ADAPTIVE MANAGEMENT OF ENVIRONMENTAL FLOW RESTORATION IN THE SAVANNAH RIVER

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ABSTRACT

The Savannah River is one of 9 sites for the Sustainable Rivers Project (SRP), a partnership between the Nature Conservancy's (TNC) and the US Army Corps of Engineers (USACE) to more actively incorporate environmental flow objectives into the operation of dams and reservoirs to improve ecosystem health within the context of human demands for water. With the cooperation of over 9 other government agencies and academia, the Savannah has become a case study in science, adaptive management and measuring the success of an ecosystem wide experiment in environmental flow restoration. The Savannah River was used to develop the SRP study process where scientists conducted a comprehensive literature review to compile existing knowledge of the watershed, analyzed pre- and post- dam hydrology, and developed models of the system. Environmental flow requirements were then developed by a team of scientists and water managers which serve as an initial set of hypotheses for experimentation. Environmental flow experiments have been implemented by USACE water managers in close collaboration with the SRP team. Resource agencies, TNC, and academia are conducting monitoring programs to determine pre- and post-release conditions. Monitoring includes long term response variables to measure ecosystem response, and 'trigger' variables that can give more immediate guidance to flow implementation. To date, over 4 controlled flooding experiments have been conducted spanning 3 years and the project has had measured success in terms of biological response, stakeholder education and participation, public education and outreach, increased funding support for the process, influence on water planning and policy, and lessons shared across the world.

1. INTRODUCTION

Since 2002, The Savannah River Basin has been part of the Sustainable Rivers Project (SRP), a partnership between the Nature Conservancy (TNC) and the United States Army Corps of Engineers (USACE) to more actively incorporate environmental flow objectives into the operation of dams and reservoirs to improve ecosystem health within the context of human demands for water. The 10,500 mile^2 Savannah River watershed contains extremely high biodiversity, including over 74 rare and endangered plant and animal species. The Savannah has the greatest number of native fish species (108) of any U.S. river draining to the Atlantic Ocean. Although the Savannah is rich in natural resources, it remains heavily impacted in terms of historic channel modifications for navigation, hydrologic alteration due to dams, and industrial use. The river supplies water for two major cities and contains the fourth busiest port in the U.S. The mutual agency goal of the Savannah SRP is ecologically sustainable water management (ESWM; Richter et. al, 1993) which strives to find a balance between meeting the needs of water for people and water for nature.

The upper two thirds of the watershed contains three large multipurpose reservoirs owned and operated by the USACE (Hartwell, Russell, and Thurmond dams) that are operated for flood damage reduction, hydropower, water supply, water quality, fish and wildlife management, navigation, and recreation. In the lower river USACE also owns and operates a low-head lock and dam, the New Savannah Bluff Lock and Dam (NSBLD) that was historically used for navigation. The hydrology of the Savannah River has been modified significantly due to reservoir construction. Under the dam management regime of the last 50 years, the 100-year flow is approximately the same size as the pre-dam 2-year flow. The current two-year flow (approximately 35,000 cubic feet per second, cfs) is one-third the size of the pre-dam two year flow (approximately 90,000 cfs)(Wrona et al. 2007). However, subsequent urban development of the floodplain has effectively "brought back" the flood risk, and now localized flooding occurs when the river reaches a mere 30,000 cfs. River-floodplain interactions probably have decreased commensurately.

Given a set of ecosystem flow recommendations, USACE water managers have operated dams to provide a series of controlled pulse release experiments to allow partner agencies to evaluate restoration effectiveness within an adaptive management framework. In this paper we summarize our adaptive management efforts to date for restoration of environmental flows, share lessons learned in the process, and present future goals for restoration efforts in the Savannah Basin.

2. METHODS

The Savannah Process

Of the nine river projects, the Savannah River has become a national and international focus on the adaptive management of ecological flow restoration.. In order to increase the likelihood of the USACE to formally adopt ecologically sustainable water management as a standard practice in the Savannah basin, hypothesized flow requirements to restore downstream habitats and benefit native species were crafted in a scientifically credible manner. In 2003, TNC convened leading scientists from across the southeastern United States in a workshop to develop ecosystem flow recommendations for the Savannah River to rehabilitate channel, floodplain, and estuarine habitats.

