A FRAMEWORK FOR EVALUATING DISCIPLINARY CONTRIBUTIONS TO RIVER RESTORATION

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ABSTRACT
As river restoration has matured into a global-scale intervention in rivers, a broader range of technical disciplines are informing restoration goals, strategies, approaches, and methods. The ecological, geomorphological, hydrological, and engineering sciences each bring a distinct focus and set of perspectives and tools, and are themselves embedded in a larger context of social, economic, legal, and historical drivers. Restoration practices carried out in different countries and cultures reflect this context. Ecological concerns drive much of the current restoration activities in the United States, while re-introducing and re-engineering rivers for more natural functions and processes is a hallmark of European restoration. Some examples of river restoration around dams and reservoirs from the Pacific Northwest of the U.S. reveal the interplay among various disciplines, and point to more and less successful disciplinary mixes. Projects focused on dam removal, retrofitting dams to modulate downstream water temperatures, and adding gravel back to rivers below dams also demonstrate different ways that science itself is used in river restoration, and point to how best incorporate a scientific perspective in future activities.

Keywords: river restoration, international perspectives, effects of dams, dam removal, gravel, river management

INTRODUCTION

A revolution in river restoration is under way. In the past two decades river restoration has evolved from the application of a limited set of tools and concepts guided almost exclusively by ad hoc experience in scattered regional settings of mostly developed countries, to a worldwide and sophisticated enterprise. Today it is a global industry involving multiple technical disciplines, and an annual investment of billions of dollars, 1 billion dollars is spent in the U.S. alone (Bernhardt et al., 2005).

As the palette of river restoration strategies has evolved, interesting country-to-country and region-to-region differences in objectives, approach, techniques, and style of restoration have also emerged. Such differences tend to be rooted in past histories of river modifications and interventions, differing legal and cultural expectations for rivers, and different blends of technical disciplines involved in restoration activities. Beyond these differences lies the broader consideration of the extent to which river restoration in any particular cultural setting draws on the scientific method as the basis for testing new methods and approaches, and directing future activities. The goal of this short paper is to foster an appreciation of both the cultural and technical context of current restoration strategies, offer modest insight into strengths and weaknesses of various restoration schemes, point the way towards future developments.

A MULTI-DISCIPLINARY RIVER RESTORATION FRAMEWORK

A working definition of river restoration should include the full suite of actions done to improve river function to meet specific objectives. This intentionally broad definition makes no distinction between structural and non-structural interventions, riparian or groundwater strategies, etc. The Examples of restoration activities include: 1) increasing flows to dilute water contaminants; 2) removing levees to promote off channel storage of water and sediment; 3) adding gravel to a river to increase hyporheic flow; or 4) controlling invasive species to improve native ecosystems. These examples illustrate the range of technical disciplines that form the nucleus of restoration activities as currently practiced: hydrology, engineering, geomorphology, and ecology. Individual restoration projects typically draw on one or more of these disciplines to provide technical guidance for the project and the overarching objectives of the restoration itself. The multi-disciplinary universe underlying and guiding restoration can be envisioned as a tetrahedron, with the four disciplines located at the vertices (Fig. 1). Any project is represented within this universe as a point corresponding to the proportional contribution of each discipline to the objective or implementation. Increasing flows or removing levees, for example, are primarily hydrologic or engineering interventions respectively. Most restoration projects will involve a mix of technical approaches.

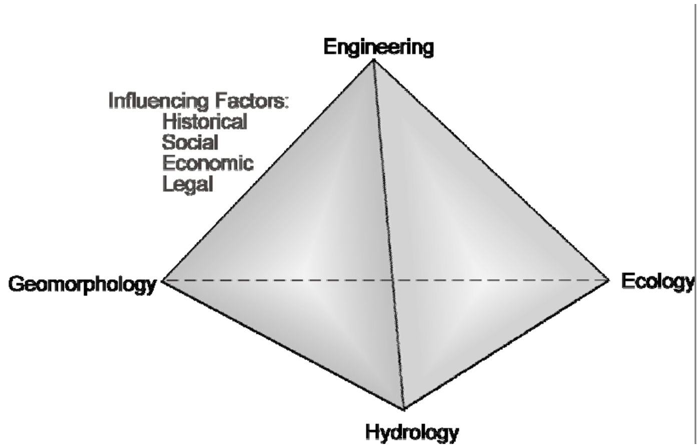

Figure 1 - Conceptual framework for restoration.

