Ecosystem Flow Recommendations for the Savannah River below Thurmond Dam
Final Report from April 1-3, 2003 Scientific Stakeholders Workshop

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The Savannah River has been altered by hydrologic regulation and channel modification in the past half century. J. Strom Thurmond Dam is the lowermost of three large dams operated by the Army Corps of Engineers on the Savannah River, which forms the border between Georgia and South Carolina. The Lower Savannah River, defined for the purposes of this report as the segment below Thurmond Dam (Figure 1) flows approximately 300 km, supports several types of ecosystems such as floodplains and river shoals, and provides habitats for a diverse array of species. Flows in the Lower Savannah River are a result of water released from Thurmond Dam and tributary inputs from the third of the Savannah River watershed below the dam; hence the hydrologic regime of the river can be altered by changing water releases from the dam. As part of the US Army Corps Savannah River Basin Comprehensive Planning Process, a cooperative agreement was signed between The Nature Conservancy and the US Fish and Wildlife Service to engage in a process to recommend flows in the Lower Savannah River that would improve ecological conditions in the river and its associated ecosystems. This project was funded by the U.S. Army Corps of Engineers and the Departments of Natural Resources in the states of Georgia and South Carolina.

The process leading to these flow recommendations began at an Orientation Workshop in May 2002 attended by over 50 individuals from academia, state and federal natural resource agencies, consulting firms, and conservation organizations. The 2002 workshop identified potential sources of information and individuals to contact for material relating to flow requirements of ecosystems of the Lower Savannah River. An interdisciplinary group of faculty and graduate students at the University of Georgia used the information from the May workshop as a starting point and compiled an extensive annotated bibliography of over 375 relevant publications and data sets and sent it to workshop participants in January 2003 (available at www.rivercenter.uga.edu). Workshop participants reviewed the annotated bibliography and identified additional information sources. The UGA group then prepared a draft summary report based on studies identified in the bibliography and made it available to workshop participants in March 2003. A final version of that summary report is available at www.rivercenter.uga.edu. Additional information available at the workshop included pre-dam hydrographs representative of average (1944), dry (1927), and wet (1936) years.

An Ecosystem Flow Workshop held in Augusta, Georgia on April 1 -3, 2003 was the next step in this process, and this document is a synthesis of workshop reports. The workshop was designed to bring together an interdisciplinary group of scientists to develop flow recommendations for the Lower Savannah River that would sustain the river and floodplain ecosystems. These recommendations are based on the expertise of the individuals attending the workshop (Table 1) as well as several documents prepared in advance of the workshop (described below). The workshop had two key goals: (1) to define river flows needed to sustain the ecosystems (including target species) of the Lower Savannah River and thereby provide flow recommendations that can be incorporated into the ongoing Comprehensive River Basin Planning Process; and (2) to identify critical research needs and information gaps that will help create a foundation for a longer term adaptive process for refining flow recommendations.

To facilitate consideration of ecosystem flow needs for the diverse array of ecosystems and species in the Lower Savannah River, it was divided into three reaches (Figure 1): Augusta Shoals reach (from Thurmond Dam to New Savannah Bluff Lock and Dam), Floodplain reach (from New Savannah Bluff Lock and Dam to river km 72), and Estuary reach (from river km 72 to the Atlantic Ocean). Flow recommendations were developed by considering three components of the flow regime: low flow, higher flow pulses with a recurrence interval of less than two years, and flood events with a recurrence interval greater than two years. Five ecologically critical aspects of the natural flow regime (magnitude, frequency, timing, duration, and rate of change) were considered when making the recommendations.

The workshop developed flow recommendations for three types of water years: dry, average, and wet. Average years were defined as occurring 50% of years, while dry and wet years represented below the 25th percentile and above the 75th percentile, respectively. The workshop participants did not provide a more refined definition of average, dry, and wet years or a process by which these conditions would be identified. Comments received after the workshop noted that this refinement is needed. Average, dry and wet years could be distinguished based on precipitation in the basin; another approach would distinguish them based on flows into Lake Hartwell, which is the beginning of the system operated by the Savannah District of the Corps. If the latter approach were selected, the effects of water storage at Duke Power and Georgia Power hydropower projects upstream of Lake Hartwell would need to be taken into account when evaluating the historical record of flows into Lake Hartwell.

After an introduction to the concept of ecosystem flow recommendations and an overview of the Savannah River Basin Comprehensive Study, presentations provided a synthesis of the major findings from the summary report. Several of these presentations were also given at the Georgia Water Resources Conference (Richter et al. 2003, Hale and Jackson 2003, Palta et al. 2003, Duncan et al. 2003) and are available at www.rivercenter.uga.edu. Workshop participants were then divided into three working groups. Each group was challenged to provide flow recommendations that would sustain the ecosystems in one of three reaches of the river: Augusta Shoals, Floodplain (Shoals to Estuary), or Estuary. Recommendations from each "reach" working group were presented to all workshop participants and are detailed below. "Reach" working group participants were then assigned to one of three different working groups who were asked to combine the recommendations from each river reach into a unified flow recommendation for either a dry year, an average year, or a wet year. These unified flow recommendations were then discussed by the entire workshop. This step served as a check to determine if reach recommendations were incompatible; no significant incompatibilities were identified. The discussions leading to the development of unified flow recommendations are summarized in this report, but the actual values are not presented, because they were an intermediate step in the process, and were based on assumptions about differences among flows in the various reaches. In discussions after the workshop, participants agreed that it made more sense to recommend flows for each section of the river, and to use hydrologic models to determine if those flows are compatible for the three reaches. In the months after the workshop, USFWS scientists further analyzed the workshop recommendations, and recommended flows for each section of the river (Duncan and Eudaly 2003). These recommendations are incorporated into the final flow prescription presented in this report.