On the Savannah, the five step process in which these flow requirements for river restoration were determined, as described by Richter et al. (2006), have been carried through several years of iterations for steps 3-5 (Figure 1). With ecosystem flow recommendations in hand, the USACE has released several experimental controlled flood pulses since spring 2004 (Figure 2). A collaborative multi-partnership initiative facilitated by TNC including U.S. Fish and Wildlife Service, U.S. Geological Survey, Georgia and South Carolina Departments of Natural Resources (GADNR, SCDNR), The University of Georgia, Savannah State University, The Southeastern Natural Sciences Academy, and Augusta State University was responsible for crafting and implementing monitoring approaches to determine pre- and post-release conditions. With modifications based on monitoring and modeling results another controlled flood was produced in spring and fall of 2005, and again in spring of 2006 (Figure 2). Overall, TNC's process of developing ecosystem flow restoration recommendations has received considerable attention from scientists working on other flow restoration projects around the world. The process is iterative, where each controlled flood pulse is viewed as an experiment that is monitored and scientifically refined over time.

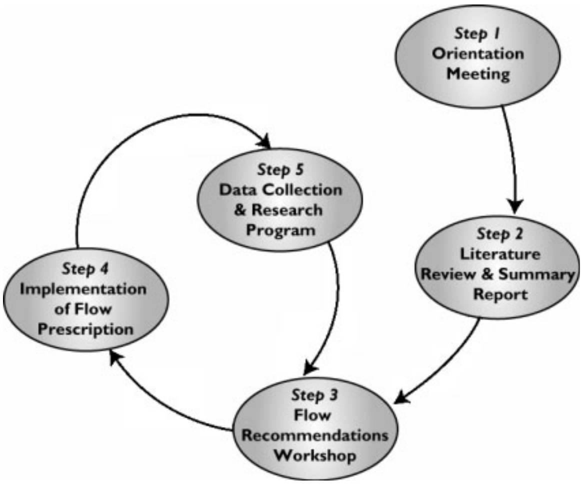

Figure 1. From Richter et al. 2006 with permission from author. The Savannah Process for determining environmental flow components for river restoration through adaptive management.

The resultant learning through testing, evaluation, and modifying management actions is called adaptive management (Holling 1978, Walters 1986, Gunderson et al. 1995). The application of adaptive management principles has been limited in environmental flow restoration. To date adaptive management has been defined by complicated examples (Johnson 1999). If adaptive management programs are expensive, complex, and take years to reach decisions, managers will be reluctant to invoke them (Walters 1997, Richter et al. 2006). The Savannah River provides an opportunity to give badly needed new definition to the concept of adaptive management. By advancing successful examples of ecologically sustainable water management in places like the Savannah River, TNC and other scientists hope to motivate other Corps of Engineer Districts and water managers in other agencies to adopt similar practices around the world (Wrona et al. 2007).

