Appendix E
The Savannah River Ecosystem Flow Prescription

1. July 2015 Savannah River Ecosystem Flow Prescription

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Revision 2.0

July 2015

Photo Credit: Mark Godfrey

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I. Background and History

In 2000, the US Army Corps of Engineers (USACE) and The Nature Conservancy (TNC) entered into a Memorandum of Understanding to "facilitate effective and efficient management of important biological resources within the context of the Corps' civil works and regulatory missions..". Several objectives were listed that are highly relevant to the Savannah District and its operations of major dams on the Savannah River, including:

- "Protect or restore freshwater and coastal habitats for native animals and plants and natural communities"
- "Encourage water management measures that benefit native animals and plants and natural communities while meeting human needs"
- "Foster demonstration projects to test promising water management strategies while monitoring their efficacy in meeting multiple objectives"
- "Cooperate in the monitoring and management of rare and endangered species and their habitat potentially affected by projects and programs pursuant to this MOU"
- "Promote the gathering and sharing of scientific data and research by either entity as it may be related to projects of mutual interest and concern".

As part of a Phase I Comprehensive Basin Study, the District and TNC worked together to develop an *Ecosystem Flow Prescription*. Completed in 2003 through a workshop process, the Prescription was one of the first-ever comprehensive set of river flow recommendations developed for a public water management facility. The Prescription was constructed by a science and engineering stakeholder group with 55 participants representing state and federal agencies, academic institutions and nonprofit conservation organizations. The Prescription described base flows, ranges of variability, and pulse and flood flows to benefit the full range of ecosystem resources and processes in the Savannah River. The original Prescription can be found here: http://tinyurl.com/p5atfa3

Ecosystem data and research for the Savannah River available at the time of the workshop was only occasionally driven at flow-ecology relationships. Workshop participants had to draw heavily on flow-ecology research from other basins and apply a large degree of best professional judgment. Participants responded by laying out a 22-item research agenda that, if carried out, would greatly improve the quality of future flow recommendations. The District and various partners also conducted a series of test releases combined with monitoring to develop relationships specific to management action. These events created a substantial new body of information that informs this document, the Savannah River Ecosystem Flow Prescription, Revision 2.0 (hereafter, Prescription 2.0).

II. Current Opportunity and Need for Revision

The development of Prescription 2.0 was driven by several factors:

- Development of a robust body of new flow-focused research covering a wide range of ecosystem values, services, and processes

- The recurrence of severe drought spates, a condition that the original Prescription did not address
- The advent of funding for, and a desire by the USACE Savannah District and partners to develop a new Savannah River Basin Drought Control Plan (SRBDCP) for Savannah River facilities.

To develop the SRBDCP, Savannah River Basin Comprehensive Study, Interim Study II was initiated in October 2013, with USACE Savannah District, and the states of Georgia and South Carolina, and The Nature Conservancy as non-federal sponsors. Six alternatives were developed (Figure 1) for analysis, including a *Drought Ecosystem Flow Alternative*, developed by The Nature Conservancy using a workshop process similar to the original Prescription. This alternative will examine system performance when operated with ecosystem directives as a priority. Also, elements of the *Drought Ecosystem Flow Alternative* may be incorporated into Alternatives 5 and 6, whose specifics will be determined based on learning from analysis of previous alternatives. Results of Interim Study II will be published in an Environmental Assessment, and a preferred SRBDCP alternative selected as the new basis for drought operations. The projected completion date with all required approvals is June 28, 2017.

Savannah River Basin Comprehensive Study Interim Study II Alternatives							
	No Action Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Drought Level 1	4200 >10% Qin 4000 <=10% Qin	3800 Feb-Apr 3500 May-Jan	4000 at 326	Drought Ecosystem Flow Prescription	3600 at Level 1 3100 Nov-Jan	TBD by Sponsors	Alternate Refill/ Flow Scenarios
Drought Level 2	4000 >10% Qin 3800 <=10% Qin 3600 Nov-Jan	2800 Feb-Apr 2500 May-Jan	3800 at 324 3600 Nov-Jan	Drought Ecosystem Flow Prescription	3600 3100 Nov-Jan		
Drought Level 3	3800 3100 Nov-Jan	1800 Feb-Apr 1500 May-Jan	3600 at 322 3100 Nov-Jan	Drought Ecosystem Flow Prescription	3600 3100 Nov-Jan		
Drought Level 4	3600 3100 Nov-Jan	1500	3600 3100 Nov-Jan	3600 3100 Nov-Jan	3600 3100 Nov-Jan		

10% Qin is defined as the 10th percentile flow at the Broad River near Bell piedmont reference stream gage for reservoir inflow.

Figure 1: Drought Control Plan alternatives for the Savannah River Basin Comprehensive Study, Interim Study II.

Note that the SRBDCP alternatives will be run over a 73-year period of record, much of which is not in drought states. To enable analysis over the full period of record, Prescription 2.0 also includes recommendations for the full range of water availability.

III. Savannah River Reaches

Definitions

The Prescription 2.0 is laid out by defined river reaches, each with a reference US Geological Survey gage. Flow values given for a particular reach and reference gage are meant to be manifested at that gage unless described otherwise. Therefore, the actual water release at Thurmond Dam will need to account for tributary inflow to deliver the flows described in the Prescription.

The reaches are defined as:

Shoals: The reach between Thurmond Dam and the head of the Augusta pool. The reference gage is USGS gage 02192700 at Augusta, GA.

Floodplain: The reach between the head of the Augusta pool downstream to Ebenezer Landing at River Mile 40. The reference gage is USGS gage 02197500 at Burtons Ferry Bridge, Millhaven, GA

Estuary: The reach between Ebenezer Landing to the River's mouth. The reference gage is USGS gage 02198500 at Clyo, GA.

IV. Ecosystem Resources and Service Values by Reach

Shoals

Shoals are an essential engine of a healthy river. Shoals provide a disproportionate degree of primary productivity in southeastern US rivers when compared to other reach types (Marcinek et al, 2005). In shoals supporting aquatic vegetation, such as those of the Savannah, productivity can exceed 2 orders of magnitude over nearby pool settings. This productivity cascades downstream through the river's food chains and biogeochemical cycles. The shoals also oxygenate the water through tumbling action and photosynthesis, providing saturated to supersaturated dissolved oxygen conditions that offset oxygen-depressing conditions of hypolimnetic releases and ponding at the Stevens Creek pool (Southeastern Natural Sciences Academy, 2008). These fundamental biogeochemical properties set the stage for the values enjoyed within the Augusta pool, and downstream reaches including primary contact recreation and fishing, and maintain aesthetic quality.

Shoal habitats are particularly valuable to riverine fishes, many which do not actively build nests to create spawning substrate. The rocky substrate and oxygen-rich flow are essential to their nesting success. Overall, the middle Savannah River from Thurmond Dam to the downstream end of Savannah River Site supports 89 species of fish of which 45 are true riverine species for which non-flowing habitats are unsuitable (Marcy et al., 2005). The Savannah River shoals also support the imperiled redeye bass (*Micropterus coosae*) and a limited freshwater mussel fauna composed primarily of *Elliptio icterina* and *E. congarea* (The Catena Group, 2007). The reach also supports abundant Asian clams (*Corbicula fluminea*) that, while non-native, may be an important food source for the federal candidate species robust redhorse (*Moxostoma robustum*). The robust redhorse has pharyngeal teeth to grind and consume molluscs, its primary food, and specimens from the Oconee River (GA) are known to have Asian clams in gut contents (Marcy et al., 2005). Robust redhorse were found in the shoals in the late 1990's (Hendricks, 2000), and the shoals also receive downstream migrants from restored populations in the Broad River (GA; DeMeo 2001). The shoals will also gain new importance for fish productivity once fish passage is implemented at NSBLD as much of the quality habitat for gravel-depended spawners is found here.

The shoals also support the imperiled rocky shoals spider lily (*Hymenocallis coronaria*), a federal plant species of concern. The plant is obligate to instream environments. While it can withstand short periods without inundation, the Savannah shoals population is particularly imperiled by exposure as it enables deer browsing on the plants.

Since the original 2003 Prescription, the valuation of ecosystem services and products has grown considerably as a discipline, though the work started well before 2003. Ecosystem valuation provides a potential basis by which tradeoffs in resource management decisions can be evaluated. We are not aware of any Savannah-focused eco-service valuation studies. However, relevant studies have occurred in other areas. For example, Loomis and White (1996) conducted a nationwide meta-analysis of willingness to pay (WTP) studies on endangered, threatened, and imperiled species. Annual average WTP values from households to conserve fishes ranged from $6 to $63 (1993 USD), with higher values predictably attached to higher profile sport species such as Chinook salmon and steelhead. The study did include obscure species of which robust redhorse might be considered. With 84,427 households in the Augusta-Richmond county area, the value of robust redhorse conservation might be said to total $835,827.00 annually (84,427 x $6.00 x 1.65 inflation adjustment to 2015 dollars) just to this census area alone.

