A Call to Enhance the Resiliency of the Nation's Water Management

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A little more than a decade ago, a small band of engineers and ecologists came together along the banks of the Green River of Kentucky to discuss a simple idea. The Green River—"where Paradise lay" in the words of John Prine—is in fact a magical place. Although Prine's song "Paradise" laments the region's environmental degradation and associated social decline—including the literal disappearance of the riverside town of Paradise—a large segment of the Green River remains a natural wonderland. Today, it is one of the most ecologically rich rivers in the nation, supporting more than 150 species of fish, 70 species of mussels, and a host of species endemic to the hydrologically connected Mammoth Cave complex.

However, the environmental health of an extended reach of the Green has been diminished by changes in natural river flows caused by the Green River Dam, built as a multipurpose project by the U.S. Army Corps of Engineers (Corps). It was this nexus of engineering infrastructure and ecological richness that spurred the group of engineers and ecologists to ask whether reservoir operations could be changed to restore the health of a significant reach of the Green River below the dam and meet—or even enhance—other project purposes. Their solution offers lessons on how water and floodplain management can be changed to better meet the nation's current and future needs for more sustainable flood protection, water supply, hydropower, recreation, and environmental health. On a much larger scale, the current flooding in the Mississippi Basin—and the effectiveness of the flood-management system designed in the aftermath of the disastrous 1927 Mississippi flood—emphasizes the importance of using floodplains to help manage floods and the great value in learning from past events and responding with comprehensive water-management systems. As we describe subsequently, it is time to explore more sustainable approaches to floodplain management and to examine opportunities for reallocation of reservoir storage coupled with tighter integration of reservoir and floodplain management. These two components of Integrated Water Resources Management (IWRM) will help to alleviate current stresses on water resources and enhance both social and ecological resiliency.

Growing Stresses on Water Management

Water and floodplain management over the preceding half century has struggled with growing conflicts over water supplies, ongoing encroachment into flood-prone areas, increasingly limited operational flexibility of multipurpose reservoirs, and a decline in river-floodplain ecosystems and a loss in the economically important services they provide. Significant challenges and trends include:

- The average age of a federal dam is 60 years. Over that time, the United States population has doubled to 300 million people and is projected to reach 400 million by 2050.
- The average age of the 14,000 miles of Corps levees is 50 years and much of the estimated 100,000 miles of nonfederal levees is considerably older (National Committee on Levee Safety 2009).
- Despite nearly a century of social investments in dams and levees (hard infrastructure):
  - Economic losses atrributed to flooding have continued to increase and now stand at $6 billion per year (U.S. Army Corps of Engineers (USACE) 2009; Freitag et al. 2009).
  - Levee maintenance has been chronically underfunded, with estimates for repair and rehabilitation exceeding $100 billion nationally (ASCE 2009).
- Tens of millions of Americans now live and work in areas behind levees (Freitag et al. 2009).
- During the preceding half century, there have been considerable shifts in United States demographics, industrial and agricultural production, climate variability, societal objectives, and improved understanding of ecosystems and ecosystem services.
- The geography of "water wars" has expanded considerably, with intense conflicts over water breaking out in places previously assumed to have abundant water, such as in the southeastern United States (Poff et al. 2003).
- River-floodplain ecosystems are both disproportionally rich and disproportionally imperiled. Thirty-nine percent of North American fish species are imperiled or extinct—up from 20% a few decades ago (Jelks et al. 2008)—and 67% of mussels, 51% of crayfish, and 40% of amphibians in the U.S. are listed as imperiled or extinct (Master et al. 1998). Extinction rates of North American freshwater fauna are estimated to be five times greater than those of terrestrial fauna (Ricciardi and Rasmussen 1999), and alteration of flow regimes by dams and disconnection of rivers from their floodplains are among the primary causes of the ongoing degradation (Postel and Richter 2003).
- Although modest adjustments tend to be made in reservoir operations over time, few water-control plans that guide Federal dam operations have been revised since being developed decades ago, and fewer projects have been considered for congressional reauthorization to align their operations with current and projected future circumstances.
- Hydrologically, the future is not likely to look like the past (Milly et al. 2008). Climate change is further straining water and floodplain infrastructure, with many areas of the country expected to experience increasing frequency in both floods and droughts and declining snowpacks.

Although we clearly acknowledge the social benefits from investments in dams and levees, we question whether status quo approaches to water and floodplain management are capable of addressing the diverse and interacting challenges facing the nation. The previously cited trends emphasize the growing strains on the nation's water governance and infrastructure—also noted by others (e.g., Sheer 2010)—and illustrate the urgency of finding innovative approaches to contemporary water-management problems. The challenge of the 21st century is to make the most effective use of our legacy capital investment in water infrastructure by adjusting its design and operation to meet the needs of today and tomorrow.