Restoration activities are themselves embedded within a broader cultural context that includes legal, economic, historical, and social issues and drivers (Fig. 1). For example, a major driver of restoration activities in the western U.S. is the Endangered Species Act, a national law intended to protect imperiled species and the ecosystems on which they depend. In Europe, a major driver of river restoration is the Water Framework Directive of the European Union, which sets the ambitious goal of achieving a “good status” for all of Europe's surface waters and groundwater by 2015. Beyond these legal directives lie a complex set of culturally defined historical and social expectations for rivers that also strongly influence the extent and types of restoration strategies employed.

From a global perspective, there has been tendency for restoration practices within different countries and regions to emphasize or be motivated by particular disciplinary foci. In the Pacific Northwest salmon example above, ecological considerations motivate restoration activities, which include a wide range of projects such as riparian planting, adding large woody debris back to streams, gravel augmentation to improve spawning habitat, etc. In southern Europe, on the other hand, a century of gravel extraction and extensive river engineering for erosion control has promoted dramatic channel incision (Liébault & Piégay, 2002; Rinaldi et al., 2005). Here, restoration activities principally involve engineering or geomorphic approaches designed to add gravel back to rivers by promoting active bank erosion in degrading reaches, building control weirs to check bed erosion, and actively trenching channels and floodplains to promote gravel transport from gravel rich to gravel poor zones (Piegay et al., 2006). Other examples include re-engineering of channels to promote meandering, as in Switzerland and Japan.

Restoration practices tend to evolve over time in response to changing societal expectations and collaboration among practitioners around the world. Such evolution can shift the disciplinary mix towards other vertices over time. For example, there is a growing utilization of engineering approaches in the United States, and increasing use of non-structural geomorphically- and ecologically-based approaches in countries such as Japan (Nakamura et al., 2006).

SOME EXAMPLES FROM THE US PACIFIC NORTHWEST

I now offer a few brief, heuristic, and undoubtedly biased examples of how this framework can potentially be useful in understanding the strengths and weaknesses of river restoration activities. These examples are drawn from some recent restoration projects in the U.S. Pacific Northwest that illustrate some salient aspects of current restoration thinking. In particular I emphasize the interplay and relative degree of integration among different technical disciplines involved in restoration activities, and the overall role of science in informing restoration strategies. These examples are offered not so much to critique specific projects as to compare the consequences of utilizing different disciplinary mixes with an eye to encouraging a more rigorous scientific basis for river restoration.

I focus specifically on river restoration examples involving dams, since dams represent some of the most significant human interventions in rivers worldwide (Nilsson et al., 2005). The three examples represent different restoration strategies to different aspects of this problem: dam removal to improve fish migration, dam retrofitting to improve river temperatures, and evaluating potential gravel augmentation below a dam for temperature benefits. The details from each of these examples have been published elsewhere and cited below; here I focus on how successfully were the technical disciplines involved and with what consequences.

Removal of Marmot Dam, Sandy River, Oregon

Dam removal has been widely viewed as an important river restoration strategy and interesting scientific opportunity, the latter because it represents a real-time, full-scale field experiment on fluvial adjustment (Grant, 2001; Doyle et al., 2003). Removals offer an excellent setting for validating analytical models of sediment transport and morphologic change, and testing our capacity to predict short- and medium-term channel evolution in response to changing water and sediment transport regimes. Most dam removals have involved relatively small structures and modest releases of sediment stored in pre-removal reservoirs. The largest instantaneous and uncontrolled release of sediment accompanying a dam removal occurred with the breaching of the Marmot coffer dam on the Sandy River in Oregon in October 2007 (Fig 2).