Water quality, particularly clarity, is known to have value to waterfront properties. Braden and Johnston (2004) determined water clarity to add as much as 15% value to waterfront housing. Poor et al., (2007) reinforced this finding, with a one milligram increase in dissolved solids translating to a loss of $1086.00 in home value. The clarity of the Savannah shoals is supported in part by the capture of sediments and turbidity behind the dams, but the high oxygenation of the shoals also assists with rapid decomposition of organic matter. The flow itself is also a direct hedge against stagnation and associated sedimentation, aquatic weed and algae growth, and odors which detract from waterfront values. In addition to published studies, it is also reasonable to assume the high recreation value of the Augusta pool is aided in no small measure by water clarity which again, tracks back to biogeochemical processes driven by flows in the shoals.

Floodplain

The floodplain reach supports extensive freshwater natural resources, ecosystem services, and rare and unique species. Over 150,000 acres of hardwood forests adjoin the river, and their composition, stature and value is determined by alternating flooding and drought. Flooding controls pine competition and allows high-value hardwoods like oaks and cypress to attain full sawtimber size and value. Drought allows the establishment of new seedling cohorts for future forests. For many landowners near the River, these forests are their primary asset. As of 2010, forestry in South Carolina is a $17.4B business supporting 45,000 jobs, and the Savannah River corridor is one of the State's largest, most intact forest lands (South Carolina Statewide Forest Resource Assessment, 2010 http://www.trees.sc.gov/scfra.pdf). Export of wood products is also the largest product flow at the Port of Savannah. The economics of wood transport dictate that much of this is produced close to the Port.

The floodplain reach supports a wide array of fishes, with 118 total species (Marcy et al, 2005). In addition to diversity, the reach supports popular angling targets such as striped bass, American shad, largemouth bass, bream, pickerel and crappie. A well-used subsistence fishery is established in this reach, much of it focused on channel bends that were cut off from mainstem flow by navigational dredging. The reach also supports the federally endangered shortnose and Atlantic sturgeons, and the federal candidate species robust redhorse. The redhorse was precluded from a formal listing by the formation of a Candidate Conservation Agreement. This vehicle defrays a warranted listing on the basis that key public and private stakeholders agree to take substantive actions for the species' recovery. The Robust Redhorse Conservation Committee is the embodiment of the Agreement, governed by a 1995 MOU (http://www.robustredhorse.com/). Key signatories include state and federal agencies along with Duke Energy, SC Electric and Gas, Georgia Power, Georgia Wildlife Federation, and SC Aquarium.

The floodplain reach also support 19 species of freshwater mussels, a highly imperiled faunal group. The reach supports strong populations of the Altamaha arcmussel (*Alasmidonta arcula*), Savannah lilliput (*Toxolasma pullus*) and delicate spike (*Elliptio arctata*). The latter two were found warranted for listing under the Endangered Species Act in 2011. The Savannah River also supports solid populations of yellow lampmussel (*Lampsilis cariosa*) and barrel floater (*Anodonta couperiana*). The Savannah may be the only remaining occurrence of the barrel floater, as many recent historic survey sites are now absent this species.

Irrespective of species, mussels perform valuable water filtration functions, removing fine suspended sediment and redepositing the material out of the water column as small pellets called psuedofeces. Common species in the genus *Elliptio* can reach densities of over 500 animals per square meter (Krueger, unpublished data). A single adult mussel can filter up to 40 liters of water per day, and a one-mile, 2-million animal bed of common *Elliptio* in the Delaware River was estimated to filter 2-4 billion gallons of water per day (Urban and Welte, 2011). This is roughly equivalent to the entire Savannah River water column during low flows (3094 to 6188 cfs). An *Elliptio* population of 500,000 animals in the

Brandywine River (DE) was found to remove over 25 metric tons of suspended sediment annually (Kreeger, 2005). Due to high current velocities, quantitative assessments of mussel density in the Savannah River are extremely difficult. However, accessible reaches demonstrate very high densities of common *Elliptio* species (Krueger, unpublished data), and direct translation of the above values is reasonable.

The floodplains also perform the ecosystem services of flood retention, and sediment and nutrient retention, which lower water treatment costs of downstream municipalities and water suppliers by as much as $105 per MGD (Ernst, 2004). The floodplain reach also provides critical biogeochemical support to the river's ecology. River-floodplain interaction is the primary source of organic carbon and nutrients below NSBLD, which are the base of primary productivity in the river (Savannah River at Risk, 2007).

Floodplain wetlands perform functions that would otherwise require engineered infrastructure to make water useful to humans. Moore et al (2011) states water-related ecosystem services of flood, sediment, and nutrient / pollutant retention in forested wetlands may reach values of $8196 / acre. Combined forest values of water-related services, recreation, habitat, pollinator support, and aesthetic valuation ranged from $264 to $13,442 / acre in the same study. Forested wetlands attained the highest water-related and combined values, making the Savannah River floodplain forests potentially worth over $2T (2009 USD) in total ecosystem service benefits. Confined to water-related values only, this value may reach $1.2T (2009 USD).

Estuary

The Savannah River estuary, for the purposes of the Prescription, includes the resources from the ocean outlet up to river mile 40, incorporating freshwater habitats like tidal bottomland forests and freshwater marshes. There is substantial overlap between these freshwater areas, and the resources and values described in the Floodplain reach above. Resources and values of freshwater forested wetlands, fisheries, mussels, and biogeochemical services are described above and not repeated here.

The estuary once supported approximately 12,000 acres of freshwater tidal marsh. These marshes are notable for their high plant diversity, productivity, and provision of critical migratory and wintering habitat for waterfowl and wetland birds. A series of harbor deepening projects in 1937, 1958, 1975, and 1994 have increased the estuary depth from 12-15 to 42 feet, and have drawn the freshwater-saltwater interface upstream from RM 7 to RM21. Sea level has also risen approximately 3 feet since Savannah was settled in 1733. Approximately 8000 acres of freshwater marsh have been converted to brackish and salt marsh with lower diversity and habitat values. A large portion of the remainder exists within the Savannah River National Wildlife Refuge (Savannah NWR), a 29,175 acre complex of tidal bottomland hardwood forest, hardwood hammocks, upland pine-hardwood forest, and emergent freshwater and brackish marshes. Several thousand acres of freshwater marsh are in actively managed impoundments where the ability to flood with freshwater is an essential management tool.

Based on the Savannah NWR 2012 Visitor Survey, the Savannah NWR has over 150,000 visitors annually, with the NWR being the primary travel destination for 52% of these visitors. Visitation is 52% local (within 50 miles) and 48% non-local, with local and non-local visitors spending an average of $30 and

$81 per day in the local area, respectively. Hiking, biking, wildlife and bird watching, photography, fishing, hunting, auto tours, and environmental education are the primary uses.

The estuary is overwintering habitat for federally endangered shortnose and Atlantic sturgeons. Collins et al. (2002) tracked movements of 15 telemetered juvenile shortnose sturgeon in the Savannah estuary for two years. The authors found juvenile shortnose sturgeon staging and foraging in deeper holes at mean salinities of 0.1 (+/-0.0) to 5.3 (+/-4.3) PPT, and selecting lower salinity sites upriver as temperatures rise. The estuary is also known to support Atlantic sturgeon, which was federally listed in February 2012 as endangered in four of five population segments including the Carolina segment. Much less is known about the Atlantic sturgeon, though initial telemetry studies indicate similar staging behavior in the estuary, but with spawning movements occurring the fall as water temperatures reach 23-28^{o} C (Bill Post, SCDNR, unpublished data). The estuary also supports fisheries for striped bass. In the Savannah River, striped bass congregate in the estuary in November-March, and move upriver in warmer months for thermal refugia. The Savannah River striped bass population is primarily riverine, and spawns in the estuary at upper low-salinity areas. The 9 PPT halocline is considered the limit of salinity tolerance for striped bass eggs (Will et al., 2002). Striped bass drive a significant portion of the GA and SC angling economy. In 2011, striped bass alone accounted for 12% of the $873M ($105M) angling economy in Georgia (http://tinyurl.com/qfxw9hu) and 16% of the $686M ($109M) angling economy in South Carolina (http://tinyurl.com/pov7cjb).

A commercial gill net fishery for American shad is still active in the Savannah estuary. Assessing the size and value of commercial shad fisheries in the Savannah estuary is difficult, however, as the legal fishery and tracking thereof ranges up to US Highway 301, and commercial landing reports are state and regionally based. American shad is considered the most valuable commercial fish in South Carolina. Statewide SC commercial shad landings were valued at $241K and statewide GA landings at $71K in 2013, the most recent year of available data (http://tinyurl.com/o3udzre).

The estuary is also a critical nursery for marine commercial and recreational fisheries. Many marine fishes and crustaceans use the estuary as juveniles, gaining size and strength before migrating into the open ocean. Examples include king mackerel, Spanish mackerel, bluefish, groupers, red drum, black drum, and southern kingfish, shrimp, and Atlantic menhaden. These estuary-dependent fish make up the majority of marine commercial landings in the South Atlantic states (NC, SC, GA, FL east) by weight (80%) and dollar value (73%), accounting for $644M of regional commercial landings in the period 2000-2004 (Lellis-Dibble et al., 2008). These same fishes form a highly desirable recreational fishery as well, with at least 9 fishing charters currently operating out of Savannah, GA (http://tinyurl.com/q28nrhq). Recreational saltwater angling (2011) accounted for $86M of the total angling economy in Georgia (http://tinyurl.com/qfxw9hu) and $177M of the total angling economy in South Carolina (http://tinyurl.com/pov7cjb).

