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

OUT, OUT, DAM SPOT!
THE GEOMORPHIC RESPONSE OF RIVERS TO DAM REMOVAL

Approximately 100,000 dump trucks worth of sediment will be released from a "blow-and-go" dam removal on the Sandy River in Oregon.

IN SUMMARY

About 75,000 irrigation, flood control, and hydropower dams in the United States are aging, deteriorating, or have outlived their useful lives and purposes. Not surprisingly, dam removal is emerging as both a challenge and opportunity for river management and research. Scientists at the PNW Research Station in Corvallis, Oregon, are using scale models and monitoring actual dam removals to predict the response of rivers to various dam removal scenarios.

Of particular concern is the fate of sediments that have accumulated behind the dams. Reservoirs created by small dams are often completely filled with sediment and no longer store water. In these situations, the dam can be removed in one stage with only moderate impacts downriver. In contrast, reservoirs behind large dams typically still store water and are only partially filled with sediment. For this reason, large dams must be removed slowly by progressively notching the top of the dam. Through this method, the volume and quality of sediment released can be controlled, or at least predicted.

Information generated by this research is being used to guide the dam removal process for two high-visibility removals—one on the Sandy River in Oregon scheduled for 2007 and another on the Elwha River in Washington scheduled for 2008. The experience gained through these and other removals will be used to develop preremoval monitoring protocols for dam removals throughout the United States. As larger dam removals are carried out, opportunities arise to learn how rivers erode and digest sediment that has been stored behind the Nation's many dams, and the consequences for downstream resources.

"Men may dam it and say that they have made a lake, but it will still be a river. It will keep its nature and bide its time, like a caged animal alert for the slightest opening..."

—Wendell Berry

At first glance, the flume is reminiscent of a giant sandbox, or maybe of the sandcastles we built on the beach as children. But don't be fooled, this sandbox is, in fact, a 1-to-500 scale model of Lake Mills, the reservoir upstream of Glines Canyon Dam on the Elwha River in Olympic National Park, Washington. And it is hardly child's play. Gordon Grant, a geomorphologist and research hydrologist at the PNW Research Station in Corvallis, Oregon, and Chris Bromley, a graduate student at the University of Nottingham, United Kingdom, have painstakingly recreated the reservoir boundaries, installed electric pumps to simulate the river's flow and sediment load, and most importantly, built a miniature version of the Glines Canyon Dam. With the upstream end of the reservoir filled with sediment much like the real river, and with video cameras rolling, Bromley tears down the dam.

Here's where the science kicks in. The sediment once trapped behind the dam is now unconstrained. The future of that sediment—whether it is released slowly or quickly—will have a great impact on the river, both up- and downstream from the dam. Bromley and Grant measure the flow of sediment and how it reacts under different dam removal scenarios. Their findings will help prepare them for the life size removal of the Glines Canyon Dam, scheduled for 2008.

Predicting the response of rivers to dam removal is a new challenge for geomorphologists like Grant. And the need for information, spurred by thousands of aging dams in the United States, is outpacing scientists' ability to gather and analyze data.

It is estimated that over 75,000 dams across the country are nearing the end of their useful lifespan. Most of these dams were built in the 1950s and 1960s, a time during which it was estimated that a United States river was dammed every 6 minutes. Today, many of these dams are scheduled for relicensing by the Federal Energy Regulatory Commission. "This is prompting scrutiny of past dam effects and is raising the bar with regard to the acceptable impacts of dams on river ecosystems. In some cases, this has led to discussions of removal," says Grant.

There are many reasons owners might chose to remove their dam. "Like anything you build, dams have a lifespan. Beyond that, they can pose risks to people and property downriver," says Grant. Often it is simply a cost benefit analysis; once the costs of operating and maintaining the dam in a safe condition exceed the benefits gained from hydroelectric power, irrigation, or flood control, then removal becomes a feasible option.

The reservoir behind Dinner Creek Dam was completely full of sediment in 2002, before the dam was torn down. Photo by Greg Stewart.

After Dinner Creek Dam was removed, the creek eroded through the sediment toward the former streambed. Photo by Greg Stewart.

"Dam removal also has great symbolic value in terms of representing our good intentions toward the environment," says Grant. "This was embodied by former Secretary of the Interior Bruce Babbitt wielding a sledge hammer at the face of dams around the country."

For most, the topic of dam removal conjures the image of large dams being removed from large rivers. However, most dams are small—less than 30 feet high and 30 feet wide. These are referred to by those in the business as LDDs, little dinky dams. Most of the recent removals and those in the foreseeable future will be of these more modest dams. Their greater number, smaller size, and lower political profiles provide tractable opportunities for studying river and ecosystem response to dam removal, according to Grant.