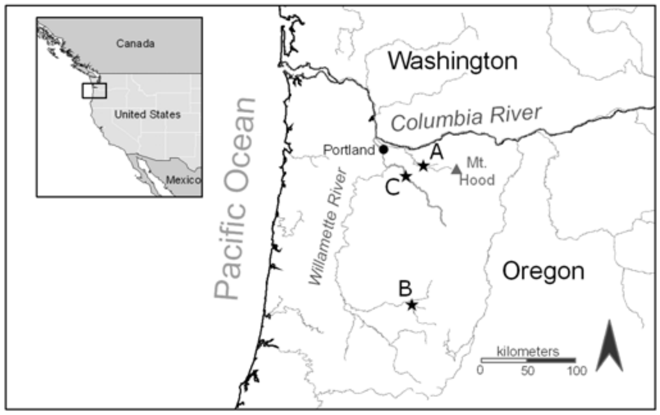

Figure 2. Location Map showing A. Marmot Dam, Sandy River, B. Cougar Dam, South Fork McKenzie River, and C. River Mill Dam, Clackamas River.

Marmot Dam was a concrete diversion dam built in 1913 as part of a larger hydroelectric project that located on the Sandy River approximately 45 km upstream from its confluence with the Columbia River near Portland, Oregon, U.S. The Sandy River is an energetic river that naturally carries copious quantities of volcanic sand and gravel, because it drains the western flanks of Mt. Hood, an active stratovolcano. At the time of removal, the reservoir upstream of the dam was completely filled with 750,000 m^3 of sediment. The river below the dam includes bedrock gorges, mixed bedrock/alluvial reaches, and alluvial reaches with well-developed gravel and sand bars.

The decision to remove the dam was motivated by a combination of increasing maintenance costs and an unfavorable future economic return due to the necessity of installing expensive fish passage facilities to meet relicensing requirements. The dam's owner surrendered the license in 1999, and removal commenced in summer, 2007. To remove the concrete structure, a temporary coffer dam was constructed out of river bed and reservoir sediment upstream. The main structure was dynamited in July 2007, but the combination of high stream power during even modest flows and high natural sediment fluxes was a key factor in the decision to allow the river to naturally breach the coffer dam and erode the remaining impounded sediment during the first fall storms. Physical modeling helped project engineers design the breach scenario (Grant et al., 2008).

A multi-agency initiative organized to conduct pre-, during, and post-event monitoring of channel evolution and sediment transport. Individual study elements included event-based measurements of suspended sediment and bedload, repeat surveys of channel cross-section and planform change, reservoir incision, and repeat LIDAR surveys to capture three-dimensional changes. High-resolution time-lapse photography recorded changes occurring during and subsequent to the breach. These data have provided and will continue to provide a treasure trove of measurements useful for evaluating models of sediment transport and geomorphic change that are applicable not only to future dam removals, but to a wide range of geomorphic problems, including the fate of landslide dams and river response to changing base level (Major et al., 2008).

The specific set of external issues driving removal of Marmot Dam involved a combination of legal, economic, and social factors. Engineering played a major role in the design and construction of the coffer dam and removal of the main structure. The scientific focus was on geomorphic response of the river, and involved a coordinated set of numerical and physical models, sediment transport and discharge measurements, and geomorphic surveys. The resulting data offer rich geomorphic insights.

On the down side, however, is the relatively poor integration of ecologists and measures of ecological response following removal. This is an unfortunate consequence of limited funding and the rather grassroots organization of the studies; basically the disciplines represented are those that chose to show up. A “top-down” approach might have yielded stronger cross-disciplinary integration, but there was neither the funding nor the institutional home to effect this.

Retrofitting Cougar Dam to improve downstream temperatures for fish

Large flood control projects that store and release water at different times of the year can change the natural temperature regime of a river, depending on timing and temperature of water influxes and discharges. These shifts in temperature can affect the timing of triggers for key stages of resident and anadromous fish, such as spawning and migration. Retrofitting dams to permit water to be withdrawn from multiple levels within a temperature-stratified reservoir is an emerging, though expensive, strategy to restore and manage temperature regimes downstream of large dams.