The estuary also supports two commercial and one public oyster grounds, and blue crab fisheries. The estuary is also defined as Essential Fish Habitat for a variety of marine finfish species, and provides nutrients to the ocean through tidal flushing of dissolved and particulate substances.

Freshwater input from the river to the estuary is the key determinant to how these resources are distributed, and whether appropriate conditions are available for breeding, maturation, overwintering, and predator and disease avoidance. Freshwater pulses provide sediment and nutrients for marsh growth and accretion, provide turbidity that protects juvenile fish from predation, and control oyster disease. Appropriate base flows maintain the salinity distributions that dictate the natural resource values present in the estuary.

V. The Ecosystem Flow Prescription 2.0

Prescription Development Process

The Prescription 2.0 was developed collaboratively with university scientists, agencies and stakeholders over the year 2014. Fifty-one (51) individuals representing 21 organizations participated in its development. The process included six months of preparatory work from January-June 2014 through a 20-person technical committee. Important aspects of this preparation included acquisition and mining of new flow-ecology data and studies generated since 2003, and detailed review of the original 2003 prescription for elements whose context may have changed or for which new data may have been acquired since 2003. The preparatory work culminated in a Savannah River flow strawman; essentially a very rough draft of a new prescription intended for further development.

The strawman was then used as a launching point for a two-day participatory workshop held in Augusta, GA on July 23-24, 2014. Workshop participants were also provided with several supporting documents ahead of the dates, including the original 2003 prescription (Meyer et al., 2003; located here: http://tinyurl.com/p5atfa3), a post-2003 literature review through 2012 of direct Savannah River research and other highly relevant findings (Long and Jackson, 2012), and a compendium of drought-focused instream research conducted in 2012-13 by the US Fish and Wildlife Service (Duncan et al., 2014). Also provided were analyses of pre- and post-dam flows in the *Ecosystem Functions Model* (http://tinyurl.com/q8hf9vn), using flow benchmarks developed in the pre-workshop strawman to provide context of which benchmarks are already met in normal operations versus those needing targeted management action. Participants were also briefed on significant unpublished research regarding movements of endangered sturgeons (B. Post, unpublished data), and relationships of floodplain forest elevations to flow magnitude (B. Sharitz, M. Davis, and L. Lee, unpublished data).

Participants then broke out into shoal, floodplain, and estuary sub-groups, with the task of defining the magnitude, frequency, duration, timing, and rates of change of river flow that would best suit the ecosystem values of those reaches. Participants were directed to consider system constraints while defining flows, and to consider effects of major system changes such as the Savannah Harbor Expansion Project (SHEP) and associated mitigation works. These are key differences from workshop directions given for the 2003 prescription, where constraints were not considered and the details of SHEP impacts were unknown. When complete, groups returned to a full-group session, reported findings, and attempted to resolve conflicts between flow prescriptions by reach. The full group also defined a set of research needs to improve future versions of this prescription.

Prescription Elements

Following is the revised ecosystem flow prescription. The revised prescription is built first and foremost upon 2014 workshop outcomes, which were driven by post-2003 research that directly addressed Savannah River flow-ecology relationships. Some 2003 elements were reaffirmed in the same research and carried forward. Other elements were refuted in research, modified significantly in light of other constraints on flow operations, or were found to already be served in normal operations. A notable example of this is flood frequency and duration in forested wetlands. Analyses of Millhaven and Clyo gauge records using new data on flood elevations and forest communities (B. Sharitz and M. Davis; 2007 unpublished data) showed that floodplain inundation still occurs in a relatively natural manner through normal operations. The largest loss in inundation is for mid-level oak terraces, declining from 17% to 11% growing season duration across pre- to post-dam analysis periods. Post-2003 research has also determined that flow volume has little to no influence in cueing anadromous and resident fish spawning; water temperature is the primary driver. These changes and findings drive the justifications provided for individual flow recommendations.

The prescription proceeds through time according to water state. This is the relative abundance of water at any point in time. Ecosystem goals and the flows associated with them vary by water state. The 2003 prescription used percentiles of mean annual flow to determine dry, average and wet "years". The 2014 technical committee determined that mean annual flow was not an actionable basis for delivering prescription elements through dam operation, and sought a real time alternative that could define water state at any moment. Thus, water state is now described by the percentiles of 28-day moving average of inflow at the Broad River gauge at Bell, GA (02192000). Water states include wet (>75 percentile inflow), average (25-75 percentile inflow), dry (10-25 percentile inflow), and drought (<10 percentile inflow). The companion Excel prescription spreadsheet lays out each water state across a calendar year. The intent is for Thurmond operators to have flow prescription instructions across the calendar where changes in water state are handled by simply moving to the applicable prescription sheet for that water state. This will result in a river operation that better reflects natural variability.

Drought State Prescription

Drought conditions exist when inflows are less than 10% of historical normal. When inflows are less than the 10^{th} percentile of 28-day moving average flow at the Broad River gage near Bell, GA (USGS 02192000), the drought state prescription will apply.

Shoals Reach

Introduction

Flows prescribed for the Savannah River shoals reference the USGS gauge at Augusta (USGS #02197000). Practically speaking, implementation of shoals base flows rely on the issuance of the Augusta hydropower license under the Federal Energy Regulatory Commission (FERC), and implementation of the settlement flows therein. The shoals prescription does call for some additional variation and volume over settlement flows, but uses settlement flows as the baseline of the prescription. Note also that the settlement flows are daily average flows, not continuous minimums. A continuous minimum would be ideal for shoal health, but is not enforceable within the settlement as written.

An important new aspect to this revised prescription is conditions for managing subdaily variation. As Thurmond Dam releases are still the primary control on flow during drought at priority fish spawning sites, variation conditions in the floodplain imply a targeted operation at Thurmond to meet them. The seven-day moving average was selected as a trigger for implementing variation conditions. Empirical analysis of available continuous temperature records from the Savannah River indicates that temperature will not regress below a selected threshold from that calendar point once the 7-day average reaches that threshold value. Once the trigger is reached, operations will follow subdaily variation rules for a prescribed period of 30 (robust redhorse) or 45 days (shortnose sturgeon).

Base Flows

- January: Provide a minimum of 1500 cfs in the shoals *after* Augusta Diversions are accounted for in all drought years.

- February through April: Provide a minimum of X in the shoals *after* Augusta Diversions are accounted for where X equals:
  - 3300 cfs every four of ten drought years. In the other six of ten drought years provide:
  - 2000 cfs when Thurmond Dam releases are >3600 cfs
  - 1800 cfs when Thurmond Dam releases are <3600 cfs

- May: Provide a minimum of X in the shoals *after* Augusta Diversions are accounted for where X equals:
  - 2500 cfs every four of ten drought years
  - 1500 cfs in the other six of ten drought years

- June through December: Provide 1500 cfs in the shoals *after* Augusta Diversions are accounted for.

Maximum Flows

- January 1st – April 30th: No maximum flow recommendation
- May 1st –June 30th: Constrain base flows to a maximum of 20,000 cfs for 2-3 days, if feasible.
- July 1st – December 31st: No maximum flow recommendation

Ramping / Variation Rates

- January 1st to December 31st: When reducing output at Thurmond Dam, decrease flows such that shoals flow declines at ≤ -1000 cfs per day to reduce stranding of aquatic organisms.
- Transition *downward* through drought stages at -5% daily until next flow stage is met.
- Transition *upward* via the 2006 and 2012 drought guidance which states "During drought recovery periods, the discharge restrictions at J. Strom Thurmond Dam will be raised to those of the next higher action level when the pools at Hartwell and JST rise approximately two feet into the new zone."
- Note: Variation recommendations in the floodplain reach below New Savannah Bluff call for no more than +/- 500 cfs variation during fish spawning periods. Additional modeling or experimentation may be required to identify the variation at Thurmond Dam which meets the +/- 500 cfs downstream criterion. Variation at Thurmond can likely be greater than this, and still meet the criterion through channel friction, wave attenuation, and re-regulation through the Stevens Creek and Augusta pools.

Pulsing and Flooding

No pulse or flood recommendation

Justifications: Shoals Reach Drought Flows

Base and Maximum Flow:

Shoal drought flow values and timing provide adequate wetted perimeter and dissolved oxygen to support resident riverine fishes and mussels. This includes passage up to the Augusta Diversion Dam, and some limited spawning opportunity. Export of primary productivity to downstream reaches will also be provided. The shoals workgroup referenced the Physical Habitat Simulation (PHABSIM) outputs of the Augusta FERC settlement as the basis for flow recommendations (see ENTRIX, 2002: *Savannah River Instream Flow Study: Augusta Canal Hydropower Project*). The Study is a very detailed analysis of the flow-habitat relationships in the shoals, covering a wide variety of resident fish groups and invertebrates. The workgroup further argued that the weighted usable area (WUA) outputs for robust redhorse spawning (*figure 2*) provides an appropriate surrogate for shoals mussel populations, as the two co-occur in many rivers and streams. This WUA output is reflective of many other resident riverine fish species as well (see ENTRIX 2002; Figures 5-1 through 5-17).