"From past work on the effects of dams on rivers, we know that not all dams are created equal. The same will be true of dam removal: some will stimulate dramatic effects on river and ecosystem processes, others will have no effect, and some may open a Pandora's box of new problems," says Grant.

For now, it seems prudent to start small, even really small, concentrating on the dinky dams and the one in the sandbox.

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NOT ALL DAM REMOVALS ARE CREATED EQUAL

When a river is dammed, a reservoir is formed upstream. At the entrance to the reservoir, the river loses momentum and a triangle-shaped accumulation of sediment, called a delta, is deposited. Given enough time, the delta will grow and the reservoir will fill with sediment. Exactly how long that takes is a function of the size of the dam, the size of the river, and the amount of sediment it transports.

One public misconception, Grant notes, is that dam removal will be accompanied by a wall of water cascading downstream. This almost never happens. Any stored water is released slowly—either before removal or as the dam is being dismantled.

"The real risks and unknowns are linked to the fate of the stored sediment, which can reorganize the river channel and may cause ecological damage. For example, fine sediment, like clay, can fill in gravel beds that are crucial to spawning fish, such as Pacific salmon," says Grant.

The most important factors determining the downstream response of rivers to dam removal are the volume and size distribution of sediment within the reservoir and the rate at which it is released from storage. In setting out to predict the fate of stored sediment, Grant makes an immediate distinction: The effects of removing large dams are categorically different from those involved in removing smaller structures.

Unlike their larger counterparts, small dams can be removed all at once. This is typically done with a bulldozer or some strategically placed dynamite. These projects are euphemistically referred to as "blow-and-go" dam removals. Another graduate student working with Grant, Greg Stewart at Oregon State University, has been studying this type of removal scenario.

Reservoirs behind older, small dams are typically filled with sediment such that they no longer store any water. In this situation, the dam acts simply as a step in the river's profile. Once the face of the dam is removed, the river drops over a waterfall of sediment and begins eroding toward the predam channel. The sharp break in slope as the new channel cuts backward into the wall of sediment is called a knickpoint.

"At the time a small dam is removed, there is often a pulse of sediment entering the channel associated with the formation of the knickpoint. Additional pulses then coincide with the first major storms after the removal," says Grant. "Erosion continues in an episodic fashion until the wall of sediment that had accumulated behind the dam is broken down and the knickpoint gradually retreats upriver." Through this process, he explains, the river reestablishes its original gradient, though it may or may not return to its predam riverbed.

Erosion continues until the stored sediment is gone or vegetation establishes on the remnant deposit. Typically, the sediment stored behind small dams will be transported downstream with only modest effects on channel morphology.

KEY FINDINGS

- Downstream patterns of sediment deposition and storage following removal are broadly predictable, and controlled by both the shape and composition of the downstream channel and the size distribution of sediment being released.
- Removing small dams results in a rapid pulse of sediment entering the channel, typically during the first major storms following removal. Most of the sediment stored behind the dam will be transported downstream with only modest effects on channel morphology.
- Removal of larger dams unleashes a much more complex, dynamic, and difficult-to-control set of processes. Because reservoirs behind large dams are typically not fully filled by sediment, initial effects of dam removal are sustained high-turbidity events.
- Despite broadly predictable patterns, dam removal can result in many surprises. These can include the release of stored toxic sediment into the downstream river ecosystem.

LARGE DAM REMOVALS

"The removal of larger dams unleashes a much more complex, dynamic, and difficult to control set of processes," says Grant.

Predicting the river's response to dam removal is intrinsically complex. After a dam has been in place for many years, the river channel adjusts and grows accustomed to the altered flow regimes. Consequently, dam removal can be a great disturbance to the river system. With the dam gone, a river is reenergized; gravity pulls water and sediment along a new gradient and in new directions.

Unlike small dams, reservoirs behind large dams are typically only partially full of sediment. For this reason, "blow-and-go" dam removals don't work. In fact, the opposite approach is used: large dams are

A miniature version of the Glines Canyon Dam on the Elwha River in Olympic National Park, Washington, was constructed to model the release of sediment after the dam is removed in 2008. Photo by Gordon Grant.

