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INSIDE

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

A RAVENOUS RIVER RECLAIMS ITS TRUE COURSE: THE TALE OF MARMOT DAM'S DEMISE

Dismantling Marmot Dam on the Sandy River, Oregon, improved river access for fish and provided valuable information about how a river system responds to dam removal. Above, crew breach the cofferdam that held back the river while Marmot Dam was removed.

"Any river is really a summation of the whole valley. To think of it as nothing but water is to ignore the greater part."
—Hal Borland

Across the country, hundreds of thousands of rivers dissect the landscape with watercourses totaling 3.5 million miles. Since the Nation's founding, humans have harnessed this freshwater wealth, impounding roughly 600,000 miles behind dams big and small. As former Secretary of the Interior Bruce Babbitt once observed, the national inventory of approximately 80,000 dams used for flood control, water supplies, and hydropower corresponds to roughly a dam per day since the ink dried on the Declaration of Independence.

But dams do not last indefinitely. They are subject to damage from natural disasters and inevitably fill with silt and debris that a free-flowing river normally carries downstream. Operating dams involves costly maintenance, and, if used for producing hydropower, dams

IN SUMMARY

Removing dams that are outdated, unsafe, or pose significant economic or environmental costs has emerged in the last 10 years as a major river restoration strategy. The removal of the 45-foot-high Marmot Dam on the Sandy River in 2007 resulted in the biggest sediment release accompanying any dam removal to date. It also provided an unprecedented opportunity for a team of scientists from the Pacific Northwest Research Station and other organizations to predict, monitor, and evaluate the river environment before, during, and after the event.

The dam removal was successful on many levels. The earthen cofferdam that had been temporarily constructed while Marmot Dam was dismantled rapidly eroded on cue, and reservoir sediments were transported downstream on a timetable that surpassed all expectations. This happened with no detrimental effects on fish habitat or increased flooding that might impact downstream properties. Removing Marmot Dam showed that an energetic river can rapidly and efficiently do the work of redistributing huge volumes of unconsolidated sediment, even under very modest flows. Results are likely to guide future dam removals for the next decade or more, and offer dam managers a cost-effective option for sediment disposal in some cases.

require oversight and licensing by the Federal Energy Regulatory Commission (FERC). Since the last decade, the licenses of hundreds of hydropower dams built primarily during the 1950s and 1960s have begun to expire, forcing their parent agencies to evaluate whether to renew their licenses—which necessitates meeting provisions that now include environmental and other public interest considerations—or decommission the dams.

Portland General Electric (PGE) faced this quandary with the 22-megawatt Bull Run Hydroelectric Project, a complex comprising a diversion dam (Marmot) on Oregon's Sandy River that shunted water via flumes to a second dam and power station on the Little Sandy River. For nearly a century, the structures blocked the natural migration of river-spawning fish, including threatened species such as salmon, steelhead, and cutthroat trout, and prevented their access to some 280 miles of habitat, primarily on the stretch of river above Marmot Dam. According to PGE hydro-project manager Dave Heintzman, the price tag for relicensing—including protection, mitigation, and enhancement measures required by FERC—was a whopping $20 million. In view of this and the escalating costs of maintaining a hydro-system originally constructed in 1913, PGE opted in 2002 to remove the dam and associated facilities.

KEY FINDINGS

- The Sandy River's response to the Marmot Dam removal showed that even under modest flows, a river of sufficient flow and gradient can rapidly incise and transport downstream very large stores of unconsolidated sediment. About 20 percent of the sediment from the former reservoir was exported within the first 48 hours after dam breaching, exceeding all expectations.
- The river's breach of the cofferdam began slowly, then sped up as the channel deepened and widened. Turbulence eroded the dam face, while the "knickpoint" retreated upstream, temporarily stalling at the crest, then accelerating rapidly.
- Immediately following the breach, sediment traveled downstream in waves, with the sand moving out ahead of the gravel. Over the following months, the channel evolved from a single thread to braided, and new bars and riffles developed.
- Most of the channel alteration occurred upstream of the bedrock gorge, with only limited changes downstream, confirming predictions made by the numerical models.