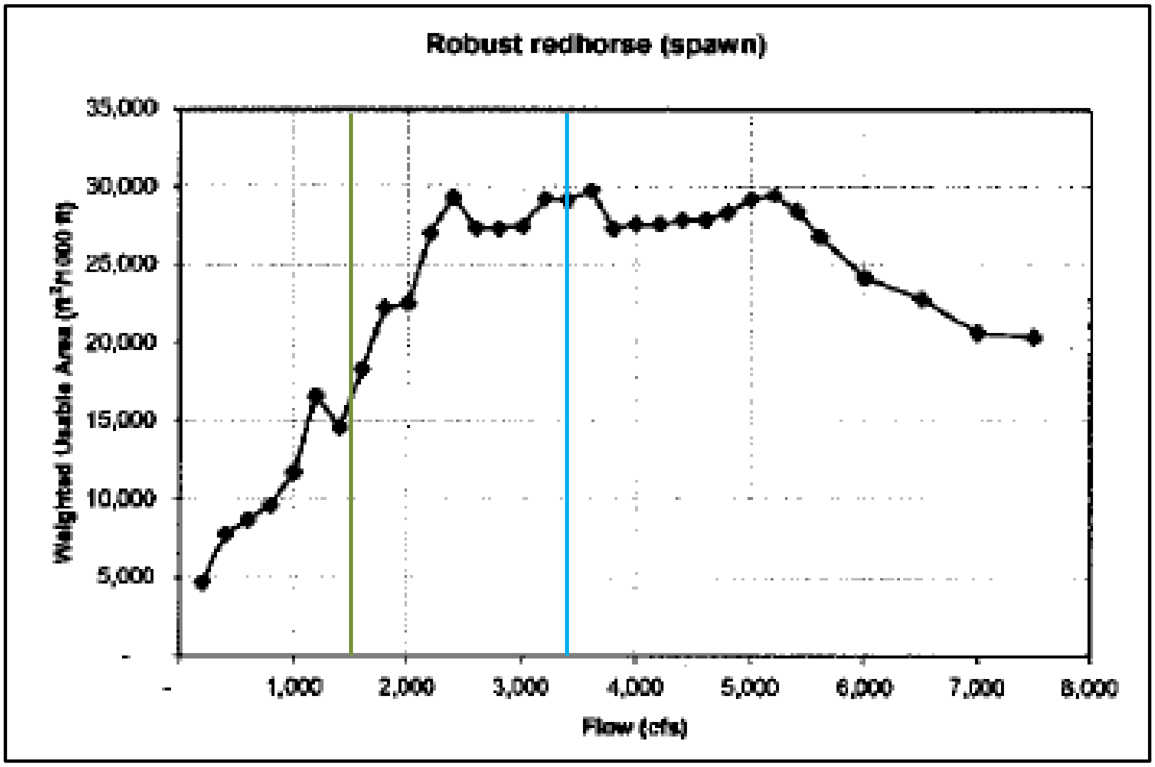

Figure 2: Weighted usable area for robust redhorse spawn, as a surrogate for freshwater mussels and many other riverine fishes in the shoals reach (ENTRIX, 2002; Fig 5-2). The low (green) and high (blue) ends of the 2014 shoals recommendations are added.

The maximum flow recommendation to cap flows at no more than 20,000 cfs for 2-3 days will protect spider lily colonies from physical damage to flowering parts. Flood control priority and short-term climate spates may force deviation from this cap; return to <20,000 cfs as soon as feasible.

Ramping / Variation Rates:

Constraining flow reductions to no more than 1000 cfs per day will reduce stranding of aquatic organisms, and allow low-mobility fauna like freshwater mussels to relocate before stranding. Freshwater mussels have very limited mobility, with a maximum ability of 1 meter horizontally per day (Amyot and Downing, 1997).

<u>Floodplain Reach</u>

Introduction

The floodplain reach is defined as the terminus of the Augusta shoals downstream to Ebenezer Landing at approximate river mile 40. Flows prescribed for the Savannah River floodplain reach reference the USGS gauge at Millhaven, GA (USGS #02197500).

Base Flows

- January 1st – March 15th: No base flow recommendation
- March 16th – October 15th: Provide a minimum of <4000 cfs
- October 16th – December 31st: No base flow recommendation

Maximum Flows

- March 16th – October 15th: Constrain base flows to ≤10,000 cfs if feasible. If short-term climate conditions require higher releases, endeavor to constrain releases over 10,000 cfs to two weeks or less.

Ramping / Variation Rates

- When the 7-day moving average temperature rises to 10° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs for six weeks hence. The variation is around whatever flow value is present when the temperature criterion is hit. The 10° C temperature is the trigger for endangered shortnose sturgeon spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 10° C criterion is February 18th over the last 9 years.

- When the 7-day moving average temperature rises to 16° C at River Mile 179: Within 5 days, control subdaily variation to +/- 500 cfs for four weeks hence. The variation is around whatever flow value is present when the temperature criterion is hit. The 16° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 5 days. The median date for arrival of the 16° C criterion is April 12th over the last 9 years.

- When the 7-day moving average temperature declines to 23° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs for six weeks hence. The variation is around whatever flow value is present when the temperature criterion is hit. The 23° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 23° C criterion is October 10th over the last 9 years.
- For all *flow reductions* through drought stages, reduce flow at -5% daily until next drought stage flow is met.

Pulsing and Flooding

- January 1st – December 31st: Provide 1-2 day pulses at 4000-6000 cfs at a recurrence of approximately 1 per month. Whenever feasible, time these pulses to enter the estuary at high tide so as to retard salinity intrusion.

Justifications: Floodplain Reach Drought Flows

Base and Maximum Flow:

In drought periods, limited to no flooding is a normal consequence. Drought is also the primary opportunity for floodplain forests to establish new tree cohorts, as seedlings of floodplain tree species are not immediately flood-tolerant. The primary goals for floodplain flows during drought are:

- Germination and establishment of tupelo-bald cypress (bottomland swamp) and bottomland hardwood forest species
- Egg and larval drift of pelagic spawning fishes
- Juvenile fish survival
- Spawning habitat in gravel shoals
- Adequate adult fish habitat during low flow periods
- Water exchange and dissolved oxygen maintenance in cutoff meander habitats

Base flow provisions for upstream shoals and downstream estuary were deemed sufficient to meet drought floodplain functions in the non-growing season (defined as October 15th through March 15th). Base flows for growing season (<4000 cfs base / 10,000 cfs maximum) will enhance germination and establishment of floodplain hardwood tree species. Flows as low as 2000 cfs could be adequate, though work group participants recognize the necessity of meeting assimilative capacities. The max flow of 10,000 cfs is driven by specific floodplain elevation data revealing flooding onset thresholds of 17,200; 14,000; and 11,700 cfs at Augusta, Millhaven, and Clyo gages, respectively (Long and Jackson, 2012). Short-term climate conditions and flood control priority may force violation of the 10,000 cfs maximum; the goal is to avoid inadvertent flooding through management action. Flows in the 2000-10,000 range should meet most requirements of pelagic fish like American shad, and common angling targets like largemouth bass, bream, and other Centrarchid fish.

Ramping / Variation Rates:

Since 2003, abundant new information was developed on the flow-ecology relationships of endangered and candidate species fish. Telemetry and acoustic monitoring of shortnose and Atlantic sturgeon, and robust redhorse (Grabowski and Isley, 2006; Straight, 2014; B. Post; unpublished data, 2011-15) has revealed these fishes initiate spawning movements primarily on temperature cues, and travel upriver independent of flow volume. Flow appears to play little to no role in triggering initial movement and staging actions. Shortnose and Atlantic sturgeon spawn in spring and fall, respectively, following temperature cues of ~10° C (ascending) and ~23° C (descending). After an approximate 7-day upriver migration from the head of the estuary, they spend approximately two weeks at RM 187 and return downriver (Trested et al., 2011; B. Post; unpublished telemetry data, 2011-15). Sturgeon egg maturation and development to a free-swimming stage with the ability to escape predators requires 20-40 days, the exact duration of which is strongly driven by temperature (National Marine Fisheries Service, 1998, Hardy and Litvak, 2004). Robust redhorse begin upstream movement at ~10° C as well, but do not begin actual spawning until ~16° C is achieved at the spawn sites (bars at RM 187 and 177) (Straight, 2014).

Once engaged, robust redhorse spawning activity will continue for 4-5 weeks, though the majority of spawning action occurs within the first two weeks of onset (Straight, 2014). After egg deposition, larval fish will emerge in 10-14 days.

Flow volume and variation become critical once these fishes are on spawning sites and eggs are deposited in nests. The critical factor is to avoid dewatering of nests, as exposure of fish larvae to open air is 100% lethal (Fisk et al., 2013). Nest dewatering is a recurrent event in the Savannah River floodplain reach. This phenomenon was first officially recorded in the Savannah River in 2004 and 2005 (Grabowski and Isley, 2007), and observed again in 2015 (Krueger, Duncan, 2015 – personal observation), though flow records indicate these events to be historically common.

The highest quality spawning habitat at the present time is on the tops of the bars at RM 187 and 177, and 6540 cfs for is required for 100% habitat suitability. However, limited habitat is available at RM 187 and 177 at flows as low as 3300 and 3800 cfs, respectively. Successful spawning for sturgeons and redhorse can be accomplished in all but the most severe droughts by controlling flow variation by +/-500 cfs for limited periods after temperature cues are reached. This will assure that fish choose nesting sites only in areas that will remain underwater during incubation, hatching and emergence. Note that while the Excel-based layout of the Prescription uses fixed-date start and endpoints, the attainment of temperature cues on a 7-day moving average defines the implementation of floodplain flow variation recommendations (note: add 7 days from the attainment date of the temperature cue for sturgeons to account for migration time).