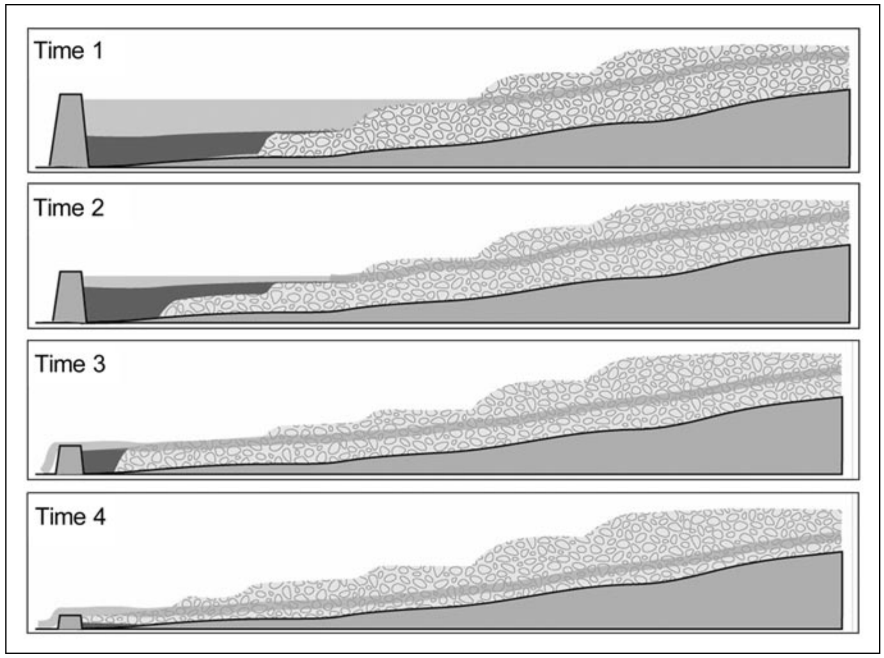
progressively notched out from the top and removed piece by piece over a period of many weeks. The rate at which the dam is removed is based on the rate of sediment released and the river's ability to process it.

Deltas are formed at the back of reservoirs, at the point where the river first slows down and loses its ability to carry sediment. Therefore, when a large dam is notched and the reservoir shrinks, the delta marches forward toward the dam. With time, the delta advances to the former dam location.

"The nature of material being released, stability of the remaining deposits, and overall time period during which the river will be experiencing heightened sediment loads is very strongly controlled by the rate at which the dam is lowered," says Grant. "We try to graduate the pace of removal based on what we want to happen upstream."

Grant and his colleagues are the first to show that the rate at which the dam is removed is the single most important factor managers can use to influence the outcome of removal.

An instantaneous removal of a big dam would cause the river to rapidly downcut through the delta toward its original grade, causing unstable canyons to form and unleashing a potentially uncontrollable sequence of events. Staged removals, in contrast, can be used to form terraces on the delta, which helps stabilize the material and mitigates downstream impacts.



Large dams are removed incrementally from the top. As the reservoir behind the dam shrinks, the sediment marches forward toward the dam. Graphic by K. Ronnenberg.

"By removing large dams in stages, we are able to control, or at least predict, the type of sediment that is released. Large particles are carried more slowly than small particles. This is important because a river is transformed by its history. If the river downstream of the former dam first sees sand then gravel being released from the impoundment, it will respond differently than if it sees gravel and sand all at the same time," Grant explains.

BUILDING A BODY OF EXPERIENCE

After a dam is built, the river ecosystem slowly grows accustomed to the obstruction, as do people living around the dam. New river channels are developed and people adjust to the regulated flows, sometimes even building homes in the former path of the river. Moreover, sensitive habitat for aquatic organisms often lies downstream of dams. Given all this, accurate predictions of postdam river dynamics are crucial.

To date, there just isn't a lot of data to use when planning a dam removal. Little thought was given to the long-term fate of dams while they were being constructed. And it is only within the past 5 years that dam removal has been debated and studied.

"In spite of all the interest and enthusiasm, we actually know very little about the biophysical consequences of removing dams," says Grant. "With only a few exceptions, virtually no dam removals have been conducted with rigorous pre- and postremoval monitoring and analysis."

In planning for a removal, Grant and his colleagues must address many questions: Where will sediment be deposited? How much sediment will be deposited? How will water quality and habitat be affected? When will this happen in relation to dam removal? How will the channel respond?

The miniature river in the sandbox can help answer some of these questions. Other information can be gained from reservoir drawdowns. Computer simulations offer yet more information. But nothing compares with monitoring actual dam removals.

Stewart and Grant recently had a chance to put their hypotheses to the test in southern Oregon. They worked with personnel on the Umpqua National Forest to monitor the effects of a small dam removal on Dinner

LAND MANAGEMENT IMPLICATIONS

- Measurements that should precede dam removal include the volume of sediment stored, size distribution and quality of stored material, and channel morphology both upstream and downstream of the reservoir to predict the direction of channel adjustment. Combining these preremoval measurements with an understanding of likely trajectories of change can be used to develop a monitoring plan following dam removal.

- Laboratory flume experiments are providing managers with high-resolution measurements of how different dam removal scenarios are likely to affect the evolution of reservoir deposits and downstream supply of sediment.