Cougar Dam on the South Fork McKenzie River, Oregon., USA, is a multi-purpose dam and reservoir impounding 270 million cubic meters of water (Fig.2). The reservoir becomes thermally stratified in summer, with warmer, less-dense water near the surface and colder, more-dense water at the bottom. A low-elevation outlet in the dam resulted in the release of relatively cold water from near the bottom of the reservoir in mid-summer. As the reservoir was drawn down in autumn to make room for winter floods, warmer surface water was released as well. This altered temperature pattern was potentially causing problems with the timing of migration, spawning, and emergence of juvenile salmonids. In order to restore the temperature regime, the dam owner modified the intake structure at Cougar Dam to permit extraction of water of different temperatures from different reservoir levels. These modifications, which were constructed from 2002 to 2005, allow operators to release colder water during the winter, and warmer water during the summer, to improve habitat conditions for threatened bull trout and spring Chinook salmon.

In order to carry out work on the intake tower, Cougar Reservoir was lowered below minimum pool elevation in April 2002, thereby exposing deltaic and lake bottom sediments to reworking by the South Fork McKenzie and other reservoir tributaries. The incision and reworking of these sediments resulted in a prolonged discharge of turbid water from Cougar Reservoir that was highly visible for kilometers downstream and even affected the turbidity of the Willamette River below the confluence of the McKenzie (100km downstream). Although turbidity was predicted to increase during the drawdown, the magnitude, timing, and duration (4 months) of the problem was underestimated, prompting concern that sediment contained within the turbidity plume might intrude into river gravels, with potentially negative effects for fish and other aquatic biota.

Follow up studies focused on both the source of the sediment giving rise to the turbidity and whether fines had intruded into the coarse gravel bed below the dam. The latter studies showed that significantly higher concentrations of fines in the gravel bed downstream of the dam than above it, but these could not be conclusively tied to the drawdown and subsequent erosion. A key finding of the sediment studies was that the source of the clays that caused the turbidity was not delta incision, but erosion of the toe of a large landslide complex that had entered the reservoir subsequent to dam construction. Erosion of the toe caused extremely fine clays with very low settling velocities from this landslide to become resuspended in the reservoir; these turbid waters were then released below the dam.

This example highlights how focus on one aspect of a restoration strategy – in this case the dam retrofit with the temperature control structure – to the exclusion of other potential effects (erosion and resuspension of fines) can result in unintended consequences (turbid water releases and possible impacts on gravel quality). While the restoration itself was clearly motivated by ecological considerations, and involved extensive temperature modeling and re-engineering of the dam, there was little attention paid to potential geomorphic effects of the drawdown itself. A more integrated approach might have incorporated a geomorphic perspective that evaluated the potential for the drawdown to remobilize turbidity-causing sediments. Fortunately, the long-lasting ecological impacts from this incident appear to be minor.

Evaluating potential thermal benefits from adding gravel below dams

Reintroducing gravel to rivers whose sediment supply has been reduced or depleted by dams and reservoirs is emerging as a new approach to river restoration. Although gravel augmentation is primarily used to allow rivers to rebuild bars, riffles, and other habitat features, it may also help mitigate the thermal effects of reservoirs by increasing hyporheic exchange, where surface water enters the riverbed and flows along subsurface paths before returning to the main channel. In theory, gravel augmentation could increase hyporheic exchange by increasing total gravel storage in a depleted river reach and by promoting lateral migration. Increased hyporheic flow, in turn, could have temperature benefits, because this exchange promotes mixing of waters of different ages and temperatures in the subsurface, thereby potentially reducing maximum temperatures.

As part of a dam relicensing on the Clackamas River, a large gravel-bed river in northwestern Oregon, US (Fig. 2), the dam owner is considering a substantial gravel augmentation that may involve adding thousands of cubic meters of gravel annually to the river. This augmentation is primarily intended to create habitat for spawning fish and to restore channel morphology and sediment transport interrupted by the River Mill dam complex, but may also have ancillary benefits for mitigating temperature effects of the upstream dams and reservoirs, which is a legal requirement of the new operating license. Determining the magnitude and timing of temperature changes that might result from gravel augmentation is challenging. No current models address both hyporheic flow and heat exchange in rivers, and there is little field data. Because of this, the dam owner funded a set of preliminary and anticipatory studies to evaluate the magnitude of the potential effect through a coordinated set of modeling, experimental, and field studies.

