The Sustainable Rivers Project:
Incorporating Environmental Flows into Federal Reservoir Operations

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The scientific community has made substantial advances during the past two decades in understanding the relationship between patterns of river flow and environmental and ecological health and the ability of ecosystems to provide a range of goods and services valued by people. In general terms, this improved understanding recognizes that natural patterns of river flows – from seasonal low flows up to periodic floods – are vital for maintaining the long-term health of our rivers and associated floodplains and estuaries (e.g., Poff et al. 1997; Table 1).

These advances in science have not, however, become integrated with or transformed water management practice during this same period. In fact, during the past century, societal demands for municipal water supplies, irrigation to support agriculture, industrial water use, flood control, hydropower generation and navigation have resulted in extensive modification of river flows. Even when water management has considered environmental concerns, the focus has largely been limited to maintaining some level of "minimum instream flow." The scientific methods being used to determine environmental flow[1] needs are, with few exceptions, grossly outdated and lagging decades behind the progress made in scientific knowledge.

Example River Flow Alterations due to Dam Operations

- Decreased low flows due to agricultural or municipal water supply
- Elevated low flows to accommodate pollution discharges
- Loss of small floods (2-20 year events) for flood control, water supply, or hydropower
- Sustained high flows (near bankfull) for flood control
- Rapid and increased fluctuations in flow conditions for hydropower

This is beginning to change and a growing amount of work is going on globally to develop and implement innovative water policy and river-specific management practices that protect or restore ecosystem health while meeting human needs for water, food, and energy. On such example in the United States is the Sustainable Rivers Project (SRP), a national collaboration between the U.S. Army Corps of Engineers (Corps) and The Nature Conservancy (TNC). The first

[1] Environmental flows are defined as flow of water in a natural river or lake that sustains healthy ecosystems and the goods and services that humans derive from them. Effective quantification of environmental flows includes the ecologically important range of flow magnitudes (low flows, high flow pulses, and floods), as well as the timing, duration, frequency, and rate of change of the flow conditions. Globally, "environment flows" is the most common term used, but "ecological flows" or the more dated "instream flows" are also used in some places to have the same intended meaning.

section of this paper provides a brief summary of select work conducted through the SRP, all of which is carried out within existing Corps authorities. The final section looks beyond the SRP and outlines a climate change adaptation strategy as an example of the type innovative idea this country should be considering to more effectively optimize water management to meet a diversity of modern social goals.

The Sustainable Rivers Project

While the Sustainable Rivers Project includes staff sharing, software development and joint training, the primary focus of the SRP is on a set of demonstration sites. The collaboration on the SRP between the Corps and TNC began on the Green River in Kentucky. Working together on the Green since 1998, the Corps and TNC identified a more ecologically compatible water release schedule for the reservoir. Experimental operations using this modified release schedule were assessed for three years prior to making the changes permanent in a revise water control plan. Ecological benefits have included improved spawning for threatened and endangered mussel species, re-establishment of more natural in-channel habitat and river temperatures, and improved conditions in the physically-connected Mammoth Cave complex. These operational changes have provided other benefits including extending the recreational season on the reservoir by more than a month, while maintaining or improving authorized purposes such as flood damage reduction.

The experience on the Green River catalyzed the Corps and TNC to expand the work by launching the SRP in July 2002, and the project now involves 36 Corps dams in 8 river basins across the country (Figure 1), with additional dams and rivers under consideration. The ultimate purpose of the SRP is to demonstrate ecologically sustainable water management so that it can be applied at all dams operated by the Corps as well as at facilities operated by other water managers.

A number of advances have been made since 2002, including establishing a formal process for defining and implementing river-specific environmental flows within an adaptive management context (Richter et al. 2006). Nicknamed the “Savannah Process” for the river where it was first applied, the process is designed to be open, science-based, deeply inter-disciplinary, adaptive, and flexible enough to be customized based on available time and resources. The Savannah Process involves five basic steps (Figure 2):

1) <u>Orientation Meeting</u> – This is the kick-off of the Savannah Process, bringing together diverse scientists and representatives from all key agencies and organizations with water management interests in the basin. The remaining steps (steps 2-5), expected timeline, products, costs, and roles and responsibilities are outlined and discussed. Orientation meetings have involved between 40 and 100 people.