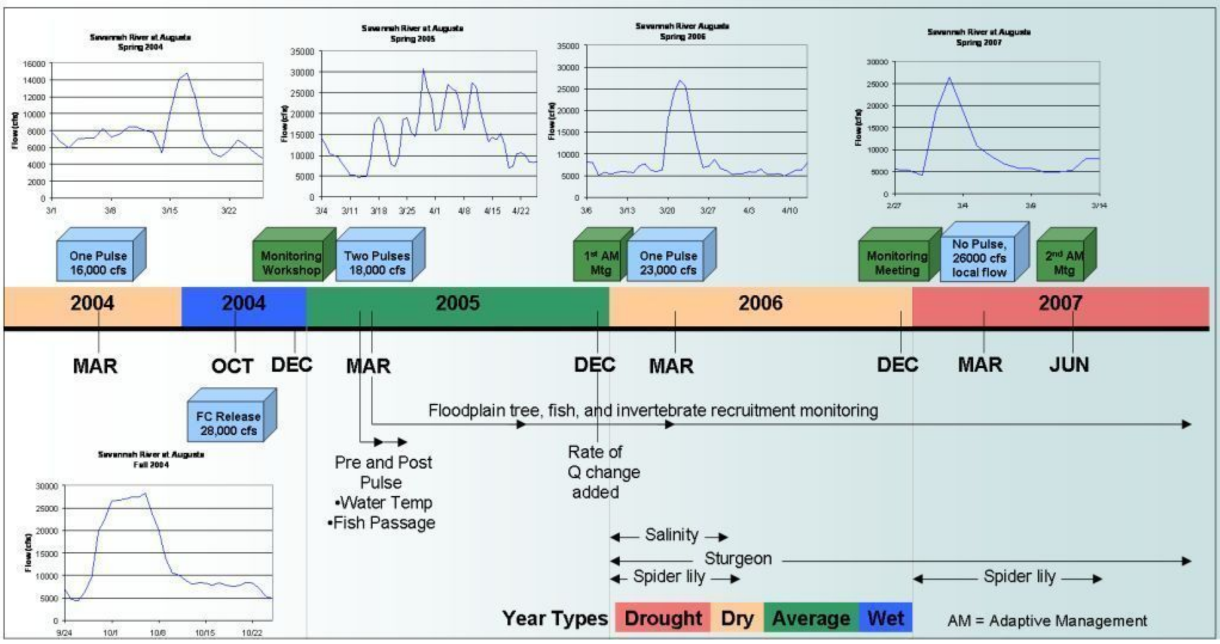

Figure 2. Timeline of ecosystem flow restoration of the Savannah River from March 2004 through June 2007.

Reservoir Storage Allocation

Multipurpose reservoirs serve concurrent and sometimes competing water allocation functions when hydrologic conditions are at extremes. The Savannah system of USACE reservoirs have multiple purposes that are authorized by the United States Congress including flood damage reduction, hydropower, water supply, water quality, fish and wildlife management, recreation, and navigation. Allocation of water resources to these purposes is done in a collaborative manner between Federal and State resource agencies using the best available data. In the Savannah Basin reservoirs, storage is divided into the flood control pool, conservation pool, and inactive pool (Figure 3). The flood control pool is allocated to reduce the risk of damage to downstream municipalities. The conservation pool is primarily used for water supply, hydropower, and recreation. Lastly, the inactive pool is used for storing sedimentation within the impoundments.