We examined the relationship between hyporheic exchange and temperature along a 24-km reach of the lower Clackamas River (Burkholder and others, 2008). Hyporheic exchange was primarily identified by temperature anomalies, which are patches of water that demonstrate at least a 1 °C temperature difference from the main channel. These anomalies were located through field investigations and thermal-infrared-radiometry (TIR). Anomalies were associated with specific geomorphic features, primarily bar channels and bar heads that act as preferential pathways for hyporheic flow. Detailed field characterization and groundwater modeling showed that hyporheic discharge from anomalies comprises a small fraction (−1%) of mainstem discharge, resulting in almost negligible main-stem river-cooling. However, the presence of cooler patches of water within rivers can act as thermal refugia for fish and other aquatic organisms.

First, multiple disciplinary perspectives underlay the motivation for this study: to investigate whether an engineering manipulation (gravel augmentation) could effect a geomorphic change (bar growth), leading to hydrologic change (development of more hyporheic flow and temperature anomalies) that in turn would result in peak temperature reductions, thereby improving ecological habitat for threatened fish species. Stated in this way, these different disciplinary perspectives form a chain of logic or causality that provided the framework for the research. Second, this work was done in anticipation of a future action – adding gravel to the river – and represented the direct application of a scientific process to guide a management decision. The research results revealed that while the direct temperature benefits from gravel augmentation were likely to be small, the effects were large enough to potentially have other, more localized, benefits to habitat. In this way, the science helped guide future actions on the part of the dam owner and river managers towards more effective strategies.

REFLECTION AND IMPLICATIONS

The lessons that we draw from these examples highlight some recent developments in river restoration, including emergence of new approaches and methods, and the overall maturation of river restoration as a sophisticated and deliberate set of actions aimed at improving river function. But perhaps most importantly, they demonstrate different ways that scientific disciplines and the scientific process itself is (and is not) being incorporated into river restoration. Both the Marmot and Clackamas River examples illustrate how science is being used in an anticipatory fashion: to test hypotheses, operational strategies, and potential outcomes prior to full implementation. The physical modeling of the breach scenarios on the Sandy River helped design the actual breach scenario. Field and modeling studies on the Clackamas helped steer river managers away from a particular path of speculation towards other more fruitful areas. On the other hand, absence of certain key studies and perspectives in the case of Cougar Dam may have contributed to undesirable consequences. Incorporation of the broader landscape context (in this case, the geomorphic setting and history of the reservoir itself) might have forestalled the fine sediment erosion, or at least allowed project engineers to anticipate it and possibly change the drawdown schedule to accommodate it.

These examples point to the conclusion that river restoration projects that explicitly incorporate a scientific process of stating then testing hypotheses at all stages of project development are likely to be more effective and efficient in the long run. Such a process is capable of identifying the most effective strategies in particular situations, including what is likely not to work. Projects underlain by this type of information will inevitably be better situated to adapt to changing environmental conditions or societal expectations.

Although not all restoration projects require the perspectives of multiple disciplines, the examples presented here suggest that restoration that draws on more than one scientific discipline may be more successful in the long run. Each discipline brings with it a certain set of methods, approaches, and ways of evaluating larger contexts within which restoration activities sit. The hydrologic sciences offer rigorous means of characterizing river flow and hydraulic regimes, the ecological sciences provide the context of understanding the interplay between individuals, species, communities, and ecosystems, the geomorphic sciences emphasize understanding physical processes and watershed history over broad spatial and temporal scales, and the engineering disciplines help define what is doable within a rigorous context of risk analysis. With the world's rivers changing in response to human interventions and climatic trends, river restoration will require the perspectives and tools of all of these disciplines in order to be successful.

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