As a final step in the April workshop, "reach" working groups reassembled to identify data gaps and to prioritize the most critical research needs for each section of the river. The recommendations were discussed by the entire workshop and the consensus of the group is presented in Section IV of this report.

This report is divided into four sections. Section I presents the reports of the reach level working groups. For each river reach, the initial flow recommendations, justification for those recommendations, and data gaps are provided for (1) low flow, (2) high pulses, and (3) flood events during (a) a dry year, (b) an average year and (c) a wet year. Section II summarizes the discussions of the unified flow working groups and presents flow recommendations as example hydrographs for the Augusta Shoals reach. Section III presents the final flow recommendations as target flows in each river reach for each month in a dry, average and wet year. These final recommendations are the result of deliberations at the workshop as well as the further analysis documented in Duncan and Eudaly (2003). Section IV presents the critical research needs as identified and prioritized by workshop participants.

SECTION I.
INITIAL FLOW RECOMMENDATIONS FOR THE THREE REACHES OF THE LOWER SAVANNAH RIVER

The preliminary flow recommendations from each group are summarized in Table 2. The scientific justification for these recommendations, the benefits expected if these recommendations are implemented, and the needs for additional information are identified in the following reports from individual working groups.

A. FLOW RECOMMENDATIONS FROM AUGUSTA SHOALS WORKING GROUP

Assumptions

These recommendations are for the flows in Augusta Shoals (Figure 2). This is a critical 7.2-km reach beginning just below the Augusta Diversion Dam. The group identified this as the critical ecosystem in the reach from Thurmond Dam to New Savannah Bluff Lock and Dam (Figure 1). Augusta Shoals harbors a unique assemblages of fishes, mussels and an endangered plant, the shoals spider lily (*Hymenocalis coronaria*). Prior to dam construction, shoals habitat could be found over 175 km of this river, and Augusta Shoals represents what is left of this once extensive habitat type. Flow in the Shoals is determined by releases from Thurmond Dam, reregulation of flows at Stevens Creek Dam, and diversion of water into the Augusta Canal by the Augusta Diversion Dam. When calculating releases from Thurmond Dam necessary to support these recommended flows, the flows transferred to the Augusta Canal MUST be added to the recommended flows. The flows measured at the USGS Augusta gage (#02197000) include flows in the Shoals as well as the flows diverted into the Augusta Canal.

These recommendations were informed by recent research on flow requirements of fishes in the Shoals based on PHABSIM modeling (ENTRIX 2002) and the preliminary recommendations of the state and federal agencies developed as part of an on-going FERC relicensing process for the Augusta Diversion Dam. Because the state and federal recommendations were constrained by current operational procedures, those estimates are likely low for ecosystem protection.

Definition of Reach

The Shoals are defined as that 7.2-km stream segment upstream of Augusta, GA and downstream of the Augusta Canal Diversion Dam

(1) Low Flow Recommendations for Augusta Shoals

1(a) Dry Years

Recommendation

January- May: 4,000-6,000 cfs; 4,000 base flow with variability above.

June-July: at least 2,700 cfs

Aug-Oct: at least 2,000 cfs

Nov-Dec: at least 2,700 cfs

Justification

Spawning season flows elevated above 4,000 cfs to benefit shad and robust redhorse spawning and passage. These flows may be low for Atlantic sturgeon, but as a long-lived species, good years need not occur every year. These flows should also benefit the shallow-fast guild based on the ENTRIX study. The shallow slow guild will not benefit, but habitat for this guild is better downstream.

June-July flows are at least 2700 cfs to protect spider lily (see average year).

August-October flows designed to mimic summer lows in a natural flow regime.

November-December flows designed to mimic natural flow regime, ensure that there is more gradual increase towards spawning flows, and allow for out-migration of juveniles.

Data gap: Passage and spawning requirement for Atlantic Sturgeon

1(b) Average Years

Recommendation

Minimize subdaily and subweekly fluctuations related to peaking hydropower generation. Attempt to have rate-of-change in flow in the shoals that mimic pre-dam rates. Manage for mussel specific flow needs by managing for host fish due to the lack of data to base decisions upon. Snails require light penetration to the shoals (for algal growth) and inundation in order to have habitat needs met. Our goal was to meet these needs through all recommendations.

January through May: 6,000-10,000 cubic feet per second (cfs). 6,000 cfs should be used as the base flow recommendation, but variability up to 10,000 cfs is desired (assuming natural rate-of change and frequency)

June through December: 4,000- 5,000 cfs. 4,000 as the base flow recommendation although small variations above that flow are desirable.

Justification

Jan-May is spawning season for anadromous fish and fish in the deep-fast guild that currently access (or may access in the future) the shoals for spawning. Figure 25 in Summary report (Meyer et al. 2003) and ENTRIX report shows that Weighted Usable Area continues to increase at flows above 6,000 cfs for American shad (spawning and larval) and striped bass. It also should provide adequate habitat for robust redhorse.

Expert opinion was that sturgeon need sustained flows of at least 5,000 cfs for 2 1/2 months. They require 45 days for spawning in Feb-March and an additional 30 days of sustained flows to prevent drying of substrate/eggs. Shallow slow and shallow fast guilds would have less WUA available under this average year regime, yet the group believed that these habitat needs were better taken care of further downstream. These guilds will benefit from the dry year regime in the shoals.