PLANNING FOR AN UNPRECEDENTED DAM REMOVAL

The utility decided on a so-called "blow-and-go" strategy for Marmot Dam, situated some 27 miles above the Sandy River's confluence with the Columbia River. This would entail several steps. First, work crews would build an earthen cofferdam (from a portion of the dammed sediments) about 250 feet upstream of the main structure, and divert the river (at low summer flow) around the dam. Then, using explosives, they would "soften up" the concrete structure and excavate and truck out the rubble. Finally, instead of hauling away the sediments stored behind the dam, PGE planned to wait for a late-2007 rainstorm to raise the river's flow, allowing the water to breach the cofferdam and have its way with the sediments.

At the time, this was the largest dam to be removed in the Pacific Northwest. The dozens of small dams torn down in the Pacific Northwest during the previous decade had been fairly small structures impounding modest amounts of sediment. In contrast, decommissioning Marmot—which stood 45 feet high and 165 feet wide—would

Gordon Grant

Marmot Dam was situated on the Sandy River, about 27 miles above its confluence with the Columbia River.

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release a million cubic yards of sand and gravel (the equivalent of 100,000 dump-truck loads) originating from volcanic debris on Mount Hood.

It was an unprecedented move, and it offered a unique opportunity, says Gordon Grant, a research hydrologist with the Pacific Northwest Research Station in Corvallis, Oregon. “There was no assigned scientific team for the dam removal project, yet this was a rare opportunistic field experiment, a chance to study one of the biggest unknowns in river geomorphology: how a large, energetic river digests a mammoth meal of sediment.”

So Grant, along with Jim O’Connor, and Jon Major, both with the U.S. Geological Survey (USGS), jumped at the prospect. “The science just self-organized around it, with tremendous grassroots enthusiasm. The scientists pooled research dollars, and PGE, the Forest Service, USGS, and National Science Foundation also chipped in funds,” explains Grant. The project eventually drew in a diverse group of some two dozen collaborators to provide what Grant describes as “the most detailed dataset of geomorphic response to dam removal ever assembled.”

Diagram courtesy of Portland General Electric

A temporary cofferdam upstream of the dam diverted the river to a bypass channel while work crews removed the concrete structure.

ANTICIPATING THE RIVER’S APPETITE

“The overriding scientific question on everyone’s minds was what would happen to the sediment after the river was unleashed,” Grant recalls. “The chief management concerns were that material transported downstream once the river breached the cofferdam might directly affect fish or bury their habitat. There was also the potential for the flooding of downstream property,” he explains.

This led to other questions, Grant says. “One big uncertainty was how quickly the river, with its relatively steep gradient, would erode through the cofferdam and move sediment downstream. We knew a knickpoint—an abrupt change in channel slope, such as a waterfall—would form in the cofferdam and retreat upstream; the issue was, would it stall and thereby block fish passage?”

Another unknown was whether the river would erode all of the reservoir deposits, or would some remain in place, forming unstable terraces that would continue to erode, posing possible hazards? Finally, how would the moving water and sediment alter the river channel and affect fish habitat? In an effort to prevent unwanted impacts, the decision was made to facilitate rapid erosion from the reservoir, if possible.

To begin addressing these questions, researchers from 10 institutions collected a slew of baseline data on the river above and below the dam. Using field survey techniques, remote sensing, and aerial photos, they obtained profiles of the channel and mapped its geometry. The research team measured stream properties such as temperature, discharge, and the volume of sediment moving in the water as well as along the riverbed. They documented the configurations of pools and riffles—essential components for suitable fish habitat. This and other information would serve as the basis for evaluating changes to the river during and after the dam removal.