Key to addressing this challenge is an evolution of water management toward IWRM, including greater emphasis on natural processes, such as river flows and seasonal river-floodplain connectivity. Toward this end, we propose steps to reexamine reservoir operations (water management) and advance integration of river-floodplain (flood-risk) management, and to reestablish sufficient natural river processes to restore the ecological integrity of our river systems and the valuable services they provide. First, we return to the Green River and describe the integrative solution devised by the engineers and ecologists that coordinates reservoir operations and floodplain management to achieve a broader set of objectives.

Integrated Solution for the Green River

The group that was seeking solutions for the Green River was not convened to address a regulatory mandate or legal action. Instead, they recognized that the water-control plan guiding the dam's operations had not been revised in its 30 years. The Corps, The Nature Conservancy, and other partners shared a common interest in changing operations for environmental benefits. In essence, they were probing the dam's operational flexibility and seeking alternatives that could meet downstream environmental objectives while still fulfilling its authorized purposes (primarily flood control, but also recreation and water supply). After a few years of collaborative study, modeling, and test releases, the water control plan for the Green River Dam was revised and formally adopted, the first time the Corps had done so solely for environmental purposes. The changes in reservoir operations restored critical components of the natural hydrograph to benefit the downstream river, floodplain, and Mammoth Cave ecosystems. Although the plan was a notable accomplishment, even more compelling is the fact that the revised water-control plan gave up 5% of the original reservoir flood pool without increasing the downstream flood risk. Private and public funding of targeted and voluntary floodplain acquisitions and easements downstream of the reservoir helped to maintain equivalent levels of flood protection and to increase the operational flexibility of the dam. Furthermore, the revised operations extended economically important recreational access to the reservoir by 6 weeks each year.

Defining a New Way Forward

The Green River provides a tangible demonstration of the premises we put forth here: First, strategic reconnection of floodplains can allow "green infrastructure" to complement the traditional "gray infrastructure" of dams and levees. Second, reallocating reservoir water storage, in coordination with innovations in downstream floodplain management, can improve economic productivity, restore ecosystem health and services, and enhance the resiliency of the nation's water-management systems. These ideas are worthy of much broader consideration and investigation, even as the long-term benefits on the Green continue to be assessed. Although the Green has relatively limited water-management conflicts or constraints, other projects from around the nation also highlight the opportunities and potential benefits of both revising reservoir operations and improving the integration of river-floodplain management, including relying less on hard infrastructure and more on the natural infrastructure of connected river floodplains.

In the following, we offer a set of principles that describe the potential benefits of greater reliance on the green infrastructure of floodplains, as well as the ability for floodplain reconnection to facilitate a reallocation of current reservoir storage to re-optimize reservoirs' societal benefits. These principles merit further investigation and test applications to evaluate underlying assumptions and devise technical, economic, and policy solutions. The Corps and The Nature Conservancy—individually and together—are working on a number of research and applied projects related to these principles, some of which are noted as examples.

1. *Large-scale reconnection of floodplains can reduce flood risk to nearby communities and farms in a more socially and ecologically sustainable manner.* Large-scale reconnection of floodplains increases the cross-sectional area available to store and convey flood flows, potentially reducing the stage and velocity of floodwaters in downstream river reaches and thus reducing the risk of levees overtopping and failing. The disastrous 1927 Mississippi flood destroyed scores of levees and, in so doing, also destroyed the "levees only" paradigm for river management (House of Representatives Document No. 90, 1927, also known as the Jadwin Plan after Chief of Engineers Major General Edgar Jadwin). In response to that flood, the Corps designed a comprehensive approach to flood management—the Mississippi River and Tributaries Project (MR&T)—that included strategic reconnection to floodplains during very high flood stages. The use of several floodways during the current flood has allowed the system to manage a larger volume of water than the 1927 flood with no levee failures within the MR&T. The increasing frequency of large floods in the Mississippi, along with climate-change forecasts indicating increasing flood magnitudes for the basin, suggests that an expansion of these "release valves" should be explored for the Mississippi, and similarly, on other rivers across the nation. While the Corps, The Nature Conservancy, and others are reconnecting rivers and floodplains in a number of states (e.g., California, Illinois, Louisiana), focused analyses should be conducted to define the extent and spatial pattern of floodplain reconnection that is necessary to maximize public-safety and environmental benefits.
2. *Significant net social benefits result from reallocating current water storage in multipurpose reservoirs to reflect contemporary societal values and needs.* Most multipurpose reservoirs have flood control (flood-risk management in current terminology) as a significant and often primary purpose, and real-time water management is constantly engaged in balancing the need for reserved (empty) reservoir flood storage against the benefit of water storage for other purposes (e.g., water supply, hydropower, recreation, and environmental flows). Multipurpose reservoirs may have the flexibility to reallocate water storage between purposes to better reflect current needs and values, and the aforementioned large-scale floodplain reconnections can facilitate a reallocation of a portion of flood-control storage volume to other valuable purposes. The coordinated large-scale reconnection of floodplains and reallocation of reservoir storage may be particularly valuable for increasing the flexibility and resiliency of water management confronting climate change. Even though the Corps, The Nature Conservancy, and University of California-Davis are conducting research

on this concept, much additional work is needed to explore the technical, economic, and policy dimensions of this approach as well as spatial analyses of where these solutions are most feasible.