June and July flows need to be sustained above 2,700 cfs to limit deer grazing on the spider lily (which are not known to enter shoals when river edges are wetted). Flows above 2,700 cfs throughout the non-spawning season are necessary to provide upstream and downstream fish passage through the shoal area. 4,000-5,000 cfs was selected for June through

December based on the pre-dam baseflow conditions during those months, because it provides constant habitat for resident fish species, and because it allows for juvenile outmigration.

Recommendations were not made based on mussels due to evidence of low abundance and diversity in the shoals area. Nonetheless, these base flows, coupled with more natural rate-of-change in flows, should benefit mussels by providing habitat stability.

Data gap: Need cross sections to confirm flow required to protect spider lily population through inundation.

1(c) Wet Years

Recommendation

January-May: 6,000-10,000 cfs

June- Dec: 4,000-5,000 cfs

Justification

Same benefits and numbers as in an average year. High pulses are more important in wet years than increased base flow. In addition, the ENTRIX study did not model discharges greater than 8,000 cfs, so benefits to fish in terms of PMWUA for higher discharges were not determined. However, we can assume that flows above 10,000 cfs may have negative impacts on habitat for deep fast and shallow fast guilds.

4,000-5,000 cfs in October-November may allow fall spawning of sturgeon.

Data gap: Discharges of 4,000-5,000 cfs in October-November may allow fall spawning of sturgeon. This behavior has been documented on other regional rivers, but needs to be verified on the Savannah.

Quantify the relationship between water temperature and river discharge in the Shoals. Without such a relationship there may be temperature impacts on fish and mussel species from low temperatures associated with higher releases that are not accounted for in these recommendations.

An understanding of pre-dam sediment dynamics is desired, but what is more critical is a model of what flows result in significant scouring of the channel that might impact spawning habitat for fish as well as mussel habitat.

(2) High Pulse Recommendations for Augusta Shoals

General recommendation:

Overall, high pulses are less necessary to the shoals than are persistence of adequate base flows. Recommendations attempt to get velocities of 1 ft/sec for striped bass reproduction (entrainment of eggs), however quantification of downstream flow-velocity relationships is needed to ensure that *Morone* eggs are kept in suspension as they move downstream (particularly through the New Savannah Bluff Lock and Dam impoundment) (*data gap*).

Although there was a general assumption that high pulses could benefit the shoals, the mechanics of how the ecosystem would benefit from these high pulses was not known (*data gap*). However, based on data from other systems, high pulses can be expected to be important triggers for migration, especially on the descending limb of the pulse.

High pulses during the summer months are assumed to have a negative effect on shoals species due to the cold temperatures that may disrupt life cycles of fish and mussel species.

2(a) Dry Years

Recommendation

January- April: 1-2 pulses of approximately 20,000 cfs during these four month in total. Duration of each of these pulses should be 1-2 days.

Justification

Recommendations are based on pre-dam flow pulses. Need at least 16,000 cfs to provide fish passage for herring over New Savannah Bluff Dam to the shoals. Passage needs for other species needs to be confirmed (*data gap*). Once passage over New Savannah Bluff Lock and Dam is provided (through dam removal or a fish ladder) these pulses will enhance migration of anadromous fish. The 1-2 day pulse provides a diversity of durations (in relation to wet and average years) while being adequate for *Morone* egg suspension.

2(b) Average Years

Recommendation

January-April: Pulses of 20,000-40,000 cfs each month for a duration of 2 to 3 days per month.

Pulses during the summer (July-September) may have negative impact due to the potential effects of cold, hypolimnetic water on resident fish species and mussel reproduction and growth.

Pulses during the rest of the year not necessary for shoals, but are more likely to be beneficial than not.

Justification

Pattern and magnitude is based on natural flow regime (similar to pre-dam pulses). These high pulses should benefit anadromous fish as triggers to migration (as seen in literature). There is some evidence that striped bass have higher reproductive success after January pulse flows in the Roanoke. Although the shoals have been sediment-starved since regulation of the river, high pulses may provide benefits related to moving silt accumulations downstream that may be affecting habitat conditions, including existing gravel bars. Finally, *Morone* recruitment should generally benefit from January-April high flows since eggs will be more likely to stay suspended in the water column as they move downstream.

Data gap

Research is necessary to better understand negative/positive impacts on spider lily populations from high and low pulses. Cindy Smith completed a report of flow impacts on the lily and concluded that high flows were beneficial in reducing terrestrial vegetation encroachment on spider lily habitat. More research is needed to examine other potential impacts throughout the range of flow conditions that might be experienced. This research may be most important during blooming season, May-June, where a negative impact is hypothesized.

2(c) Wet Years

Recommendation

January-April: monthly pulses of 20,000 to 40,000 cfs. January-February duration of 2-3 days. March to April duration of at least 14 days.

October-November: 1 pulse of 20,000 cfs for 2-3 days.

Justification

The natural flow regime creates the basis for the pulse magnitude and timing. Duration of pulses during March and April match longer duration flows seen during pre-dam conditions as well as occasional spring pulses seen in the post-dam period. These long duration pulses may also provide more opportunity for passage to the shoals (whether New Savannah Bluff dam is there or not). The 14-day pulse was set to capture a greater opportunity for migration, spawning, and egg suspension of fish that may not all be at the same point in their life cycle.

The fall pulse is for sturgeon migration and spawning flows (assuming there may be a fall spawning season).

Data gaps

There are no temperature data for the shoals- particularly flow-temperature relations and how the temperature profile changes from the beginning of the shoals to the end. However, there may be temperature data available through Mike Alexander who is leading the Stephens Creek Dam DO study. We need an accurate USGS gage for the Shoals. There is currently no gage that records flow in the Shoals.