The advent of fish passage at NSBLD will likely reduce the concentrated use of bars at RM 187 and 177 for spawning in favor of similar or better habitats in the shoals reach. This may *increase* the importance of controlling flow variations at Thurmond Dam during the spawn periods, as flow changes from any dam are most directly manifested the closer one is to the facility due to reduced channel friction and wave attenuation. This proximity effect will be offset somewhat by fact that shoal depths are not as sensitive to flow volume as in downstream reaches due to greater slope.

Pulsing and Flooding:

Surveys of cutoff channel bends (oxbows) since 2003 found these sites to be important reservoirs for a diverse and imperiled mussel fauna (Catena Group, 2007), and for local recreational and subsistence fisheries (Duncan et al, 2014). Duncan et al. (2014) surveyed connectivity of oxbows to mainstem river flows during the drought spate of late 2012. Angler access and navigability was also assessed. The lowest flows (nominally 3100 cfs at Thurmond Dam) retained connectivity with 68% of oxbows surveyed. Angler access however, was reduced to 32% of oxbow acreage, and other oxbows disconnected at low flows contain high resource values. Oxbow H (RM 136.35), a site of very high numbers of the imperiled Savannah Lilliput mussel (*Toxolasma pullus*), requires 4781 cfs at the Millhaven USGS gage for connectivity. Also, preliminary dissolved oxygen monitoring indicated some restoration of oxbow dissolved oxygen levels when recharged by mainstem flows exceeding connectivity thresholds. Short, low magnitude pulses of 4-6000 cfs for 1-2 days duration are recommended to recharge the majority of oxbows in the floodplain reach.

Estuary Reach

Base Flows

- January 1st – March 15th: Provide a minimum of 4000 cfs
- March 15th – October 15th: Provide a minimum of 5000 cfs
- October 16th – December 31st: Provide a minimum of 4000 cfs

Maximum Flows

- No maximum flow recommendation

Ramping / Variation Rates

- No ramping / variation recommendation

Pulsing and Flooding

- January 1st – Dec 31st: Provide one pulse of 7500 cfs in timing with lunar high tides (~1 per month); release approximately 9 days ahead of high tide to offset salinity intrusion; attempt to align with floodplain pulse recommendation.
- March 1st – May 31st: Provide one pulse of 12,000 cfs for fourteen (14) days duration. This pulse can account for one of the 7500 cfs monthly pulses recommended above, if timed to high tide.

Justifications: Estuary Reach Drought Flows

Base Flow:

Growing season interstitial soil salinity has the strongest influence on marsh vegetation composition (Welch and Kitchens, 2006). A base flow of 5000 cfs during the growing season will prevent salinization of freshwater marsh, while 4000 cfs in the non-growing season should prevent a degree of soil salinization that cannot be reversed by resumption of growing season flows (minor salinization of marsh soils during drought flows appears reversible within 1-3 years – see Wetzel and Kitchens, 2007). Duncan et al. (2014) also determined that flows below 4500 cfs at Clyo will drive freshwater marshes on the downstream end of the Savannah NWR to brackish communities, and recognized the greater importance of growing season salinity. Note that the Final Environmental Impact Statement for the Savannah Harbor Expansion Project projects a 223-acre conversion of freshwater marsh due to increased salinity penetration, and proposes an intensive wetland monitoring plan to evaluate planned salinity mitigation measures. This monitoring may reveal a more articulate flow recommendation than is possible with current data and models.

Will et al. (2001) documented recovery of striped bass spawning in the estuary following removal of the Back River tide gate in 1991. The recovery was reaffirmed in various studies through the 2000's, and restoration of freshwater conditions in historic spawning sites was cited as a major factor based on egg and larvae collections (summarized in Reinert and Peterson, 2008). This suggests that estuary base flows, in combination with other factors, are currently suitable and maintaining them will continue supporting striped bass reproduction, though populations still lag behind historic values. This period of recovery did include the drought years of 1999-2002, a period with April-May flows very similar to the growing season recommendation of 5000 cfs.

Fishery habitat modeling for SHEP is useful comparison point, as the calculated habitat and post-deepening impacts are based on "current conditions", which has included severe drought spates in 1998-2002, 2007-08, and 2012-13. Striped bass habitat modeling for SHEP indicates 640, 961, and 200 acres of current suitable striped bass habitat (spawn, eggs, and larvae, respectively) at April 80% exceedance flows (spawn, eggs; 7050 cfs at USGS Clyo) and May 80% exceedance flows (larvae; 6000 cfs at Clyo), the modeled flows closest to drought conditions. Note that the 90% exceedance flows (a closer correlate to the <90% exceedance inflow at Broad River) for April and May are 6210 cfs and 5360 cfs at Clyo, so 5000 cfs is a lower bound with respect to the modeled results from SHEP.

Current shortnose sturgeon habitat was modeled in SHEP based on January 50% exceedance and August 1997 average flows (9944 cfs at USGS Clyo). Available habitat for wintering juveniles, wintering adults, and summer adults is 1726, 4000, and 1391 acres, respectively. DO was also an important factor in the model. The provision of sturgeon habitat under estuary drought flows of 4-5000 cfs is more difficult to qualify, as modeled flows are much higher than recommended drought flows. Juvenile shortnose sturgeon are known to use a variety of estuary locations in apparent response to changing temperature and salinity conditions (Collins et al., 2002), so there is reason to believe they will migrate to favorable settings under drought flow conditions.

Pulsing and Flooding:

The Estuary sub-group raised the concern that a combination of drought, lunar high tides and harbor deepening will draw the salinity wedge into freshwater marsh zones, causing loss of freshwater communities and plant diversity. Base flows of 4000 and 5000 cfs during the non-growing and growing seasons, respectively, are on the lowest boundary of flow conditions needed to maintain the current distribution of fresh, oligohaline, and brackish vegetation and associated wildlife (see Dusek and Kitchens, 2003; Welch and Kitchens 2006; Conrads et al., 2006; Duncan et al., 2014). Peak tide events are likely to exceed this boundary. Short-term pulses that meet 7500 cfs at Clyo 5 days ahead of lunar peak tide should offset these tidal salinity forcings. This should have the ancillary benefit of reducing chloride at the City of Savannah's water intake on Abercorn Creek.

A March-May pulse of 12,000 cfs would provide a variety of benefits to the estuary including sediment transport to support marsh accretion, turbidity cover from predators for young-of-year estuary dependent fishes, oyster disease control, soil desalinization from previous low flow spates, and maximizing striped bass reproductive habitat if delivered in April-May.

Dry State Prescription

Dry conditions exist when inflows are between 10% and 25% of historical normal. When inflows are between the 10th and 25th percentile of 28-day moving average flow at the Broad River gage near Bell, GA (USGS 02192000), the dry state prescription will apply.

Shoals Reach

Base Flows

- January: Provide a minimum of 1500 cfs in the shoals *after* Augusta Diversions are accounted for in all drought years.

- February through April: Provide a minimum of X in the shoals *after* Augusta Diversions are accounted for where X equals:
  - 2000 cfs when Thurmond Dam releases are >3600 cfs
  - 1800 cfs when Thurmond Dam releases are <3600 cfs

- May through December: Provide 1500 cfs in the shoals *after* Augusta Diversions are accounted for.

Maximum Flows

- January 1st – April 30th: No maximum flow recommendation
- May 1st –June 30th: Constrain base flows to a maximum of 20,000 cfs for 2-3 days, if feasible.
- July 1st – December 31st: No maximum flow recommendation

Ramping / Variation Rates

- January 1st to December 31st: When reducing output at Thurmond Dam, decrease flows at -1000 cfs per day to reduce stranding of aquatic organisms.
- Note: Variation recommendations in the floodplain reach below New Savannah Bluff call for no more than +/- 500 cfs variation during fish spawning periods. Additional modeling or experimentation may be required to identify the variation at Thurmond Dam which meets the +/- 500 cfs criterion. Variation at Thurmond can likely be greater than this, and still meet the criterion through channel friction, wave attenuation, and re-regulation through the Augusta pool.

Pulsing and Flooding

No pulse or flood recommendation.

Justifications: Shoals Reach Dry Flows

Base Flows and Maximum Flow:

The shoals workgroup referenced the Physical Habitat Simulation (PHABSIM) outputs of the Augusta FERC settlement as the basis for flow recommendations (see ENTRIX, 2002: *Savannah River Instream Flow Study: Augusta Canal Hydropower Project*). The Study is a very detailed analysis of the flow-habitat relationships in the shoals, covering a wide variety of resident fish groups and invertebrates. The study also formed the basis for the Augusta FERC Settlement flows, which are directly reflected in the dry state recommendations.

The weighted useable area (WUA) analyses (ENTRIX, 2002) indicate that recommended shoal flows will provide 80-100% suitable habitat values to shallow fast guild species. This includes resident riverine fish like margined madtom, striped jumprock, redeye bass, and a wide range of invertebrates. Deep, slow guild species like largemouth bass and redbreast sunfish also reach 80-100% habitat values under the recommended dry state shoal flows. These flows will also keep spider lily colonies inundated and restrict deer browsing. Shallow, slow guild members like spawning redbreast sunfish, and young-of-year redeye bass and striped jumprock reach 50-80% habitat values. These values decline with greater flow, so these species may actually benefit from lower drought and dry state flows. These lower flows perform less well for deep, fast guild species like spawning robust redhorse, silver redhorse, and northern hogsucker and anadromous fish such as American shad.