2) Literature Review and Summary Report – A small team of scientists is tasked with: i) conducting an extensive review of existing published research and gray literature related to flow-ecology relationships in the river and similar rivers in the region; and ii) synthesizing this information into a "summary report" designed to inform the environmental flow workshop (step 3). This team has a designated lead, typically consists of 5-10 scientists, and needs to be diverse in its expertise. For example, a team might consist of a hydrologist or fluvial geomorphologist, fish and mussel experts, and riparian and estuarine ecologists. Drafts of both the literature review and summary report are distributed for comment to all who attended the orientation meeting, with comments addressed and the reports redistributed a month prior to the flow workshop.
3) Environmental Flow Workshop – This facilitated workshop, which is typically an intensive 2-3 day event, produces two very important products. The first is a unified set of environmental flow recommendations that give consideration to river, floodplain, and – where appropriate – estuarine systems and encompass requirements for low flows, high flow pulses, and floods for different year types (e.g., climatically dry, average, and wet years). Each of the environmental flow components that make up the recommendations are quantified (flow magnitude, duration, timing, frequency, and rates of change) and explicitly stated in terms of the ecological processes that are hypothesized to support (Figure 3). The second product is a prioritized list of information gaps to help guide research and monitoring efforts. These flow workshops have involved between 35 and 90 people.
4) Environmental Flow Implementation – This involves modifying reservoir operations or other water management practices to create river flows as called for in the workshop recommendations (step 3). In terms of implementation, defined environmental flows tend to fall into one of three categories: i) those that can be implemented immediately without significant conflict; ii) those that require study – typically involving computer modeling – to assess the implications of their implementation; and, iii) those with significant social and/or economic implications that require long-term planning and likely substantial investment to implement.
5) Monitoring and Research – As noted above, a list of priorities for monitoring and research is one of the important products emerging from the flow workshop (step 3). Each of the environmental flow components that comprise the recommendations is linked to specific ecological processes. They are, in effect, hypotheses that are tested through coordinated reservoir operations and monitoring. These hypotheses and the scientific knowledge gaps identified and ranked during the workshop provide a foundation for setting formal monitoring and research priorities.

The time and cost for this process varies. To date, environmental flows have been defined (steps 1-3 completed) at six of the eight SRP sites. At any one site, these three steps take between six and 12 months to complete and cost between $40,000 and $90,000. Environmental flows have been partially implemented (step 4) at five of these sites, along with different degrees of associated monitoring, modeling, and research (step 5). Implementation involves planning, such as storing water earlier in the year, but is also responds to specific circumstances such as large rainfall events. Most of the engineer-scientist teams meet periodically to discuss and coordinate on reservoir releases and monitoring for the upcoming season. Estimated costs for monitoring and research at SRP sites range from a low of less than $10,000 to more than $150,000 per year. Sites at the higher end of this range are those where more intensive fieldwork has been conducted to support computer model development.

Environmental flows defined using the Savannah Process are not constrained by real or perceived limits to their implementation, including those that are physical, legal, social, political, or financial. The purpose of the process is to define the river flows that are necessary to maintain long-term ecosystem health. Any necessary tradeoffs between this goal and other expectations for water management are made subsequently. This approach to defining environmental flows: i) helps advance understanding of critical flow-ecological relationships; ii) supports strategic prioritization of monitoring; iii) pin-points the ecosystem processes that will not be supported by different management options; and, iv) highlights opportunities to align ecosystem restoration or protection with other more traditional human demands for water such as improving flood risk management or hydropower generation.

In collaborating to move through the Savannah Process, water managers and scientists establish working relationships that are mutually beneficial. At each of the SRP sites where environmental flows have been defined and are being implemented, formal and informal conversations now occur between these groups on a quarterly, monthly, or even weekly basis. The engineers benefit from having real-time access to experts who can provide constructive guidance on how to meet multiple management objectives in the most ecologically beneficial – or at least benign – way. The scientists benefit by engaging the water managers – those who control river flows – as partners in research. As a collective, they are positioned to run experiments to reduce uncertainty on how different flow conditions relate to ecosystem health and the goods and services humans derive from healthy, functioning ecosystems. This engineer-scientist partnership is ongoing and allows for experimentation not only around a single event or for a single year, but for long series of years, thereby advancing river science and directly supporting adaptive management.

The Savannah Process has begun to see application beyond the Sustainable Rivers Project, and is being used to define environmental flows to help guide management of municipal water supply reservoirs and groundwater extraction. The process is also being applied in China and Honduras, the latter of which is faced with a dearth of scientific information and is relying heavily on indigenous knowledge. It is in part this flexibility which has gained the process a growing acceptance, and the collaborative pairing of engineers and scientists through the process is helping to improve management, advance science, and provide better protection and restoration of rivers globally.