(3) Flood Flow Recommendations for Augusta Shoals

All Years

The workgroup determined there was no need for floods in the shoals since the ecological benefits of higher flows could be provided by high pulses. Due to the lack of sediment input to the shoals area because of the dam, there was a concern that extremely high flows could lead to channel scouring and thereby decrease critical habitat (e.g. gravels) in the shoals area. However, it was noted that woody debris and nutrient transport might be increased by occasional floods. More research on the costs and benefits of floods to the shoals area is an important research topic (*data gap*).

General information needs

Many of the recommendations are based on the needs of anadromous fishes. The local native fish assemblage, since it is not well understood, was not fully taken into consideration with these recommendations. Once a survey of fish species composition and distribution in the shoals has been completed, the recommendations should be reexamined based on that information.

Extreme low and high flows were not included in our recommendations due to concerns about negative impacts on the shoals' physical and ecological system. Concerns about excessive scouring of the channel at high flows should be examined through a physical study of the system. Assumptions about the negative impacts of extremely low flows were made based on loss of habitat concerns and water quality issues (temperature and dissolved oxygen). These assumptions should be examined through a physical study of the system at extremely low flows (less than approximately 500 cfs).

B. FLOW RECOMMENDATIONS FROM FLOODPLAIN WORKING GROUP (FROM NEW SAVANNAH BLUFF LOCK AND DAM TO ESTUARY)

Assumptions

The floodplain group was challenged in making recommendations as they lacked detailed elevation data for the floodplain, and also lacked detailed information on the location of gravel and sandbars in the main channel. Some members of the group, however, had anecdotal information regarding the relationship between river stages and inundation of landmarks and geographic features such as trails, boat ramps and oxbows. This anecdotal information, coupled with the limited numbers of cross-sections available, was used to make assumptions about percent inundation of the floodplain. These assumptions should be revisited as detailed floodplain data are gathered.

Definition of Reach

This reach begins downstream from the Augusta shoals and extends to the beginning of the estuary.

(1) Low Flow Recommendations for Floodplain Reach

In general, these flows should facilitate processes influenced by base flow conditions. These include:

- Germination and establishment of tupelo-bald cypress (bottomland swamp) and bottomland hardwood forest species
- Growth of adult trees
- Egg and larval drift of pelagically spawning fishes
- Juvenile fish survival
- Spawning habitat in gravel shoals
- Adequate adult fish habitat during low flow periods

The group noted that the 30d minimum flow post-dam is about 60% higher than pre-dam and 90-d minimum flow post-dam is about 25% higher than pre-dam. Ecosystem limitations may occur as a result of higher flows in late spring and early summer, pulses during low flows, or lack of years with prolonged low flows.

1(a)Dry Years

Recommendation

Need about a 3-yr sequence of about 3,000 cfs base flow, April - October; this should occur every 10-20 yrs. However our knowledge of what low flow level allows appropriate germination sites on the floodplain is limited.

Justification

Low flows are needed for seedling establishment. However, we do not recommend flows so low that desiccation of floodplain is exacerbated; in addition, water quality is of concern (need to meet assimilative capacity). The current COE drought plan requires 3,600 cfs during low flows.

Data gap

We need to know what low flow level allows appropriate germination sites on the floodplain.

1(b) Average years

Recommendation

5,000 cfs April – October

Justification

During the growing season (April- October) need base flows low enough so that floodplain drainage is not impeded. From June-October, base flows should be low enough to provide shallow water habitat for small-bodied fishes.

Data gap

We need to know flow-habitat relations on gravel bars to recommend appropriate base flows. David Allen, SCDNR, has observed that gravel bars are submerged when flow is at about 4ft on Augusta gage, which equates to about 5,000-6,000 cfs.

1(c)Wet years

Recommendation

8,000 cfs for prolonged periods during March –May at least once a decade.

Justification

This flow should ensure good larval drift for pelagic spawners.

Data gaps

Need to know base flow effects on temperature.

Need to know at what levels base flow impedes drainage of the floodplain.

(2) High Pulse Recommendations for Floodplain Reach

These are episodic events, occurring multiple times each year. In general, pulses should facilitate :

- Seed dispersal
- Flow into oxbows
- Floodplain access for fishes for spawning and foraging
- Nutrient and water replenishment to floodplain soils
- Fish passage past New Savannah Bluff Lock and Dam (NSBLD)
- Woody debris export to channel from floodplain
- Good nesting habitat for birds, prevention of predator access
- Preventing access/knocking back feral pigs
- Macroinvertebrate habitat on floodplain

2(a) Dry years

Recommendations

From mid-March through growing season, no pulses (>=13,000 cfs) for 3 yrs in a row, once every 10-20 yrs.

Justification

Sequential low flow years are needed for tree recruitment. Several years are needed for seedling establishment; one can expect tree mortality if "establishment years" are followed by an extremely wet year.

2(b) Average years

Recommendation

From January to April, pulses of 20,000 – 40,000 cfs are needed at least once a month, lasting 2-3 days. Rate of change: rapid rise and gradual recession over 2-3 day period. Need substantial inter-annual variation in pulse magnitude. Could be as low as 13,000 cfs if NSBLD were removed.

From May-September: pulses of 8,000 – 12,000 cfs, no more frequently than once every 10 days on average.

Justification

January-April pulses are needed to: allow migratory fishes passage at NSBLD; allow fish floodplain access (e.g., blueback herring spawn on floodplain); provide nutrient, carbon exchange between river and floodplain; woody debris export to channel from floodplain; larval fish transport; provide predator-free bird nesting habitat (e.g. prothonotary warbler); seed transport. Note that mast producers, e.g. oaks, may produce every 5-6 years.