The maximum flow recommendation to cap flows at no more than 20,000 cfs for 2-3 days will protect spider lily colonies from physical damage to flowering parts. Flood control priority and short-term climate spates may force deviation from this cap; return to <20,000 cfs as soon as feasible.

Ramping / Variation Rates:

Constraining flow reductions to no more than 1000 cfs per day will reduce stranding of aquatic organisms, and allow low-mobility fauna like freshwater mussels to relocate before stranding. Freshwater mussels have very limited mobility, with a maximum ability of 1 meter horizontally per day (Amyot and Downing, 1997).

Floodplain Reach

Base Flows

- January 1st – March 15th: No base flow recommendation
- March 16th – October 15th: Provide a minimum of ≤4000 cfs
- October 16th – December 31st: No base flow recommendation

Maximum Flows

- March 16th – October 15th: Constrain base flows to ≤10,000 cfs if feasible. If short-term climate conditions require higher releases, endeavor to return to <10,000 cfs in two weeks or less.

Ramping / Variation Rates

- When the 7-day moving average temperature reaches 10° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs for six weeks. The variation is around whatever flow value is present when the temperature criterion is hit. The 10° C temperature is the trigger for endangered shortnose sturgeon spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 10° C criterion is February 18th over the last 9 years.
- When the 7-day moving average temperature reaches 16° C at River Mile 179: Within 5 days, control subdaily variation to +/- 500 cfs for four weeks. The variation is around whatever flow value is present when the temperature criterion is hit. The 16° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 5 days. The median date for arrival of the 16° C criterion is April 12th over the last 9 years.
- When the 7-day moving average temperature declines to 23° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs for six weeks. The variation is around whatever flow value is present when the temperature criterion is hit. The 23° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 23° C criterion is October 10th over the last 9 years.

Pulsing and Flooding

- January 1st – December 31st: Provide 1-2 day pulses at 4000-10000 cfs at a recurrence of approximately 1 per month. Whenever feasible, time these pulses to enter the estuary at high tide so as to retard salinity intrusion.

Justifications: Floodplain Reach Dry Flows

Base Flows and Maximum Flows

The principles cited for drought flows apply to dry state flows as well. Dry states are opportunities to promote new tree cohorts on floodplains.

Ramping / Variation

The principles cited for drought flows apply to dry state flows as well. A key difference is higher water availability should allow for a higher baseline flow around which variation is controlled, providing a higher percentage of available habitat.

Pulsing and Flooding

The principles cited for drought flows apply to dry state flows as well. A key difference is higher water availability should allow higher flow volumes for short-term pulses to recharge oxbow habitats. The recommendation is that some of these monthly pulses attain up to 10,000 cfs to allow nearly 100% connection with oxbows, and to recharge both at inlet and outlets.

Estuary Reach

Base Flows

- January 1st – March 15th: Provide a minimum of 5000 cfs
- March 15th – October 15th: Provide a minimum of 6000 cfs
- October 16th – December 31st: Provide a minimum of 5000 cfs

Maximum Flows

- No maximum flow recommendation (*Note:* The Estuary sub-group did recommend variation in base flows at Clyo, ranging up to 7500 cfs. This is captured in the Excel companion sheet as a max flow, but is not intended as a cap on flow).

Ramping / Variation Rates

- No ramping / variation recommendation.

Pulsing and Flooding

- January 1st – December 31st: Provide a pulse of 7500 cfs 9 days ahead of lunar tidal extremes (~ once per month) to retard salinity intrusion into freshwater wetlands
- March 1st – May 31st: Provide one pulse of 12,000 cfs for 14 days duration
- Once Every 5 Years: Provide one flood flow of 30,000 cfs for 2-3 days duration

Justifications: Estuary Reach Dry Flows

Base Flows and Maximum Flow

The principles cited for drought flows apply to dry state flows as well. Key differences include higher base flow volumes based on likely higher water availability, and the ability to provide spates of higher base flows up to 7500 cfs. These higher volumes will expand available habitat for striped bass spawning and rearing, and sturgeon overwintering. Flows in the recommended ranges will also provide more certainty against salinization of freshwater habitats, and will help to reverse minor salinization that may occur during drought periods.

Pulsing and Flooding

The principles cited for drought flows apply to dry state flows as well. Monthly 7500 cfs pulsing recommendations remain the same for drought state. If base flow variations up to 7500 cfs can be timed to lunar high tides, these would satisfy that element of the estuary pulse recommendation. A March-May pulse of 12,000 cfs would provide a variety of benefits to the estuary including sediment transport to support marsh accretion, turbidity cover from predators for young-of-year estuary dependent fishes, oyster disease control, soil desalinization from previous low flow spates, and maximizing striped bass reproductive habitat if delivered in April-May.

A key difference is to provide a 30,000 cfs, 2-3 day pulse once every five dry years to assure the estuary receives sediment deposition for accretion to offset sea level rise. This pulse should be timed with a higher spate of downstream tributary inflow to take advantage of attendant sediment loads.

Average State Prescription

Average conditions exist when inflows are between 25% and 75% of historical normal. When inflows are between the 25th and 75th percentile of 28-day moving average flow at the Broad River gage near Bell, GA (USGS 02192000), the average state prescription will apply.

Shoals Reach

Base Flows

- January: Provide a minimum of 1500 cfs in the shoals *after* Augusta Diversions are accounted for in all drought years.

- February through April: Provide a minimum of X in the shoals *after* Augusta Diversions are accounted for where X equals:
  - 2300 cfs (**Feb-Mar**), then 2200 cfs (**Apr**) when Thurmond Dam releases are >4500-5399 cfs
  - 2000 cfs (**Feb-Apr**) when Thurmond Dam releases are >3600-4499 cfs

- May: Provide 2500 cfs in the shoals *after* Augusta Diversions are accounted for (*Note:* This is an enhanced flow over the Augusta FERC Settlement, recommended for robust redhorse spawning in the shoals).

- June through December: Provide 1500 cfs in the shoals *after* Augusta Diversions are accounted for.

Maximum Flows

- January 1st – April 30th: No maximum flow recommendation
- May 1st –June 30th: Constrain base flows to a maximum of 20,000 cfs for 2-3 days, if feasible.
- July 1st – December 31st: No maximum flow recommendation

Ramping / Variation Rates

- January 1st to December 31st: When reducing output at Thurmond Dam, decrease flows at -1000 cfs per day to reduce stranding of aquatic organisms.

Pulsing and Flooding

- Provide a 30,000 cfs peak flow at Thurmond Dam once every five years, minimum 2-3 day duration

Justifications: Shoals Reach Average Flows

Base Flow and Maximum Flow

The higher flows of average state recommendations provide increased habitat to resident fisheries. Species benefitting still include the shallow fast and deep slow guild members that performed well under drought and dry state flows, with only minor declines in available habitat for margined madtom, bluehead chub, and adult redbreast sunfish. However, the increased flows in average years will now expand habitat for deep fast guild members like northern hogsucker, silver redhorse, robust redhorse, American shad, and striped bass. Another key difference in base flow recommendations is the addition of an enhanced flow period of 2500 cfs for the month of May to provide 80% habitat for robust redhorse spawning. These higher flows also increase fish access to shoals, as areas suitable for fish navigation open up at thresholds of 1900 cfs (three passages) and 2500 cfs (seven passages). The maximum flow recommendation is retained for the protection of flowering spider lilies.

Ramping /Variation

The -1000 cfs daily downramp recommendation is retained to prevent stranding of aquatic organisms.

Pulsing and Flooding

Occasional high flow events will benefit shoals habitats by scouring excess algae growth from rocky substrates and dispersing fine sediments out of gravel, cobble, and boulder habitats.

Floodplain Reach

Base Flows

- When the 7-day moving average temperature reaches 10° C at River Mile 27: In 7 days hence, provide a base flow of 6500-8200 cfs for six weeks
- When the 7-day moving average temperature reaches 16° C at River Mile 179: Provide a base flow of 6500-8200 cfs for four weeks

- When the 7-day moving average temperature declines to 23° C at River Mile 27: In 7 days hence, provide a base flow of 6500-8200 cfs for six weeks
- For all other periods: Provide operating flows typical of average conditions while meeting shoal and estuary conditions

Maximum Flows

- When the 7-day moving average temperature reaches 16° C at River Mile 179: Constrain base flows to ≤10,000 cfs for four weeks hence, if feasible. If short-term climate conditions require higher releases, return to <10,000 cfs as soon as feasible.

Ramping / Variation Rates

- If the recommended base flow of 6500-8200 cfs is provided: No ramping / variation recommendation applies. If base flows are <6500 cfs, observe the following:
- When the 7-day moving average temperature reaches 10° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs until March 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 10° C temperature is the trigger for endangered shortnose sturgeon spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 10° C criterion is February 18th over the last 9 years.
- When the 7-day moving average temperature reaches 16° C at River Mile 179: Within 5 days, control subdaily variation to +/- 500 cfs until May 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 16° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 5 days. The median date for arrival of the 16° C criterion is April 12th over the last 9 years.
- When the 7-day moving average temperature declines to 23° C at River Mile 27: Within 7 days, control subdaily variation to +/- 500 cfs until November 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 23° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 23° C criterion is October 10th over the last 9 years.