Beyond the Sustainable Rivers Project

It is important to recognize that Sustainable Rivers Project work has advanced within the existing authorized purposes of the dams involved. It does not compromise existing authorities. And yet, progress made to date on incorporating environmental flows into Corps dam operations is notable and ecological responses encouraging. Public funding should be substantially increased to support the expansion of SRP work across the Corps, as well as to other federal water management agencies.

It is equally important to recognize that there are a host of problems with our 20th century water management model that the SRP is not designed to address, and exploration of innovative water management ideas is timely. One such idea that deserves attention involves re-allocating flood control storage in federal reservoirs to other purposes such as water supply, hydropower, and environmental flow restoration. In order for this to work, substantial floodplain restoration downstream of reservoirs needs to be undertaken to allow these areas to again function for flood mitigation. While there is considerable complexity and cost behind this idea, a number of emerging factors suggests that it is time to give it serious consideration:

1) One of the most certain predictions about climate change is that floods will become more frequent and severe, and improved floodplain management can minimize increasing flood risks;
2) Economic losses and deaths associated with flooding are already rising in the U.S. due to continuing encroachment of human populations and infrastructure into floodplains, a false sense of security that dams can protect us from large floods, and possible changes in flood frequency associated with climate change;
3) The economic value of “ecosystem services” such as the provision of natural flood storage in floodplains, purification of water supplies by floodplain wetlands, recreation and tourism opportunities, and commercial fisheries strongly justify investigating this idea; and
4) The list of aquatic species endangered by flow alteration, including alteration of natural flooding patterns by flood control dams, is growing longer every year increasing the likelihood of future legal clashes.

The potential benefits of implementing this idea are huge, and the number of possible places in the US to implement it is great. The most obvious candidates for these changes in reservoir operations would be dams that are presently being operated for flood control and other purposes already. According to the National Inventory of Dams, there are 640 dams in the US being operated for flood control and water supply; more than 400 being operated for both flood control and hydropower. If the flood control needs of these dams were to be lessened, specifically by enabling higher levels of flood releases from the dams by moving downstream structures out of harm's way and appropriately compensating landowners whose existing uses of floodplain lands may be temporarily and occasionally impacted by higher floodwaters, the reservoir space presently allocated to flood control could be reduced. The freed-up space in these reservoirs could then be re-allocated to other purposes, including water supply storage, hydropower generation, and restoration of environmental flows.

The potential benefits of re-allocating reservoir space in this way can be illustrated with the example of Lake o' the Pines in Texas, owned and managed by the Corps. The ecological health of Big Cypress Creek and the Caddo Lake system downstream of Lake o' the Pines have suffered greatly since the reservoir was built in 1959, primarily because the river's floods have been reduced from an annual average of 6,000 cubic feet per second (cfs) to a maximum of 3,000 cfs. By enabling higher flood releases from the dam, the ecological health of the river and lake can be restored. Importantly, some of the flood control storage space in the reservoir also could be made available for additional water supply storage in this water-short region. In fact, approximately 28,000 acre-feet of water supply could become available for every additional vertical foot of storage freed up in the reservoir (presently, 21 feet of flood control storage is reserved in the reservoir). Each foot of freed-up flood control space would store enough water to supply a population of approximately 17,000 people each year. Alternatively, this additional water supply could be held in reserve, for use during the more-frequent droughts expected under climate change.

Another way to illustrate potential benefits of using floodplains to store and convey floods is to review what has taken place in the Sacramento valley, where a floodplain stores much of the floodwaters that enter the valley. This floodplain, called the Yolo Bypass, serves as an effective substitute for an immense amount of reservoir flood storage. During major floods, such as in 1986, the Yolo Bypass safely conveyed approximately 2.4 million acre-feet of water through the valley during a four-day period. It would be prohibitively expensive to provide that amount of storage in upstream reservoirs. The Yolo Bypass provides important habitat for native fish and waterfowl, recreational opportunities, and two-thirds of its area is in productive agriculture.

While the above illustrations and examples give some sense of the potential benefits of this idea, the feasibility of implementation will require rigorous engineering evaluation in each case. However, it is these types of ideas that need to be considered if we are to find ways to meet social needs for water while restoring and maintaining the health of our river ecosystems and the goods and services they provide.