Inter-annual variability is essential to providing a diversity of habitats on the floodplain for trees, fishes, macro-inverts and birds. Conditions that promote a diversity of tree species will also maximize biodiversity of macro-arthropods and birds.

May-September pulses are needed to exchange water with oxbows, but it is essential to avoid rapid up and down fluctuations that reduce survivorship of juvenile fishes.

Data gaps

We need to know floodplain inundation – flow relations, specifically how much water is needed to inundate differing riverine floodplain habitats. These habitats need to be inundated for 14 d during growing season every one in two years on average.

2(c)Wet years

Recommendation

From December - March, 5-8 pulses of 30,000 - 40,000 cfs about once every four years; of at least 1week duration each.

Justification

These flows are needed to: allow migratory fishes passage at NSBLD; allow fish floodplain access (e.g., blueback herring spawn on floodplain); provide nutrient, carbon exchange between river and floodplain; woody debris export to channel from floodplain; seed transport; larval fish transport; provide predator-free bird nesting habitat (e.g. prothonotary warbler). Multiple pulses, provide good floodplain access for fishes

Dormant season floods increase soil moisture and can inhibit germination of upland species. There is however anecdotal information indicating that substantial floodplain inundation occurs when discharge is 25,000 cfs at Augusta and 32,000 cfs at Clyo.

(3) Flood Flow Recommendations for Floodplain Reach

Historically, the 2-yr flood event was about 90,000 cfs and occurred December- March or August – September. In general the flood should:

- Maintain channel
- Kill invasives
- Transport organic matter
- Provide fish access to floodplain
- Facilitate denitrification, improve water clarity
- Facilitate aquatic macroinvertebrate production
- Recharge groundwater
- Fill oxbows/sloughs
- Disperse seeds
- Create topographic relief on the floodplain through erosion and sedimentation
- Maintain jurisdictional wetland conditions

Less frequent events (less than 2-10 yr events) are important for shaping floodplain topography. These processes occur during very large floods over which we have little control.

3(a) Average years

Recommendation

January – April, need 1-2 peaks of 50,000 - 70,000 cfs; every 1 in 2 yrs on average.

Justification

Regulation has eliminated peaks **and** reduced sediment supply; therefore restoring pre-dam flood regime will degrade the channel. If cutoffs are restored, and sediment is entering channel downstream from Augusta, peaks are needed to redistribute sediments. Rhett Jackson estimated that 50,000 – 75,000 cfs might be a good flow to balance the need for geomorphic effects with reduced sediment input. It is important to consider that pre-European sediment loading would have been lower.

General information needs

The absence of detailed floodplain topography profoundly limits our ability to understand the impacts of flow alteration, channel dredging, and dredge spoil deposition on floodplain inundation and drainage. Because the timing and extent of floodplain inundation impacts both floodplain vegetation and fauna, accurate floodplain topographic analyses will significantly improve our understanding of the impact of flow alteration on Savannah River floodplain processes, and is likely to result in modifications of these recommendations.

C. FLOW RECOMMENDATIONS FROM ESTUARY WORKING GROUP

Assumptions

The recommendations from the Estuary Group for ecosystem flows were predicated on a number of assumptions and conditions. First, recommendations are based on records from and presented for the river at the USGS Clyo gauge. Second, recommendations are considered appropriate ***only*** for the current (2003) harbor configuration. Due to the extensive modification of the harbor (deepening from approximately 12 feet to 42 feet for navigation), the group explicitly identified the natural (pre-dam) flow regime as not appropriate for consideration for ecosystem protection/restoration. Nor should the ecosystem flow recommendations developed by the Estuary Group be considered applicable if additional harbor deepening is conducted.

Definition of Reach

For the purposes of these flow recommendations, the estuary has been defined with an upper limit of Ebenezer Landing (approximate river kilometer 65) down to the mouth of the river.

(1) Low Flow Recommendations for Estuary

1(a) Dry Years

Recommendation

8,000-cfs, January through April, and 6,000-cfs in all other months.

On the final day these recommendations were modified by adding a condition to maintain instantaneous flows at not less that 5,000-cfs at any time of the year.

Justification

This recommendation was based on two historical drought periods. First, the recent drought period (1997-2001) led to a sustained low flow of between 4,000 and 5,000-cfs and negative effects were observed in the estuary. The primary impact noted was to the tidal freshwater marsh (e.g., diminished area and stressed plant community). Secondary concerns were associated with the salinity gradient (0.5 PSU in particular) versus the spatial distribution of critical freshwater tidal marsh habitat for fish; that is, an extensive up-river shift of higher salinity zones could effectively cut-off fish access to marsh habitat. Therefore, the group's initial low flow target for dry years was to keep flow levels above 4,000 to 5,000-cfs. This was revised upward to the target presented above based on conditions and biological response observed during an earlier drought period in the 1980's. This 6,000-cfs level was deemed acceptable and set as a lower limit for sustained low flows during dry years. The January to April 8,000-cfs flow was established to mimic a seasonal rise in low flow levels that is characteristic of the Savannah even during the driest of years.

1(b) Average Years

Recommendation

Flows (cfs) at Clyo gage:

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
8100	9400	9400	12000	15500	16300	13600	9500	9200	8500	8600	8300

On the final day, these targets were modified to a set median monthly baseflow level of 8,000-cfs. This lack of variation in the low flow recommendations was considered acceptable, as the high pulse targets presented in the unified flow prescription should effectively generate ecologically important fluctuations across the months. A condition was also added to the recommendation to maintain the instantaneous flow at not less than 6,000-cfs.