Pulsing and Flooding

- March 1st – April 15th: Provide a 14-day pulse of >17,000 cfs for 14 days
- January 1st – December 31st: Provide a 30,000 cfs peak flow at Thurmond Dam once every five years, minimum 2-3 day duration

Justifications: Floodplain Reach Average Flows

Base Flow

Base flow recommendations for the floodplain in average water states are confined to rare and endangered fish spawn periods, as normal operational flows in average states typically provide adequate habitat for instream fish and invertebrates. The lower bound of the recommendation (6500 cfs) represents 100% available habitat at current spawning sites. In addition, a maximum flow of 10,000 cfs, subordinate to flood control priority, is recommended as this is the likely threshold where spawning habitat for robust redhorse begins to decline.

Should fish passage construction materialize at NSBLD, the importance of these habitats will likely diminish, though any change in recommendation should be accompanied by evidence that upstream shoal habitats are being accessed and used.

Ramping / Variation

If 6500 or greater cfs is present at spawning sites, flow variations above that number up to 10,000 cfs should have relatively little impact on habitat suitability. Should conditions require flows <6500 cfs during an average state, observe variation criteria described for drought and dry states.

Pulsing and Flooding

Floodplain inundation is a critical aspect of river ecology, and average water states should provide opportunities for such inundation. Tolerance of soil saturation is the key variable controlling the composition of bottomland hardwood and cypress forests, weeding out upland species that would otherwise out-compete typical bottomland oak, ash, and cypress species. Fish access to floodplains is an important subsidy to fishery growth and abundance. For example, largemouth bass growth rates are substantially higher in flood years due to expanded feeding opportunities (Gutreuter et al., 1999; Raibley et al., 1997; Slipke et al., 2005). In the Savannah River, a long spate of recent floodplain inundation (Nov 2009 to March 2010) produced explosive growth in pickerel populations (Batzer and Margaret, 2011) in the floodplain near Clyo, GA. Floodplain inundation also allows sediments, nutrients, and pollutants suspended in the water column to be sequestered in floodplain soils and organic matter.

Floodplain inundation still occurs regularly in average water states, though not to the extent and duration of pre-dam years. For example, growing season duration of lower terrace floods at Millhaven (14,000 cfs) have declined by 6% in the 1983-2013 record, which translates to approximately 14 days on an annual basis. A spring flood pulse of 17,000 cfs or greater for 14 days would recover much of this flood duration when combined with other naturally occurring pulses, and would also be timed to maximize fish spawning health through off-channel foraging.

Estuary Reach

Base Flows

- January 1st – March 15th: Provide a minimum of 5000 cfs
- March 15th – October 15th: Provide a minimum of 6000 cfs
- October 16th – December 31st: Provide a minimum of 5000 cfs

Maximum Flows

- No maximum flow recommendation (*Note:* The Estuary sub-group did recommend variation in base flows at Clyo, ranging up to 7500 cfs. This is captured in the Excel companion sheet as a max flow, but is not intended as a cap on flow).

Ramping / Variation Rates

- No ramping / variation recommendation.

Pulsing and Flooding

- January 1st – December 31st: Provide a pulse of 7500 cfs 9 days ahead of lunar tidal extremes (~ once per month) to retard salinity intrusion into freshwater wetlands
- January 1st – December 31st: Provide a 30,000 cfs peak flow at Thurmond Dam once every five years, minimum 2-3 day duration
- March 1st – May 31st: Provide one pulse of 14,000 -16,000 cfs for fourteen (14) days duration

Justifications: Estuary Reach Average Flows

Base Flow and Maximum Flow

Base flows of 5000 and 6000 cfs (non-growing and growing season, respectively) provide adequate volume to maintain normal salinity distributions in the estuary. Increased volume in the growing season will maintain freshwater marshes, and expand suitable striped bass spawning and rearing, and juvenile sturgeon staging habitat. In average states, base flow periods could approach the higher end of the 5000- or 6000-7500 cfs variability window more often, further expanding these habitat conditions. Periods of 7500 cfs base flow that coincide with lunar high tides can satisfy the 7500 cfs pulse flow recommendation provided to offset high tide salinity forcing.

Pulsing and Flooding

The principles cited for dry state flows apply to average state flows for monthly pulses to offset lunar high tides, and for peak floods of 30,000 cfs with a return of 5 years. March-May pulse recommendations include a higher volume (14-16,000 cfs versus 12,000 cfs) to expand the reach of pulse flows into tidal bottomlands and freshwater marshes that may be affected by salinity during drought and dry states. This would also provide sediment transport to support marsh accretion, turbidity cover from predators for young-of-year estuary dependent fishes, oyster disease control, soil desalinization from previous low flow spates, and maximizing striped bass reproductive habitat if delivered in April-May.

Also, a 30,000 cfs release at Thurmond for 2-3 days every five years in any season is recommended to provide sediment transport into estuarine marshes for accretion and offset to sea level rise.

Wet State Prescription

Wet conditions exist when inflows exceed 75% of historical normal. When inflows exceed the 75th percentile of 28-day moving average flow at the Broad River gage near Bell, GA (USGS 02192000), the wet state prescription will apply.

Shoals Reach

Base Flows

- January: Provide a minimum of 1900 cfs in the shoals *after* Augusta diversions are accounted for.
- February through April: Provide a minimum of 3300 cfs in the shoals *after* Augusta diversions are accounted for.
- May: Provide 2500 cfs in the shoals *after* Augusta Diversions are accounted for (*Note:* This is an enhanced flow over the Augusta FERC Settlement, recommended for robust redhorse spawning in the shoals).
- June through December: Provide 1900 cfs in the shoals *after* Augusta Diversions are accounted for.

Maximum Flows

- January 1st – December 31st: No maximum flow recommendation

Ramping / Variation Rates

- January 1st to December 31st: When reducing output at Thurmond Dam, decrease flows at -1000 cfs per day to reduce stranding of aquatic organisms.

Pulsing and Flooding

- January 1st – December 31st: Provide a 30,000 cfs peak flow at Thurmond Dam once every five years, minimum 2-3 day duration

Justifications: Shoals Reach Wet Flows

Base Flow and Maximum Flow

Higher base flows associated with wet years will maximize habitat for deep fast guild species like northern hogsucker, silver redhorse, robust redhorse, American shad, and striped bass. A 3300 cfs base flow will exceed the flow needed to meet the South Carolina DNR Fish Passage Criterion (10% of channel width passable; 2700 cfs). The 2500 cfs flow for May will provide 80% habitat for spawning robust redhorse. For wet years, managing maximum flows to any specific criteria were considered infeasible, so no recommendation is made for maximum flow.

Ramping /Variation

The -1000 cfs daily downramp recommendation is retained to prevent stranding of aquatic organisms.

Pulsing and Flooding

Occasional high flow events will benefit shoals habitats by scouring excess algae growth from rocky substrates and dispersing fine sediments out of gravel, cobble, and boulder habitats.

Floodplain Reach

Base Flows

- When the 7-day moving average temperature reaches 10° C at River Mile 27: In 7 days hence, provide a base flow of 6500-8200 cfs for six weeks
- When the 7-day moving average temperature reaches 16° C at River Mile 179: Provide a base flow of 6500-8200 cfs for four weeks
- When the 7-day moving average temperature declines to 23° C at River Mile 27: In 7 days hence, provide a base flow of 6500-8200 cfs for six weeks
- For all other periods: Deliver run-of-river flows mimicking the Broad River gage at Bell, GA (02192000) to the extent practicable.

Maximum Flows

- When the 7-day moving average temperature reaches 16° C at River Mile 179: Constrain base flows to ≤10,000 cfs if feasible for four weeks hence. If short-term climate conditions require higher releases, return to <10,000 cfs as soon as feasible.

Ramping / Variation Rates

- If the recommended base flow of 6500-8200 cfs is provided: No ramping / variation recommendation applies. If base flows are <6500 cfs, observe the following:

- <u>When the 7-day moving average temperature reaches 10° C at River Mile 27:</u> Within 7 days, control subdaily variation to +/- 500 cfs until March 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 10° C temperature is the trigger for endangered shortnose sturgeon spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 10° C criterion is February 18th over the last 9 years.
- <u>When the 7-day moving average temperature reaches 16° C at River Mile 119:</u> Within 5 days, control subdaily variation to +/- 500 cfs until May 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 16° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 5 days. The median date for arrival of the 16° C criterion is April 12th over the last 9 years.
- <u>When the 7-day moving average temperature declines to 23° C at River Mile 27:</u> Within 7 days, control subdaily variation to +/- 500 cfs until November 15th. The variation is around whatever flow value is present when the temperature criterion is hit. The 23° C temperature is the trigger for federal candidate robust redhorse spawning movements. Travel time to spawning sites is approximately 7 days. The median date for arrival of the 23° C criterion is October 10th over the last 9 years.

Pulsing and Flooding

- <u>March 1st – April 15th</u>: Provide a 14-day pulse of >17,000 cfs for 14 days
- <u>January 1st – December 31st:</u> Provide a 35,000 cfs peak flow at Thurmond Dam as opportunity allows. Avoid flood releases during fish spawn periods described in Base Flows, if feasible.