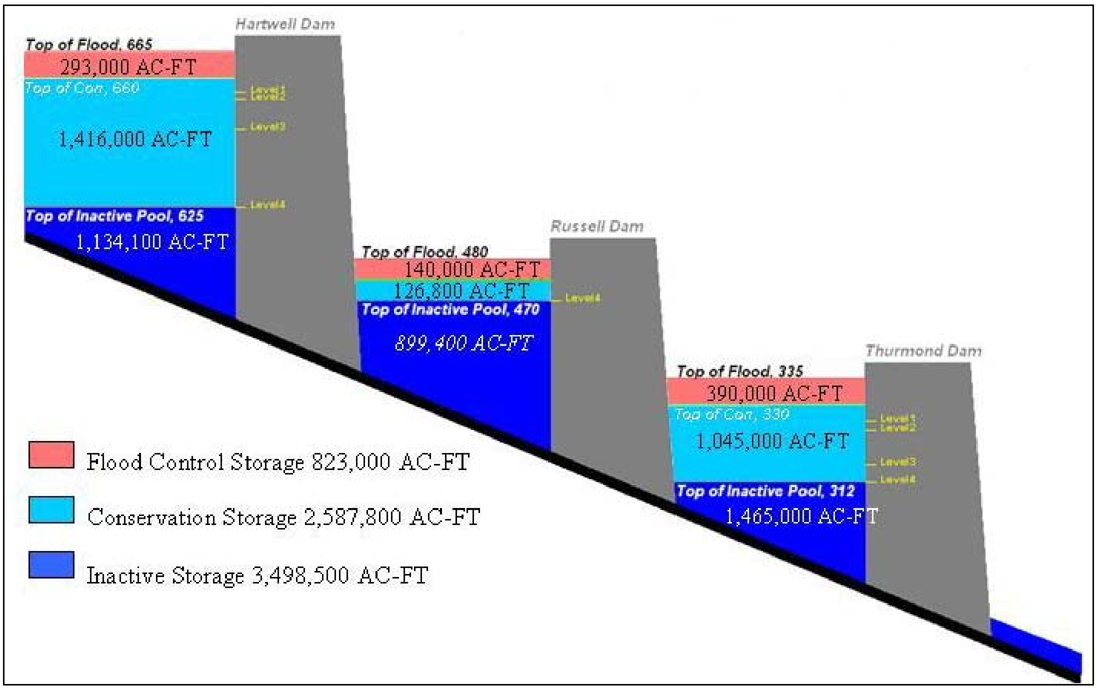

Figure 3. Profile schematic of the USACE reservoir system on the Savannah River

For the SRP flood restoration releases, water was stored in the flood control pool within existing operational flexibility during the wet winter season prior to the pulse release. Using water temporarily allocated in the flood control pool for environmental flow restoration minimized tradeoff impacts to other reservoir purposes such as water supply and hydropower whereas allocation from the conservation pool would require an impact analysis. Temporary reductions in system flood control was evaluated with HEC-ResSim, a reservoir operation model, for a range of conditions and found to be acceptable. The amount of water available in the flood control pool for pulses has varied from year to year and adaptive management has been used to modify the design hydrograph accordingly in terms of timing and duration to utilize that storage to test ecosystem response hypotheses.

Monitoring Program

In 2004, TNC began the process of collating information about current monitoring efforts on the river and concluded that monitoring was limited to water quality and quantity measurements collected by State and Federal agencies to determine if receiving waters meet water quality standards and a few fishery surveys limited to selected commercial and recreational species. Recognizing a need for a more comprehensive monitoring plan to assess the effect of ecological flow restoration, TNC convened a monitoring workshop including over 11 state, federal, academic and NGO partners to determine what indicators needed to be measured in preparation for the next year's pulse restoration effort. The scientific and field experts that were present at this meeting determined the following for three habitat sections of the river (shoals, floodplain, estuary), and for diadromous fishes;

- What is the measurable unit?
- What is the rationale (scientific, historic, cultural)?
- What is the priority?
- What is the future desired ecological conditions of the indicator?
- What methods should be used to measure?
- Are there other research needs associated with this indicator?
- Spatial frequency and timing issues – how often and when is it measured?
- How will this plan be communicated, who will pay, what is already being monitored?
- Is this an indicator that will give us immediate feedback about this year's water release (a trigger) or is a long term response indicator?

With these questions answered and seed money provided by private dollars raised by TNC, a monitoring plan was put into place. Over the next two years the following were measured;

- Diadromous Fish Passage at NSBLD – to determine if diadromous fish including federally endangered Shortnose sturgeon can pass through the dam into their historic spawning grounds
- Floodplain inundation – to quantify the relationship between discharge at Thurmond dam and inundation of the floodplain at three study sites
- Fish use of the flood plain – to verify that the timing of the pulse is correct to induce floodplain use by fish
- Floodplain Forest and Invertebrate Communities Composition and Health – to determine the extent to which hydrologic and biotic conditions have been degraded by past river regulation, and also to assess the ecological recovery of floodplains after flood pulses are restored.
- Shoals Spider Lily – to determine the effect of the timing and size of the pulse on populations of endangered plants within the shoals habitat
- Saltwater/Freshwater interface in the estuary – to determine the relationship between salinity in the estuary and dam discharge at the time of the pulse

In addition, the Southeastern Natural Sciences Academy initiated a two year comprehensive study within the middle Savannah watershed and was able to coordinate continuous water quality sampling and collection of extra data during pulse releases (Flite et al. 2007).

3. RESULTS

Adaptive Reservoir Management

Study objectives for the spring pulse flow experiments have included evaluating effects on endangered species in the shoals habitat, diadromous fish passage success at NSBLD and corresponding floodplain and estuary benefits associated with pulsing. In 2004, USACE operated with no winter time drawdown in the guide curve or target elevation at Hartwell and Thurmond reservoirs to store water in the flood control pool which provided a 3 day pulse of 16,000 cfs in March (Figure 3). Observations made at the New Savannah Bluff Lock and Dam (NSBLD) indicated that flow was not high enough to provide adequate passage conditions though the structure for diadromous fishes. In March 2005, USACE water managers targeted no drawdown again at Hartwell and Thurmond and provided two 3-day pulse flows of 18,000 cfs. At this pulse, monitoring indicated that flow was still not high enough to provide adequate fish passage and that the rising and falling legs of the hydrograph were too rapid to mimic a natural pulse event within the river channel. There was some shoreline erosion damage reported by the USACE because of higher than average pools due to winter rain events and wind driven wave run up. Following the spring 2005 experiment, an adaptive management workshop was held in order to review these results and to revise recommendations to include rate of change guidance for the pulse hydrographs to lengthen the duration of floodplain wetting. In March 2006, the USACE operated with a modified 2 foot drawdown at Hartwell and Thurmond and provided one 3 day pulse of 23,000 cfs. Dry conditions developed after the 2006 pulse and no water has been available in the flood control pool for 2007 and 2008. A local inflow event in 2007 downstream of Thurmond provided a peak flow of 26,000 cfs which helped provide a water quality comparison to releases from Thurmond dam. The magnitude of the pulse increased each year as we learned what flow was necessary to creating more suitable conditions for fish passage. Monitoring data on fish passage effectiveness, floodplain benefits, and estuary salinity response helped guide this iterative process.