Justification

These recommendations of monthly low flows during average precipitation years were based on the median monthly flows for the gauged record at Clyo, 1968-1997. This gauged record reflects regulated conditions. Seasonal variations in the gauged monthly medians were included in the recommended regime to emphasize the natural shape of Savannah River flows. By using medians in lieu of a more specific representation of base flow, these recommendations are likely higher than natural base flows and should have a restorative influence on select portions of the system such as freshwater tidal marshes and processes that are sensitive to high salinity.

1 (c)Wet Years

Recommendation

Monthly minimum flows of 10,000-cfs from May through December and 20,000-cfs from January through April, based roughly on average 75% non-exceedance flows at Clyo.

On the final day, these recommendations were modified to a set median monthly baseflow level of 10,000-cfs. The removal of the February-April 20,000-cfs is expected to be recovered by the larger and greater number of high pulse targets presented in the final flow prescription. A condition was also added to the recommendation to maintain the flow at not less than 6,000-cfs.

Justification

The ecological benefits in the estuary associated with these wet year low flows include a more extensive seed dispersal across the freshwater tidal marsh, increased invertebrate productivity, greater nutrient cycling, enhanced conditions for select species (e.g., striped bass, American eel, sturgeon, southern flounder, striped mullet) and life stages (e.g., striped bass spawning), and a "push-back" of the salt water gradient to support different fish assemblages across space as compared to dry and average years.

(2) High Pulse Recommendations for Estuary

All Years

Recommendation

One high pulse per year defined as a peak of 12,000-cfs, 16,000-cfs, and 30,000-cfs for dry, average, and wet years, respectively. Each of these pulses was defined as having a 2-week duration and confined to the March 15 to May 15 time period, with the month of April noted as the preferred window.

Justification

These flow recommendations were made considering both the roles that high pulses naturally play in maintaining the health of the estuarine system as well as their role in mitigating the impacts of harbor deepening. Additional pulses -- especially during the summer months -- were not defined by the Estuary Group, as it was recognized that characteristic summer/fall storms often occur on the coastal plain below Thurmond Dam thereby generating high pulses outside management control.

Ecological benefits associated with the recommended high pulses include a "freshening" of the tidal freshwater marsh that encompasses freshwater inputs at the beginning of the growing season (April), nutrient inputs, and increased seed dispersal. The recommended level and two-week duration of high pulses also were defined to enhance conditions for striped bass spawning (suspension and transport of eggs). Further, periodic pulses of freshwater are known to act as effective controls of oyster and blue crab parasites. Specifically, oyster drill is intolerant of salinity levels below 8-10 ppt, whereas oysters themselves are tolerant of these conditions especially in cooler temperatures and for periods up to two weeks. The Estuary Group was not in a position to quantify the flows that result in a salinity of 8-10 ppt at critical oyster bed locations (river mouth up to U.S. Route 17). However, it was noted that the Georgia Port Authority is developing a hydrodynamic model (due in August 2003) that will allow this to be done. The recommendations presented here should be modified once this modeling is complete so that flow requirements for parasite control in oysters and blue crab can be explicitly incorporated.

One concern was raised regarding the delivery of high pulses to the estuary in the absence of the extensive wetland system that was historically present in the Savannah. Without these wetlands, sharp pulses manifest themselves abruptly in the estuary resulting in a "shocking" of the system due to rapid salinity fluctuations. This can be avoided by controlling the rise/fall rate of constructed high pulses from Thurmond Dam so that the rates are more similar to pre-dam rates.

(3) Flood Flow Recommendations for Estuary

All Years

Recommendation

A single flood flow peaking at least at 50,000-cfs was recommended for one in five years (20% of the years over an extended duration such as one to two decades). Floods should not occur during dry years. The recommended time period for these flood flows was between February and the end of April, with a duration of four weeks.

Justification

These flood flow events perform a number of ecologically important functions in the estuary, including sediment replenishment; nutrient and productivity boost for near-shore marine fishes; species mixing; turbidity protection for young fish; freshwater, sediment, and nutrient replenishment of the freshwater tidal marsh; and improved habitat and forage for bird species.

SECTION II. DISCUSSIONS OF THE UNIFIED FLOW WORKING GROUPS

A. UNIFIED LOW FLOW WORKING GROUP

Assumptions

The group decided that a unified flow recommendation would describe releases from Thurmond Dam. Translating reach-based recommendations to dam release recommendations required three assumptions:

- 3,500 cfs that would otherwise flow through the Shoals area will be removed by the Augusta diversion canal. This diversion estimate is based on the most recent data provided to the USFWS. Because the gage on the canal is faulty, these numbers are not currently verifiable. Improvement of flow gauging on the canal and for flow in the Shoals is a priority. The amount of water to be diverted is currently being negotiated as part of the Augusta Diversion Dam relicensing, so this number may change in the future.
- The assumption was made that this entire diversion was returned to the Savannah River downstream of Augusta.
- The estuary group made estuarine inflow recommendations for the Clyo gage. To translate these recommendations to Thurmond Dam releases, 1,000 cfs was subtracted from these recommended inflow numbers. Clearly a more refined adjustment to these numbers would be preferable.

Recommendation Definition Process

The process of determining low flow recommendations in the workgroup involved first listing the recommendation for each reach-based group for each month and type of water year. Then these recommendations were translated into Thurmond Dam release recommendations based on the assumptions listed above. This step was followed by a discussion of how well the recommendations compared with each other. Finally, a minimum recommended flow level was selected- often by taking the lowest acceptable value that satisfied the previously defined recommendations of all three reach-based groups. The numerical recommendation(s) that acted as the “ecological driver(s)” of the overall low flow recommendation was identified. Average years were defined as occurring 50% of years, while dry and wet years represented below the 25^{th} percentile and above the 75^{th} percentile, respectively.

