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Synthesis, part of a Special Feature on Restoring Riverine Landscapes

Restoring Environmental Flows by Modifying Dam Operations

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ABSTRACT. The construction of new dams has become one of the most controversial issues in global efforts to alleviate poverty, improve human health, and strengthen regional economies. Unfortunately, this controversy has overshadowed the tremendous opportunity that exists for modifying the operations of existing dams to recover many of the environmental and social benefits of healthy ecosystems that have been compromised by present modes of dam operation. The potential benefits of dam "re-operation" include recovery of fish, shellfish, and other wildlife populations valued both commercially and recreationally, including estuarine species; reactivation of the flood storage and water purification benefits that occur when floods are allowed to flow into floodplain forests and wetlands; regaining some semblance of the naturally dynamic balance between river erosion and sedimentation that shapes physical habitat complexity, and arresting problems associated with geomorphic imbalances; cultural and spiritual uses of rivers; and many other socially valued products and services. This paper describes an assessment framework that can be used to evaluate the benefits that might be restored through dam re-operation. Assessing the potential benefits of dam re-operation begins by characterizing the dam's effects on the river flow regime, and formulating hypotheses about the ecological and social benefits that might be restored by releasing water from the dam in a manner that more closely resembles natural flow patterns. These hypotheses can be tested by implementing a re-operation plan, tracking the response of the ecosystem, and continually refining dam operations through adaptive management. The paper highlights a number of land and water management strategies useful in implementing a dam re-operation plan, with reference to a variety of management contexts ranging from individual dams to cascades of dams along a river to regional energy grids. Because many of the suggested strategies for dam re-operation are predicated on changes in the end-use of the water, such as reductions in urban or agricultural water use during droughts, a systemic perspective of entire water management systems will be required to attain the fullest possible benefits of dam re-operations.

Key Words: *dams; dam re-operation; environmental flows; flood control dams; flow restoration; hydrologic alteration; hydropower dams; irrigation dams.*

INTRODUCTION

During the latter half of the 20th century, two large dams were built each day, on average (WCD 2000). By 2000, the number of large dams had climbed to more than 47,000, and an additional 800,000 smaller dams now block the flow of the world's rivers (McCully 1996, Rosenberg et al. 2000, WCD 2000). Globally, over half of the 292 large river systems have been affected by dams (Nilsson et al. 2005). Most of these dams provide substantial benefits to human societies and their economies. Hydroelectric power dams currently provide 19% of the world's electricity supply; one in three nations depends on hydropower to meet at least half of its electricity demands (WCD 2000). By capturing and storing river flows for later use, dams and reservoirs have contributed to the global supply of water for urban, industrial, and agricultural uses. Worldwide, water demands have roughly tripled since 1950, and dams have helped satisfy that demand. About half of the world's large dams were built solely or primarily for irrigation. Today, large dams are estimated to contribute directly to 12–16% of global food production (WCD 2000).

However, damming of the world's rivers has come at great cost to their ecological health and ecosystem services valued by society (WCD 2000, Postel and Richter 2003, WWF 2004, MEA 2005). Dams have

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In considering the social values associated with flood restoration, it is important to note that re-establishing a floodplain inundation regime can make both the floodplain and the river more productive for a variety of user groups. The resultant enhancement of fish and wildlife populations can improve food availability, and many cultural groups use fiber from floodplain reeds or trees for building materials and other purposes. Improved wildlife viewing opportunities can be extremely beneficial to local tourism economies. It can also benefit agriculture on the floodplain through the regular deposition of nutrients, flushing of soil salinity, and the recharge of groundwater aquifers. Although some dwellings may need to be relocated to higher ground to make flood restoration possible, this is not like the resettlement problems associated with new dam construction and reservoir inundation, which reduces river and floodplain productivity. Here we highlight some strategies that can create flexibility in flood management systems.

Flood routing and storage in retention basins

Floodwaters can be allowed to fill natural depressions on the floodplain during periods of high flow. Floodwater may flow onto the land during periods of high river flows and then exit through the same route as the river stage lowers. In some cases, such temporary flooding has been controlled through engineered floodgate structures built into levees that allow water to move into the floodplain for a limited period, and then subsequently discharge back into the river as water levels drop in the river channel. Another possibility is that the excess flow will travel down the river valley in a "bypass" and re-enter the river some distance downstream, effectively increasing the flood conveyance capacity during periods of high flow. This can provide some degree of flood restoration benefit, while also providing flood storage to reduce damages downstream. Possible added benefits include transport of sediment and nutrients to agricultural lands, replenishment of floodplain aquifers, and revitalization of wetlands. The main trade-off associated with this management strategy is the loss of the use of the land during inundation.

This technique often requires some accommodation by landowners or other users of the affected areas, such as through flood easements, purchase of the land for parkland, or some other form of compensation for any lost utilization of the land or resources, e.g., subsistence floodplain farming or grazing. Flood easements are agreements with landowners that allow flooding of privately held lands for a limited time. One tradeoff associated with this strategy can be a delay in planting crops during the inundation period, which may be offset to some degree by the increased moisture and fertility of the soil during the remainder of the cropping season or in subsequent years. The negative side-effects of flooding can be addressed by purchasing flood easements or purchasing the land for nature preserves or other uses that are compatible with occasional flooding, or negotiating management agreements or compensation with owners of communal lands.