“Computer modeling done by Stillwater Sciences, a consultant for PGE, gave us some idea of what could happen,” Grant says. “Their results provided a range of predictions on where the sand and gravel would get deposited, given various scenarios of how rapidly the reservoir sediment eroded,” he explains. However, those results depended

Gordon Grant

A scale model allowed the researchers to test if notching the cofferdam would affect the pattern of reservoir sediment erosion.

on what river flows would actually occur during the months and years to come, something that no one could predict. And, without any detailed documentation of a comparable dam removal to go by, the team was in uncharted territory.

"Because there was no good blueprint on how to take out a dam, we were interested in whether or not we could affect the rate or volume of upstream erosion by where the cofferdam was notched," Grant explains. To study the potential outcomes, part of the team conducted studies with a scale model of the real-world dam system, created at the National Center for Earth Surface Dynamics in Minneapolis, Minnesota. "The experiments were the ultimate scenario of kids playing engineers in a sandy creek," he jokes.

Grant describes the scale model trials: "We tested eight scenarios for notching the cofferdam at various locations along its breadth. In each, the dammed basin first was filled by sediment and water supplied at the upstream end of the model. Then we constructed a cofferdam using erodible modeling clay. Finally, we made a shallow notch in the cofferdam, removed the main dam structure, and reintroduced water flow." The experiments suggested that the position of the notch would indeed affect the speed and pattern of cofferdam erosion, as well as the path of the knickpoint's incision of the reservoir sediments. "Terraces formed and ultimately abandoned by the down-cutting 'river' were larger and higher when the notch was made right of the river midpoint than when it was placed to the left," Grant says. "It turned out this was due to a curve in the river above the dam that caused it to hug the right bank, concentrating its hydraulic force there. To counteract that tendency, we determined the cofferdam notch would need to be made left of center," he explains.

A SPECTACULAR EVENT

By late September 2007, the concrete remains of Marmot Dam had been hauled offsite and the stage was set for unfettering the river. To minimize impacts on fish, PGE had decided to breach the cofferdam after the late-summer salmon migration. When news came of an approaching storm in mid-October, the PGE crew jumped into place. On October 19, a forklift was used to gouge out a notch in the cofferdam at the optimal location identified by the scale model testing. The diversion channel that had routed the river around the dam was closed off, and pumps used to remove water infiltrating the cofferdam turned off. The team of scientists eagerly took up their stations with cameras and other equipment to monitor the riverine drama as it unfolded.

As the rain fell moderately, the rising river overtopped the dam and began incising through the cofferdam to form a knickpoint, which moved upstream slowly at first but then accelerated quickly as the developing channel deepened and widened, and eventually progressed at hundreds of yards per hour. "The physical modeling was accurate in revealing how fast this would happen, but at the time of the experiments it seemed so rapid, we really didn't believe it," Grant recalls. "Intense turbulence and upstream migrating "steps" on the face of the dam combined to drive violent erosion. Downstream, a USGS stream gauge measured flows surging from about 1,000 to nearly 5,000 cubic feet per second," he recounts.

Amazing all the observers, the entire cofferdam melted away within several hours. By the next morning, all that remained of it was a large gravel bar downstream. But the river was just hitting its stride. It attacked the dammed sediments next, flushing the material downstream in waves.

Jon Major, U.S. Geological Survey

As the river rose on October 19, 2007, the earthen cofferdam became saturated and seepage erosion and mass failures appeared on the dam face.

Jon Major, U.S. Geological Survey

Less than an hour after the cofferdam was notched, the breach channel had rapidly expanded and was actively eroding the cofferdam.

"The sand moved down very rapidly during the first hours after the breach, with the gravel lagging by about 18 hours," Grant says. "About 20 percent of the stored sediment was exported within the first 48 hours, exceeding all expectations. The channel bed right below the dam site rose by over 10 feet, and the channel itself was transformed from single-thread to braided—all within the first 24 hours," he explains. "And it all happened under a discharge that was only 3 or 4 times that of the lowest summer flows—hardly a flood," he marvels.