Additional Notes

The floodplain group representatives noted the need to optimize dry periods to promote tree growth in the floodplain by suppressing growing season flood for a few years following a dry year. However, this was an issue for the estuary group due to concerns about salinity buildup. Mitigation through winter flushing flows is necessary. Another concern for the floodplain group was that the low flow recommendations were too high and might impact the channel habitat in the shoals to estuary portion of the river. This concern centered around the availability of shallow water habitat for juvenile fish species, particularly in the months of June-October. A key question for the floodplain group was at what base flow do we inhibit floodplain drainage in the growing season (April-October). There is a need to ensure the drainage occurs so that normal growth can proceed. Finally, there was a concern that dry year low flow numbers, in the Shoals in particular, might result in dissolved oxygen problems as the assimilative capacity of the stream would be tested in summer.

B. UNIFIED HIGH PULSE WORKING GROUP

Recommendation Definition Process

Participants began their discussion by layering the three hydrographs to visually examine areas of consensus and areas where recommendations differed. The group was pleased by the degree of general agreement among the shoals, estuary and floodplain groups.

Dry Years

The needs of anadromous fish were key in arriving at a unified prescription for dry years. Participants felt it was critical to provide flows between 16,000 - 18,000 cfs for 3 days in early March and again for 3 days in early April. Flows of this magnitude were slightly higher than those recommended by either the floodplain or estuary group, and slightly lower than the shoals group. Again, lacking specific elevation data, the floodplain group was uncertain about percent floodplain inundation at these levels, but thought with the limited number of days requested, they could support this recommendation.

If dry conditions extended beyond three years, the April flows should be extended to a two-week period, to support striped bass spawning. While flows of this magnitude might be detrimental to cypress and tupelo in the short term, we considered the needs of anadromous fish to be a higher priority then seedling survival during extended drought periods.

The rate of change for these flows was considered inconsequential.

Finally, it was noted that these recommendations were predicated on the continued operation of the New Savannah Bluff Lock and Dam. The group noted that alternative strategies for fish passage should be explored and if achievable, the prescription could be revised.

Average Years

Recommendations for average years by the shoals and floodplain groups were identical. The estuary groups recommendations were lower and covered a shorter time frame. Ultimately, however, the groups agreed that there were two critical time periods for fish and floodplain plant communities, each with a specific flow recommendation. Between January and April, the group suggested flows of 20,000-40,000 cfs. Participants stressed that the number should not be an average (for example 30,000 cfs each year), but that the magnitudes should vary within and between years. Flows in this range should occur for 2-3 days, once each month.

The rate of change for this prescription should reflect a rapid rise and a gradual decline.

Between May and October, the group suggested flows of between 8,000-12,000 cfs. These levels should be achieved 2-3 days each month, but with a frequency of not more than once every ten days.

Wet Years

Again the shoals, floodplain and estuary requirements were remarkably similar, with only minor variations in the duration of pulses. Between the months of January through April, the group suggested a total of 5 pulses of <u>at least</u> 30,000. They further specified that one pulse, of two weeks duration, should occur in March. A second pulse, also of 2 weeks duration, should occur in early April. The other 3 pulses should be randomly distributed throughout this time period and last a minimum of 2 days. This wet year recommendation differs from the average year primarily in the slight increase in frequency (5 vs. 4) and in the longer duration of two of the floods.

C. UNIFIED FLOOD FLOW WORKING GROUP

The Unified Flood Flow Group was comprised of representatives from each of the three systems groups (shoals, river/floodplain, and estuary). Because the shoals group did not develop a prescription for flood flows, the task became one of meshing the flood flow recommendations from the river/floodplain and estuary groups.

The original recommendations from these two groups were in fact quite similar. The river floodplain group had called for one flood to occur on average every two years at a magnitude of 50,000-70,000 cfs and to last for a duration of two weeks. These floods were prescribed to occur during wet years anytime from January 1 through April 30. The flood flow prescription from the estuary group consisted of one flood on average every five years at a magnitude of at least 50,000 cfs, to last for a duration of four weeks. These prescribed floods were to occur during average or wet years anytime between February 1 and April 30. The differences between these two prescriptions that were resolved by the Unified Flood Group included the recurrence interval of the flood (once every two years versus once every five years), the duration (two weeks versus four weeks), and the timing of the flood (January-April versus February-April).

The timing of the flood was quickly resolved, as the representatives from the estuary group saw no problems with including January as part of the flood window. One caveat brought by the river/floodplain group was that there needs to periodically be at least three consecutive years without floods during April to allow for successful establishment of bottomland vegetation. The different durations of flooding were also determined to not truly be in conflict as flood flows typically dampen out and lengthen between the river/floodplain and the estuary; that is, it was expected that a two week flood on the river would be a three to four week flood in the estuary. Consequently, much of the discussion focused on the question of flood frequency and adjusting the difference between one every five years (estuary group) and one every 2 years (river/floodplain group). The definitions of "dry", "average", and "wet" years were first re-visited, with a re-iteration that each category contains an even one-third of all years (Note: This is a different definition than used by other groups. Elsewhere in this document, average years are defined as occurring 50% of years, while dry and wet years represent below the 25th percentile and above the 75th percentile, respectively.) After additional discussion of the ecological requirements for both systems, a unified recommendation was made for floods to occur at a frequency of once every three years (on average over an extended period such as a decade). Further, the group identified no problems with these floods occurring during either wet or average years, which should provide operational flexibility to meet the prescription.