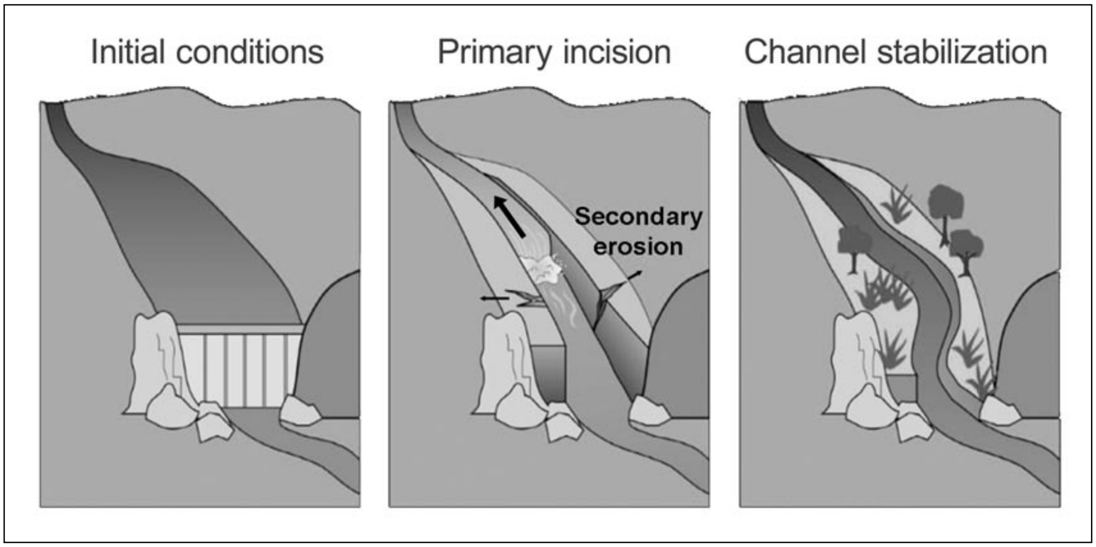
- The nature of material being released, stability of the remaining deposits, and overall time period during which the river will be experiencing heightened sediment loads is very strongly controlled by the rate at which large dams are dismantled.

Creek. Both before and after the removal, they measured upstream and downstream channel morphology, stream temperatures, turbidity, and water chemistry. Their efforts helped ensure that a downstream water intake facility for the city of Cottage Grove was not compromised.

They are now gearing up for the removal of Marmot Dam on the Sandy River just outside Portland, Oregon. In anticipation, they are conducting high-resolution measurements of the river's morphology, coupled with analysis of the river's flow patterns to predict the likely fate of sediment released when Marmot Dam is removed in 2007.

"The Marmot removal will be a 'blow-and-go' removal," says Grant. "The Sandy River can process sediment quite readily, which is fortunate considering there are about 100,000 dump trucks worth of sediment behind the dam."

This information is being provided to the agencies and stakeholders that make up the Sandy Basin Monitoring and Research Team overseeing the removal. Information generated by the research will eventually be used to develop preremoval and monitoring protocols for future small dam removals throughout the country.



River recovery after a dam removal follows a predictable sequence of events. Graphic by Shannon Hayes.

BRACING FOR SURPRISES

Large or small, any dam removal can have unanticipated impacts. "One wild card is the possibility that reservoirs may store high levels of contaminants, including heavy metals," cautions Grant.

Release of toxic material following dam removals can result in contaminant plumes with sweeping environmental consequences. Just such an event occurred on the Hudson River in New York when the Fort Edwards Dam was removed, unleashing stored polychlorinated biphenyls, or PCBs.

"Addressing this issue will require spatial analysis targeted at identifying dams that lie downstream from industrial sites, mines, and other sources of pollution," says Grant.

When these situations arise, innovative methods can be used to mitigate the environmental impacts. For example, the Milltown Dam on the Clark's Fork River in Montana is storing 10 million cubic yards of heavily contaminated sediment, mostly arsenic and copper. To minimize the impact of the removal, the toxicity of the sediment is being mapped, and most noxious wastes will be dredged and removed before the dam is dismantled.

Another option is to reroute the river around the dam. Although this can be expensive, it removes any uncertainty regarding the fate of stored sediment.

"In spite—or perhaps because—of all the uncertainties, dam removal is a very attractive scientific problem. What makes it particularly appealing is that a river's response to a dam removal represents a real time experiment to a known perturbation—a rare opportunity for those who study rivers," says Grant. "We've only just begun to sort out all the complexities."

Grant cites the need for more coordinated studies on how dams function in the landscape. As the infrastructure of United States dams continues to age, and their removal becomes an inevitability, policymakers and the public will increasingly be looking to scientists to provide sound technical information on the consequences of removing dams.

For his part, Grant will be spending his time in the sandbox and on the river trying to get this dam problem sorted out.

"Let the mountains talk,
let the rivers run.
Once more, and forever."

—David Brower

FOR FURTHER READING

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