Justifications: Floodplain Reach Wet Flows

Base Flow

Specific base flow recommendations for the floodplain in wet water states are confined to rare and endangered fish spawn periods. The lower bound of the recommendation (6500 cfs) represents 100% available habitat at current spawning sites. In addition, a maximum flow of 10,000 cfs, subordinate to flood control priority, is recommended as this is the likely upper threshold where spawning habitat for robust redhorse begins to decline. Releases mimicking the Broad River gage (02192000) in non-spawning periods should provide maximum instream habitat for instream fish and invertebrates, along with natural variability not achievable in drier states.

Should fish passage construction materialize at NSBLD, the importance of these habitats will likely diminish, though any change in recommendation should be accompanied by evidence that upstream shoal habitats are being accessed and used.

Ramping / Variation

If 6500 or greater cfs is present at spawning sites, flow variations above that number should have relatively little impact on habitat suitability. Should conditions require flows <6500 cfs during an average state, observe variation criteria described for drought and dry states.

Pulsing and Flooding

Floodplain inundation is a critical aspect of river ecology, and wet water states should provide regular opportunities for such inundation. Floodplain inundation still occurs frequently in wet water states, though reduced in extent and duration from pre-dam years. For example, the growing season of 2003 was a wet state. During that time, floodplains near the Millhaven and Clyo gages were flooded for 63% and 76% of that growing season, respectively, which are very long periods for their respective watershed positions. Pulse releases of 35,000 cfs as opportunity allows will provide nearly the maximum inundation possible under current system constraints. Tolerance of soil saturation is the key variable controlling the composition of bottomland hardwood and cypress forests, weeding out upland species that would otherwise out-compete typical bottomland oak, ash, and cypress species.

Fish access to floodplains is an important subsidy to fishery growth and abundance. For example, largemouth bass growth rates are substantially higher in flood years due to expanded feeding opportunities (Gutreuter et al., 1999; Raibley et al., 1997; Slipke et al., 2005). In the Savannah River, a long spate of recent floodplain inundation (Nov 2009 to March 2010) produced explosive growth in pickerel populations (Batzer and Margaret, 2011) in the floodplain near Clyo, GA. A spring flood pulse of 17,000 cfs or greater for 14 days would recover some lost flood duration when combined with other naturally occurring pulses, and would also be timed to maximize fish spawning health through off-channel foraging. Floodplain inundation also allows sediments, nutrients, and pollutants suspended in the water column to be sequestered in floodplain soils and organic matter.

Estuary Reach

Base Flows

- January 1st – March 15th: Provide a minimum of 5000 cfs
- March 15th – October 15th: Provide a minimum of 6000 cfs
- October 16th – December 31st: Provide a minimum of 5000 cfs

Maximum Flows

- No maximum flow recommendation (*Note:* The Estuary sub-group did recommend variation in base flows at Clyo, ranging up to 7500 cfs. This is captured in the Excel companion sheet as a max flow, but is not intended as a cap on flow).

Ramping / Variation Rates

- No ramping / variation recommendation.

Pulsing and Flooding

- January 1st – December 31st: Provide a pulse of 7500 cfs 9 days ahead of lunar tidal extremes (~ once per month) to retard salinity intrusion into freshwater wetlands
- January 1st – December 31st: Provide a 30,000 cfs peak flow at Thurmond Dam once every five years, minimum 2-3 day duration (*Note:* This condition is met if the March 1st – May 31st pulse is met).
- March 1st – May 31st: Provide one pulse of 30,000 cfs for fourteen (14) days duration

Justifications: Estuary Reach Wet Flows

Base Flow and Maximum Flow

Base flows of 5000 and 6000 cfs (non-growing and growing season, respectively) provide adequate volume to maintain normal salinity distributions in the estuary. Increased volume in the growing season will maintain freshwater marshes, and expand suitable striped bass spawning and rearing, and juvenile sturgeon staging habitat. In wet states, base flow periods should approach the higher end of the 5000- or 6000-7500 cfs variability window more often, further expanding these habitat conditions. Periods of 7500 cfs base flow that coincide with lunar high tides can satisfy the 7500 cfs pulse flow recommendation provided to offset high tide salinity forcing.

Pulsing and Flooding

Wet states present an opportunity to provide larger magnitude and duration pulses that provide sediment transport functions. Sediment transport into the estuary is an important process to build elevation in marshes and offset sea level rise to some degree. The exact timing of a spring pulse of 30,000 cfs is less important than timing it with high tributary inflows to take advantage of downstream sediment inputs. Also, the recommendation to provide a 30,000 cfs release at Thurmond for 2-3 days every five years in any season is carried forward for similar reasons though, in wet spates, this criterion is highly likely to be met without forward management action.

VI. Future Research Priorities in Ranked Order

Shoals

Evaluate presence and timing of Atlantic sturgeon fall spawn
Real-time shoals gaging
Low level green lidar physical habitat characterization
BIOBLITZ Assessment
Recreational use and value of shoals
Determine flow needed to clear fine sediment and algae
Robust Redhorse recruitment success
Robust Redhorse habitat and spawning sites

Reintroduction of shoals spider lily
Sturgeon/striped bass spawning sites and recruitment
Use EFM to determine % of the targets met over past 50 years
Mussel age and growth relative to flow metrics
Mark-recapture study to estimate survival and recruitment of mussels
Habitat and browsing study of shoals spider lily
Mussel occupancy and habitat use study; assess if comparisons to 2006-07 Catena study can be made

Floodplain

Determine sources of subdaily variation in discharge; identify control strategies
Modeling to evaluate operational propositions

Develop relative values on resources
Assessment of resource losses, and potential future losses without management Quantification of ecological services (biogeochemical processes, carbon storage, water quality)
Post flooding recession rates
Temperature at USGS gages
Refinement of Temp and other cues
Topographic surveys/ mapping of flood plain
Water budget (climate change and water use projections)
USGS gage calibration and relocation prior to fishway construction at NSBLD
Creel survey, boat ramp usability under different flows
Fish passage efficiencies

Estuary

Water quality modeling of estuary for proposed flows
Flow relationship to regulated flows at Augusta
Sediment Transport- can the marshes keep up with Sea level Rise? What are sources of sediment?
Routing of sediment, deposition and effects on marsh build up; TSS/Flow relationships as affected by the dams and tributaries
Relationship of organismal needs to timing of pulses
Marsh migration (where can the marsh migrate to as driven by changes in sea level and salinity?)
Flow variability influence on invasive species and vulnerability; species diversity

VII. Workshop Participants

First Name	Last Name	Affiliation	Shoals	Floodplain	Estuary
Merryl	Alber	UGA			X
Sheila	Barrie	TNC - GA			
Darold	Batzer	UGA Entomology		X	
Ed	Bettross	GA DNR Fisheries	X		
Liz	Booth	GA DNR EPD		X	X

Ed	Bruce	Duke Energy	X		
Herb	Burnham	Lake Hartwell Association		X	
Nap	Caldwell	GA EPD	X		
Mark	Cantrell	USFWS-NC	X	X	
Paul	Conrads	USGS			X
Jamie	Duberstein	Baruch Institute of Coastal Ecology & Forest Science			X
Will	Duncan	USFWS- Georgia ES			X
John	Faustini	USFWS- Regional Hydrologist		X	
Joel	Fleming	GA - DNR		X	
Dean	Fletcher	Savannah River Ecology Laboratory		X	
Anne	Flinn	TNC - GA			
Oscar	Flite	SE Natural Sciences Academy	X		
James	Glover	S.C. Dept. of Health and Environmental Control	X		
Judy	Gordon	Georgia Regents University, Augusta	X		
Clark	Gorman	SC DHEC			
Will	Graf	USACE Advisor, USC		X	X
John	Hickey	USACE			X
Jamie	Higgins	EPA			
Courtney	Holt	UGA - Entomology		X	
Charles	Hopkinson	Georgia Sea Grant			X
Donald	Imm	USFWS - Georgia ES		X	
Rhett	Jackson	UGA Forestry		X	
Dong Ha	Kim	GA DNR EPD	X		
Eric	Krueger	TNC - SC		X	X
Paul	Lamarre	GA DNR EPD		X	
Jason	Lavecchia	USACE			
Alice	Lawrence	USFWS - Georgia ES	X		
Hailian	Liang	GA DNR EPD	X		
Bryana	Libby Bush	UGA Entomology		X	
Jason	Moak	SE Natural Sciences Academy	X	X	
Bill	Post	SC DNR Fisheries		X	X
Ken	Rentiers	SC DNR			
Mark	Scott	SC DNR	X		
Rebecca	Sharitz	UGA SREL		X	
Joan	Sheldon	UGA			X
Harry	Shelley	Savannah River Basin Advisory Council	X		
Kelly	Shotts	NOAA	X		
Stanley	Simpson	USACE			
Carrie	Straight	FWS	X		
Alan	Stuart	Duke Energy	X		
James	Sykes	USACE Fisheries	X		

Chris	Thomason	SC DNR	X	X	
Andrew	Wachob	SC DNR			
Donna	Wear	Georgia Regents University, Augusta	X		
Jason	Wisniewski	GA DNR WRD	X		
Wei	Zeng	GA DNR EPD	X		

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