<u>References</u>:

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Table 1. Ecological Functions Performed by Different River Flow Levels (adapted from Postel and Richter, 2003)

<u>**Flow Component**</u>	<u>**Ecological Roles**</u>
Low (base) flows	**Normal level:** • Provide adequate habitat space for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living in saturated sediments)
Level	**Drought level**: • Enable recruitment of certain floodplain plants • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators
High pulse flows	• Shape physical character of river channel including pools, riffles • Determine size of stream bed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels, prevents siltation • Maintain suitable salinity conditions in estuaries
Floods	• Provide migration and spawning cues for fish • Trigger new phase in life cycle (e.g., insects) • Enable fish to spawn on floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e., different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

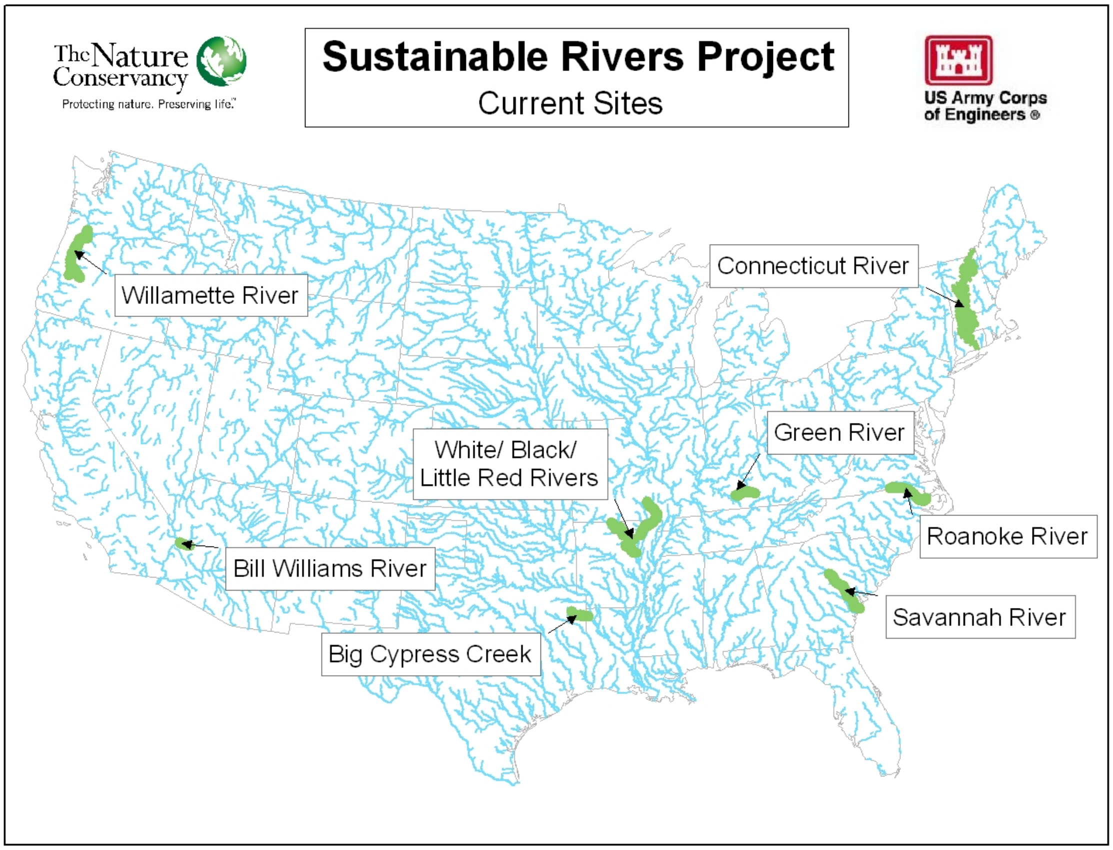

Figure 1: Current *Sustainable River Project* sites (May 2008).