Ecosystem Monitoring

Preliminary monitoring results have been published in Wrona et al, 2007; Reese and Batzer 2007; and others are in preparation. Monitoring results of endangered Shoals Spider Lily, *Hymenocallis Coronaria,* indicate that abnormally fluctuating flow rates in the river after anthesis (during May and June) have adversely affected the ability of all three Savannah River populations to produce flowers and/or seedlings which require sufficient time and opportunity to become established during the critical months following anthesis. A reference population that was studied on a non-regulated tributary of the Savannah (Stevens Creek), in contrast having less fluctuation in flow rates, has higher flower numbers and more successful seedling establishment. Researchers (Ware et al. *in prep*) have also captured an insect pollinator on the flowers and are working to verify its role in the flower's sexual reproduction. Through monitoring of these plants the timing of the pulse has been refined. If high water inundates flowers in May and June, as occurred in 2005 in natural rain events after the experimental pulses were released, then pollinators have little or no access to flowers and it is likely that pollen is dislodged from anthers and washed downstream and any high pulses within the shoals in August – October is detrimental to flowers because their seeds cannot geminate and establish. .

Effects of ecosystem flow restoration 'spring pulses' on floodplain flooding include greater than 70% of the floodplain area inundated with flows released from Thurmond dam above 27,000 cfs. The duration of the effects was less than 10 days which is significantly less than historic floods. Possible benefits of these wettings included seed dispersal, fish access, and carbon export. The pulse duration, however, probably does not result in water residing on the floodplain long enough for significant biological processes to occur under anoxic conditions (Davis et al. *in prep*).

Floodplain invertebrate communities differ somewhat between the Savannah and the Altamaha River, a non-regulated river south of the Savannah that was studied as a reference river. There is some evidence that floodplain invertebrate communities in the two rivers are becoming more similar after two years of pulse restoration. In flood pulses earlier in the year (March) monitoring showed that there was no evidence of fish movement into the floodplain (Batzer et al. *in prep*) but that fish use occurs in pulses later in the season (April-May). For the floodplain, recommendations for future pulses may include keeping the forest growing season pulses (March - May), but try lower pulses for longer duration with the goal of trying to keep water in low areas of the floodplain for longer than 10 days.

Effects of the flood pulses within estuary waters became apparent approximately 7 days after maximum release flows began. Overall vertical dimensions and integrity of the seawater/river water interface were maintained. Horizontal dimensions of the interface slightly compressed by approx. 0.4-0.5 miles due to the release; and compression lasted for approximately 10 days. The greatest alteration was a temporary displacement of the interface downriver approximately 2.5 miles for approximately 10 days. Recommendations include pulses timed with freshwater delivery to reach the estuary in April which is optimal for tidal freshwater marsh growing season and stripped bass.

Flood pulses of 26,000 cfs (needed to get gates open at NSBLD) may not have been an effective means of fish passage for shortnose sturgeon, shad, or striped bass. No sturgeon were documented passing through the dam in any year of the experimental pulses. Even though the flow rates were high enough to create the correct physical conditions to allow for fish passage through the structure, results indicate that cold water temperatures resulting from hypolimnetic releases from the dam may have sent a cue to spawning fish to return to the estuary. In an otherwise dry year with minimal rainfall, artificially induced large pulses of this size seem unnatural unless tied in with a rain event and may have detrimental effects on fish if only in a cold water pulse on its own. Continued monitoring of Shortnose sturgeon indicate that the fish continue to migrate upriver to attempt to reach their historic spawning grounds beyond the NSBLD even during drought years (Meadows et al. *in prep*). Removal of the NSBLD would give the most benefit to fish populations in the Savannah River over all other strategies.