3. *Reconnected floodplain lands can provide revenue to agricultural landowners.* Although reconnected floodplains can be restored to natural habitats, much of the reconnected land can remain in private ownership and productive agriculture. Agricultural practices consistent with periodic inundation include pasture, sustainably harvested timber, and the cultivation of flood-tolerant crops. Promising flood-tolerant crops include biomass fuel sources such as willow (Volk et al. 2004), switchgrass, and diverse native prairie plants. Future research is needed to examine the agricultural and economic feasibility of large-scale cultivation of these biofuel feedstocks on hydrologically connected floodplains. A broader variety of crops could be cultivated on reconnected lands with projected longer recurrence intervals for inundation. To the extent that these crops would be damaged or lost during relatively rare inundation, new financial mechanisms can be developed to transfer compensation from the beneficiaries of flood protection to those bearing the loss (see details in next paragraph). In addition to traditional cropping, floodplains provide a broad range of ecosystem services, several of which have the potential to provide revenue to landowners. Research should explore potential markets for carbon sequestration, nutrient filtration, groundwater recharge, and recreation. Public sources of funding, such as USDA's Wetlands Reserve Program can compensate landowners for socially valuable ecosystem services, such as wildlife habitat and open space, that may be difficult to capture through markets.
4. *Innovative policies—including the use of public-private partnerships, cost and tax incentives, and other financial mechanisms—are essential to the paradigm shift toward IWRM by strengthening the link between those bearing the costs of risk management and floodplain reconnection and management and those who benefit from these changes.* The vision outlined here is established on the premise that new floodplain land-use patterns allowing periodic inundation and storage of floodwaters and, potentially, facilitating reallocation of reservoir storage and benefits, will produce significant benefits for various communities and sectors. Innovative financial mechanisms are needed in order to link beneficiaries with the costs of floodplain reconnection (e.g., setting levees back), acquisition, easements, and management of natural floodplain areas, and where appropriate, periodic compensation for landowners. This concept can be advanced through National Flood Insurance Program revisions, ongoing flood-risk mapping and levee assessment, and certification efforts, and the Corps-FEMA-led collaboration on synchronizing risk reduction approaches, such as through the Silver Jackets Program. Additional policy innovations should also be considered, such as establishing a national ecosystem restoration trust fund and/or a national flood-risk management infrastructure bank (or state revolving loan fund).

Enhancing Resiliency—Back to the Future

We acknowledge that the vision presented here faces obstacles to its implementation. To be viable, proposed changes in policies and programs must respect private property rights and, where necessary and appropriate, provide equitable compensation for changes in water and floodplain land management. However, the status quo in water and floodplain management is not meeting the needs and expectations of the nation. Failing to develop and implement innovations today only perpetuates and exacerbates the risks to our people, economy, and environment and ensures that options for adaption will become more constrained and expensive. But we are confident that this country remains highly capable of technical and policy innovations and believe that the questions and investigations previously outlined will be central in defining a more resilient way forward.

We close by noting that our proposals are not radical, or even very new. In fact, the basic framework we are proposing was laid out more than 70 years ago, as Major General Jadwin proposed giving the Mississippi River "the room it needs, and to accord with its nature, must have the extra room laterally" (U.S. House of Representatives 1927); and in Gilbert White's seminal work, *Human Adjustment to Floods* (White 1942), in which he emphasized the need to balance structural and non-structural approaches by stating that "Dealing with floods in all their capricious and violent aspects is a problem of adjusting human occupance to the flood-plain environment so as to utilize most effectively the natural resources of the plain, and, at the same time, of applying feasible and practicable measures for minimizing the detrimental impacts of floods."

The nation is clearly indebted to both Major General Jadwin and Dr. White for their prescient calls for more balanced and comprehensive flood management. Although their proposals may not offer a full blueprint for the model of sustainability that we describe here (e.g., Jadwin focused only on flood control and navigation, not on environmental values), they do offer the foundation. Building on this foundation, we can design more broadly sustainable systems through technical, policy, and financial innovations to integrate gray and green infrastructure. Collectively, these innovations will better protect and enhance the resiliency of our communities and regional economies while strengthening the health and productivity of our river systems. Whether implemented at the broad scale of the Mississippi or on a much smaller river, we hope that decades from now, we can look back at that meeting on the banks of the Green River and recognize it as an important step toward achieving this shared vision of more sustainable and integrated management of our rivers and floodplains.

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