LAND MANAGEMENT IMPLICATIONS

- The Marmot Dam removal project successfully meshed an engineering challenge with a scientific opportunity, all within the framework of a dynamic and open public process. It proceeded on schedule to a conclusion that has been well received by most parties.
- Results from the Marmot Dam removal suggest that under the right set of circumstances, dam removal can be a cost-effective alternative for dispensing with dam fill, as well as a successful strategy for restoring ecosystem function and connectivity to large rivers and improving conditions for threatened and endangered species.
- Dam removals offer unparalleled opportunities to advance our understanding of key river dynamics and processes.

THE AFTERMATH

In the months following the dam removal, the researchers have continued to document the channel's ongoing evolution and the river's process of self-restoration. By the end of winter 2008, the river had redistributed about half of the sediment primarily over the first 2 miles below the dam site, largely confirming the predictions made in the physical and numerical modeling and dispelling concerns over the possibility of increased flooding. "We are especially eager to remeasure the river's profile since the January 2009 rains, which have generated the highest flows since the dam came down," Grant says.

The changes bode well for the future of the Sandy's finned fauna, according to Todd Albury, a fish biologist with the Oregon Department of Fish and Wildlife. "It was incredibly exciting to see how quickly the river recovered," he remarks. "New bars and riffles have developed, along with meanders, and there's now more diverse habitat for fish both up- and downstream of the dam site. If you hadn't seen the river before the dam came down, you probably would never know it had been there," he says.

For Grant, the project was a resounding success on several levels. "The Marmot experience represents a clean dam removal. It changed the river, of course, but in ways that were anticipated and not injurious to physical, biological, or human resources," he says. "We learned that where a river has ample energy, dam sediments are noncohesive and contaminant-free, downstream resources are not at risk, and managers are willing, it's possible to remove a dam and let the river do the work of disposing of the fill, saving considerable decommissioning costs," he concludes. While cautioning that the strategy used on the Sandy River would not be suitable for many other dam scenarios, he hopes that the body of knowledge derived from the project will help planners on future projects.

J.R. Wallick, U.S. Geological Survey

By mid-December 2007, the river had transported much of the stored reservoir sediment several miles downstream.

Marmot also demonstrated that opportunistic field science is invaluable in advancing an understanding of key river processes and dynamics, Grant adds, and he credits the partnerships that made it possible. "No one group had sufficient funding to accomplish all the work, but we found that individual and institutional enthusiasm can trump a lack of funding."

"Even the upper end of the river believes in the ocean."

–William Stafford

FOR FURTHER READING

Doyle, M.; Stanley, E.; Harbor, J.; Grant, G. 2003. *Dam removal in the United States: emerging needs for science and policy.* Eos. 84(29): 32–33.

Grant, G. 2001. *Dam removal: Panacea or Pandora for rivers?* Hydrological Processes. 15: 1531–1532.

Grant, G.E.; Marr, J.D.G.; Hill, C. [et al.]. 2008. *Experimental and field observations of breach dynamics accompanying erosion of Marmot cofferdam, Sandy River, Oregon.* In: Babcock, R.W., ed. World Environmental and Water Resources Congress 2008: Ahupua`a. A proceedings. Red Hook, NY: Curran Associates, Inc.

Major, J.J.; O'Connor, J.E.; Grant, G.E. [et al.]. 2008. *Initial fluvial response to the removal of Oregon's Marmot Dam.* Eos. 89(27): 241–252.

O'Connor, J.; Major, J.; Grant, G. 2008. *Down with dams: unchaining U.S. rivers.* Geotimes. 53(3): 22–28.

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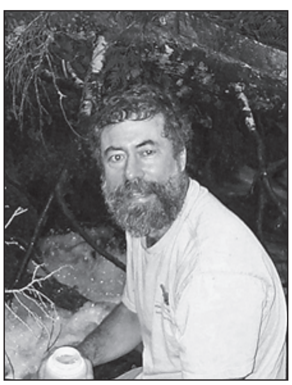

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