4. CONCLUSIONS

Successful partnerships such as the Savannah SRP benefit conservation and stewardship organizational missions, broader water management goals, and river science. Over the years, the Savannah River project has become a learning and demonstration project for all the partners involved. The Savannah Process, or portions of the process has been implemented in several different sites across the US and other nations including the Green River, Willamette, Bill Williams, and 5 other Rivers in the US, the Yangtze River in China, and the Patuca River in Honduras. The collaborative science based nature of the process helps to build consensus among multiple stakeholder groups to achieve positive changes in water management practices. With each application, it has become a more refined process including the development of software tools to help define flow hypothesis and a clearer understanding of the conservation goals when defining ecosystem flow requirements for restoration.

Working within an adaptive management framework in the Savannah basin during ecosystem flow restoration is helping with future water issues such as negotiations over flow allocation during drought. Over the past two years the Savannah River has experienced extreme low flow conditions as the result of new 54 year drought of record. Although droughts are a part of the natural variation of the hydrograph that eco-flow implementation attempts to restore, scientists that work in the Savannah have been cautious to recommend any benefits of extreme low flow conditions due to the highly modified state of the river such as harbor deepening and the artificial straightening of the river that has occurred over the last 100 years for navigation. In an attempt to conserve storage in the reservoir projects, the USACE and the States of South Carolina and Georgia are attempting to temporarily decrease water releases downstream below the historic (post dam) regulated minimum. In an adaptive management framework, the team of experts that have already become familiar with working together due to eco-flow restoration efforts have now come together to develop a low flow monitoring plan, collaborate on interagency habitat and water quality monitoring, and begin evaluation of the impacts to downstream infrastructure and ecology of the riverine habitats and species. There is currently a level of interagency trust and cooperation that will enable USACE water managers to use adaptive management to test low flows downstream to conserve storage and update allocation strategies as future drought conditions occur.

The Savannah SRP has helped garner resources and visibility for environmental flow restoration within TNC and USACE. The project has improved awareness of aquatic ecosystem health and functionality, identified data gaps, and sets a stage for a collaborative analysis of future water management strategies. With seed money made available through private fundraising from TNC and a concentrated well planned effort among cooperating agencies, this demonstration project was very successful at leveraging additional larger grants, cooperation among agencies and entities, and focusing priorities on the Savannah River watershed. The Southeastern Natural Sciences Academy was able to secure funding to extend their initial study from the Augusta corridor of the river, an additional 200 river miles downstream to the estuary. In cooperation with TNC, the SCDNR has been able to focus resources on extending shortnose sturgeon monitoring to the Savannah River in addition to the network of rivers they already sample in SC. Researchers at The University of Georgia have been successful in obtaining continuing grants to support graduate students to study floodplain fish and invertebrates. U.S. Fish and Wildlife Service was able to obtain internal funding to survey freshwater mussels along the river corridor. Even though the monitoring program seems costly when viewed from the end point picture, the leveraging of additional dollars, re-allocation of resources and focusing of priorities is invaluable and worth the result of investitures in planning, science, cooperation, and communication.

Ensuring continuation and expanding funding for scientific monitoring of this work to date has been the most significant challenge of the eco-flow restoration thus far. Scientific feedback to water managers making management changes is an essential part of adaptive management. In this example, where the ecosystem flow restoration is based on testing hypothesis about the relationships between flows and ecosystem responses, monitoring has been the key to adaptive management. By choosing both short term response or “trigger” variables such as fish passage, and longer term response variables such as floodplain tree recruitment, scientific feedback and guidance has been given each year to the timing and shape of the spring pulses, while the long term response of the ecosystem to restoration is also being measured. It has also been the key to focusing agency priority and cooperation within this river system

In order for the SRP goals to be advanced further into standard practice, a comprehensive basin study will be needed to evaluate potential allocation scenarios from conservation storage for ecosystem flow needs. Evaluations of tradeoffs costs to other reservoir purposes will guide collaborative decision making efforts to update water management plans to better reflect changes in hydrologic conditions, societal prioritizations, and ecosystem health. Population growth and increased prevalence of persistent drought in the Southeastern United States has highlighted the need for increased storage capacity.

Future goals for the Savannah River project include continued ecosystem pulse restoration to benefit floodplain and estuarine habitats, to develop a viable fish passage strategy to improve recruitment success of native species, and an adaptive management workshop to update ecological flow recommendations based on monitoring results and new data collection.

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