Levee setback

Levees built along a river can severely limit or prohibit a river from interacting with its floodplain. By moving levees further from the river channel, a river can flood onto a broader expanse of its floodplain. This provides benefits both in terms of flood control and ecosystem restoration. The further the levees are set back from the river, the greater the increase in flood storage and flood-related ecosystem benefits. These ecosystem benefits can include the partial or full restoration of fluvial geomorphic processes such as river meandering or bar formation that benefit aquatic species and riparian vegetation. The main tradeoff associated with this strategy is seasonal loss of the use of the land located riverside of the new levee system. Agriculture may still be possible within the levees; however, the natural movement of the river, and associated erosion and sediment deposition, may disrupt these operations.

Case study: restoring high flows on the Savannah River

The U.S. Army Corps of Engineers operates three large multipurpose dams on the Savannah River, which forms the border between the states of Georgia and South Carolina. The furthest downstream is Thurmond Dam, constructed in 1954, which is operated primarily for flood control. A dam re-operation project focusing on Thurmond Dam was initiated under a partnership in 2002 between the Corps of Engineers and The Nature Conservancy, an international conservation organization, with legal services provided by the Natural Heritage Institute, a nonprofit environmental law firm.

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An assessment of the hydrologic alteration associated with the dam revealed significant changes in virtually all aspects of the flow regime, particularly in higher flow events (Richter et al. 2006). Thurmond Dam has been quite effective in controlling floods and high-flow pulses (Fig. 5). Small and large floods have been eliminated, and high-flow pulses greater than 450 m^3/s occur with less frequency, particularly since 1980. However, annual average discharge has been reduced by only 15% due to water extractions, from 308 to 263 m^3/s.

The Corps of Engineers began conducting a stakeholder input process in 2003, whereas The Nature Conservancy engaged more than 50 regional scientists in an evaluation of the ecological implications of flow alteration in the river, floodplain, and estuarine systems (Richter et al. 2006). These scientists generated a comprehensive environmental flow recommendation, including specifications for both high-flow pulses and small floods (Fig. 6). The ecological goals represented in Fig. 6 can be viewed as hypotheses to be tested in the dam re-operation project.

The attainment of small flood restoration on the Savannah faces some substantial obstacles. Prior to dam construction, small floods ranged from 2500 to nearly 6000 m^3/s. However, considerable floodplain development has taken place since dam construction. Various structures such as an outdoor amphitheater in the city of Augusta, Georgia would begin to be inundated at 1000 m^3/s, and recently constructed houses would be flooded at flows of 1500 m^3/s. One option that has been proposed is to construct a flood bypass around the city, so that higher flows could be safely passed into the lower reaches of the river.

In the meantime, the Corps has begun releasing high-flow pulses ranging from 450 to 850 m^3/s to benefit fish spawning and access to low-lying floodplain areas, flush oxbow lakes, and disperse the seeds of floodplain trees. The Corps achieves this by allowing water levels in the reservoir to rise slightly to about 0.5 m above their normal target level, i.e., rule curve, for flood control operations. National Corps policy for flood control operations allows for temporary, minor encroachments of a reservoir's "flood pool." When the Corps is ready to release a high-flow pulse for environmental flow benefits, the reservoir level is allowed to rise in the weeks preceding the planned release, providing adequate water volume to create the high-flow pulse. This case study illustrates the fact that certain aspects of environmental flow restoration can be accomplished with little to no infringement on other existing water uses or dam purposes.

Species of concern such as short-nosed sturgeon (*Acipenser brevirostrum*) and floodplain tree recruitment are being carefully monitored as part of the adaptive flow restoration program on the Savannah (Richter et al. 2006), and monitoring results continue to inform the dam re-operation project (per Fig. 4). For example, the results from initial high-flow pulse releases to facilitate sturgeon migrations to their spawning grounds suggested that water temperature would likely also have an influence when the sturgeon migrate; recent releases have been timed to coincide with appropriate water temperature.

Modifying hydropower systems

Hydropower reservoirs store water to create hydraulic "head" for power production either at the dam or at some point downstream. Some of these facilities operate, more or less, on a run-of-the-river mode, when the reservoir is used simply to create the hydraulic head without storing a significant volume of water. Generally, these are facilities in which the capacity of the reservoir is small relative to the annual flow of the river. However, most hydropower reservoirs store and release water on a pattern to generate power during times of highest electricity demand, i.e., peak power facilities. Electrical demands generally peak during particular times of day when, for instance, lights are turned on in the evening or air conditioners are turned on in the late afternoon when workers return home, and during particular seasons, such as summer for cooling or winter for heating. In some cases, water may be captured in a storage reservoir and held for months before being used for power generation. The resultant dam releases can be completely out of phase with natural flow patterns, resulting in considerable damage to downstream river ecosystems and associated species, as well as livelihoods associated with aquatic or floodplain resources. If hydropower dams can be operated to release water on a daily basis at a rate that is closer to the rate of natural inflow into the reservoir, impacts on downstream ecosystems can be reduced. The primary obstacles to this type of dam re-operation include the potential revenue losses