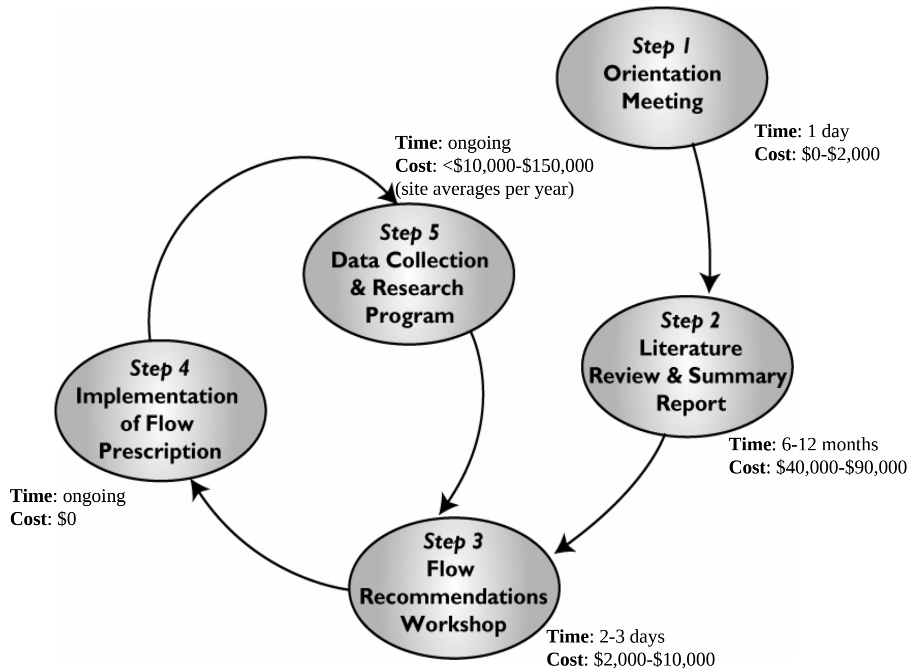

Figure 2: Process for defining and implementing environmental flows within an adaptive management context (the "Savannah Process"; modified from Richter et al, 2006). The time and costs for each step are based on Sustainable Rivers Project work to date.

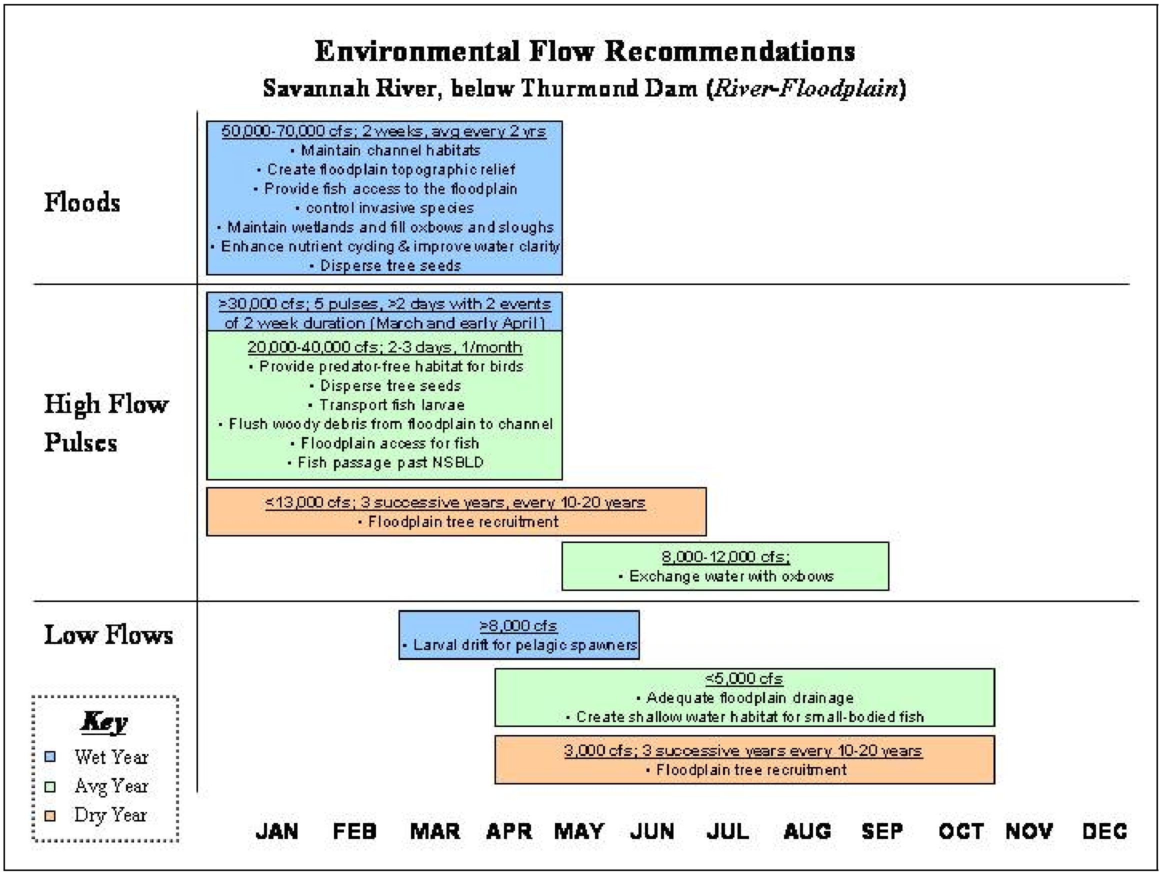

Figure 3: Example environmental flows for the Savannah River. Each “building block” quantifies a flow need in terms of magnitude, duration, timing, and frequency and identifies the specific ecological process supported by the flow. Guidance should also be provided on rates of change between different flow conditions.