned from 15 years of U.S. dam removals? In: Lollino, G. [et al.], eds. River basins, reservoir sedimentation and water resources. Switzerland: Springer International Publishing: 31–35. Vol. 3.

Major, J.; East, A.; O'Connor, J.; Grant, G., [et al.] 2015. Geomorphic responses to U.S. dam removals—a two decade perspective. Conference proceedings for Gravel Bed Rivers 8.

Major, J.J.; O'Connor, J.E.; Podolak, C.J., [et al.]. 2012. Geomorphic response of the Sandy River, Oregon, to removal of Marmot Dam. Reston, VA: U.S. Department of the Interior, Geological Survey. Professional Paper 1792. 64 p. http://pubs.usgs.gov/pp/1792.

WRITER'S PROFILE

Marie Oliver specializes in science writing and developmental editing. She can be reached through her website at http://claritywriting.com.

Science
FINDINGS

U.S. Department of Agriculture
Pacific Northwest Research Station
1220 SW Third Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, $300

PRSRT STD
US POSTAGE
PAID
PORTLAND OR
PERMIT N0 G-40

SCIENTIST PROFILE

GORDON GRANT is a research hydrologist at the Pacific Northwest Research Station and professor (courtesy) at the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University. Following a decade-long career as a whitewater river guide, he earned a Ph.D. from Johns Hopkins University in 1986. His research has focused on the geomorphic response of rivers to changes in streamflow and sediment transport owing to land use, dams, and dam removal, and climatic variation. This work has included extended collaborations with research groups in Japan, China, and Italy. He is a Fellow of both the American Geophysical Union and the Geological Society of America.

Grant can be reached at:

USDA Forest Service
Pacific Northwest Research Station
3200 Jefferson Way
Corvallis, OR 97331

Phone: (541) 750-7328
E-mail: ggrant@fs.fed.us

COLLABORATORS

Working Group, John Wesley Powell Center for Analysis and Synthesis, U.S. Geological Survey

Laura Craig, American Rivers, Washington, DC

John Elser, Portland General Electric, Portland, OR

Sarah Lewis, Oregon State University, Corvallis, OR

"USDA is an equal opportunity provider, employer, and lender."