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Dam removal: Panacea or Pandora for rivers?

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We stand at a curious juncture with respect to the increasingly passionate debate about what to do with aging dams in the US—numbering more than 75 000 by one recent count (Graf, 1999). This debate is playing out against a backdrop of power crises, cycles of flood and drought, endangered ecosystems, and changing societal expectations and demands for water. Within this larger debate, the idea that dams are not necessarily permanent features of the landscape, but can and—by some views—should be removed, has emerged as a rallying cry, political lightning rod, and unparalleled scientific opportunity for understanding the behaviour of rivers. As evidence of interest in this issue, all of the major American geoscience and ecological societies (i.e. AGU, GSA, AAG, NABS, ESA) hosted special sessions on dam removal in the past year, two national panels (at the Aspen Institute and Heinz Center) are examining dam decommissioning, and the topic surfaced in last fall's US presidential debates. Clearly, something is going on.

Why is dam removal emerging as an issue? A convergence of science, management, and policy concerns is driving it forward, centred on the increasing hazards to human and ecological communities posed by aging dams that have, in many cases, outlived either their design lives or original purposes. An open 'policy window' due to the large cohort of non-Federal hydropower dams up for relicencing by the Federal Energy Regulatory Commission (FERC) in the next decade, is prompting scrutiny of past dam effects and discussions of dam removal in some cases. Dam removal is also being proposed in response to concerns about threatened and endangered fish species, physical fragmentation of river systems, and calls for a return to a more 'natural' hydrologic regime to restore ecological and geomorphic functions to rivers (Poff *et al.*, 1997; Richter *et al.*, 1997). Finally, dam removal has great symbolic value in terms of representing our good intentions towards the environment, as embodied by former Secretary of the Interior Bruce Babbitt's sledgehammer, or a recently published comment that 'Dam breaching is America's own exercise in truth and reconciliation' (Moore, 2001).

For most, the topic of dam removal conjures the image of large dams being removed from large rivers, such as the ongoing debate over the fate of the lower four dams on the Snake River in Idaho (Kareiva *et al.*, 2000). Most dams are small, low-head, and run-of-river, however, and most dam removals in the past and foreseeable future will likely involve these more modest structures. Their greater number, smaller size, and lower hydraulic and political profiles

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provide tractable opportunities for studying river and ecosystem response to dam removal.

The issue of dam removal poses interesting and unique challenges to the scientific community. One striking conclusion that can be drawn from the recent workshops is that, in spite of all the interest and enthusiasm, we actually know very little about the biophysical consequences of removing dams. With only a few recent exceptions, virtually no dam removals have been conducted with rigorous pre- and post-removal monitoring and analysis.

The response of channels to dam removal is intrinsically complex. Because of the longevity of dams, channels typically adjust to the altered hydrologic and sediment transport regimes that dams impose; consequently, dam removal itself represents a geomorphic disturbance to a quasi-adjusted fluvial system. We know that this disturbance tends to propagate both upstream and downstream through cascades of erosional and depositional processes that are coupled in time and space. Typically, the upstream response drives the downstream response. Key upstream unknowns are the rate and mechanisms of removal (i.e. knickpoint retreat, fluvial erosion) of sediment from the upstream reservoir in relation to flow regime, grain size, channel and deposit geometry, and method of dam removal. Downstream, sediment will be transported through a channel system already altered by the presence of the dam. A complex array of storage features (i.e. channel bed, floodplains) and associated residence times limits our ability to accurately predict how long it will take for sediment to be routed downstream. Even more challenging to predict are the interactions among sediment transport and deposition, vegetation establishment, and responses of aquatic ecosystems to elevated sediment loads and transformed channel morphology.

In spite—or perhaps because—of these uncertainties, dam removal is a very attractive scientific problem. What makes it particularly appealing from a scientific viewpoint is that river response to dam removal represents a real-time experiment to a known perturbation—a rare opportunity for those who study rivers, perhaps only equalled by managed or controlled floods (Webb *et al.*, 1999). Capitalizing on this opportunity will require a more focused initiative than has occurred up to now. We need coordinated retrospective and laboratory, and field studies on how dams function in the landscape, impacts and consequences of past removals, including analysis of dam removal analogues, such as natural and artificial dam failures, and rigorous pre- and post-removal monitoring schemes for those dams slated for removal targeted at resolving key uncertainties.

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 effects, and some may open Pandora's boxes of new problems. The latter will be particularly true in cases where reservoirs are filled with sediments contaminated by organic or inorganic compounds, such as the PCB-contaminated sediments that were released down the Hudson River when the Fort Edwards Dam was removed. Policy makers, politicians, and the public will be looking to the scientific community to provide sound technical information on the likely consequences of removing dams, in order to achieve maximum benefits and avoid environmental fiascos. The workshops held this year are a good start, but we need a broader multidisciplinary dialogue involving physical, biological, and social scientists in order to help guide the dam removal juggernaut through these uncharted waters.

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