With the differences resolved, the group agreed on a Unified Flood Flow recommendation that consists of a two-week flow of 50,000-70,000 cfs (at the Augusta gage) to occur on average once every three years between January 1 and April 30 during wet or average years, with three consecutive non-flood years periodically provided during April.

D. ILLUSTRATING A UNIFIED FLOW RECOMMENDATION WITH EXAMPLE HYDROGRAPHS

When the unified flow recommendations were presented to the group as a whole, there was concern that the recommended low flows were too high. The driver of these high values was the amount (3,500 cfs) added to the desired flow in the Shoals to account for the water diverted into the Augusta Canal. This is problematic for two reasons: accurate measures of the amount of water being diverted into the canal are not available, and the amount of water that can be diverted may change under a new license that is currently under negotiation. Because of these problems, we have expressed the consensus flow recommendations as recommended flow over Augusta Shoals in the following illustrations. Figure 3 illustrates example hydrographs meeting ecosystem flow recommendations during dry, average, and wet years, respectively. To provide some comparison, we have also illustrated a pre-dam hydrograph from a dry, average, and wet year.

SECTION III. LOWER SAVANNAH RIVER ECOSYSTEM FLOW RECOMMENDATIONS

Workshop participants developed flow recommendations for each of three river reaches during dry, average and wet years. In the period since the workshop ended, Duncan and Eudaly (2003) scrutinized the recommendations, paying particular attention to times when there appeared to be a conflict between recommendations for the different reaches. They suggested the following modifications:

- The flow in the Shoals in May should be slightly reduced during dry and average years because the initial recommendations would result in discharges higher than the floodplain group recommended at this time. There is uncertainty in this estimate because water diverted from the river at the Augusta Diversion Dam does not flow over the Shoals, but does return to the river above the Augusta gage and hence is in the floodplain reach of the river. USFWS estimates that about 3,500 cfs is currently diverted, although the precise amount is not known and is currently under negotiation as part of a FERC relicensing process. Providing adequate flow in the Shoals while not having excess flows in the floodplain reach will require careful attention to the amount of water being diverted to the Augusta Canal.

- Pulse flows in dry and average years are recommended for at least five days with rapid rise and graduate recession. The initial recommendation was for a three-day duration, but further examination of the pre-dam record revealed that most floods were for at least five days. Pulse flows in January, February, and October in wet years should also occur over at least five days with rapid rise and gradual recession. Pulse flows for March and April of wet years should occur over 14 days.

These modifications have been incorporated into the flows shown in Tables 4 - 6. These ecosystem flow recommendations for the Lower Savannah River are the final product of the April workshop.

SECTION IV. CRITICAL RESEARCH NEEDS

On the last day of the workshop, each "reach" group identified critical research needs. These were prioritized and are listed below in order of their importance within each group. This priority listing was a consensus of the workshop participants.

Shoals

1. Real-time streamflow gauging in Shoals along with temperature: allows for the development of a streamflow-temperature model. In April 2003, there was no reliable gage in either the Shoals or the Augusta Canal.

2. Fish, plant, invertebrate distribution and composition (and movement tied to flows over time)

3. Physical dynamics during low and high flow extremes: this would inform sediment transport and deposition study

4. Spider Lily flow needs

5. Robust redhorse spawning habitat

6. Atlantic sturgeon spawning and passage information along with shortnose sturgeon passage data in relation to flow

7. Striped bass passage and thermal requirements as well as egg drift requirements for movement past New Savannah Bluff Lock and Dam

Floodplain

1. Cross-sectional and/or spatial topography at fine resolution

2. Vegetation community distributions in the floodplain

3. In-channel survey of physical structure (woody debris, sand and gravel bars, etc)

4. Location of gravel patches below New Savannah Bluff LD and flow-habitat relationships in these critical areas

5. Oxbows and sloughs: at what flows will water be exchanged with river, and how do these exchanges affect water quality

6. Duration of inundation in floodplain after flood events

7. Modify existing USGS stream gauges to include temperature, turbidity, dissolved oxygen

8. Revisit COE cut-off bend study

Estuary

1. Relate flow at Clyo to salinity distribution in estuary

2. Fish community distributions, inter-tidal marsh conditions during high flow periods (similar to what has been done for drought period)

3. Relate salinity conditions to inter-tidal/floodable habitat

4. How does flow affect spawning and recruitment success for estuary-dependent (including diadromous) fish species

5. Relationship between flow and dissolved oxygen

6. Analyze fish community data with a focus on flow impacts

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Table 1: Workshop participants and working groups to which they were assigned.

First name	Last name	Affiliation
ESTUARY	**GROUP**	
Merryl	Alber	University of GA
David	Allen	SC Department of Natural Resources
Bill	Bailey	U.S. Army Corps of Engineers
Mark	Collins	SC Department of Natural Resources
Paul	Conrads	U.S. Geological Survey
Ed	Eudaly	U.S. Fish and Wildlife Service
Jim	Greenfield	EPA
John	Hickey	U.S. Army Corps of Engineers
Eric	Krueger	The Nature Conservancy
Joan	Sheldon	University of GA
Matt	Thomas	GA Department of Natural Resources
Andy	Warner	The Nature Conservancy
Richard	Weyers	University of GA
Spud	Woodward	GADNR-Coastal Resources Division
FLOODPLAIN	**GROUP**	**(SHOALS TO ESTUARY)**
David	Allen	SC Department of Natural Resources
Darold	Batzer	University of GA
Robert	Cooper	University of GA
Emily	Cope	SC Department of Natural Resources
Mary	Davis	The Nature Conservancy
Will	Duncan	University of GA
Gene	Eidson	Southeastern Natural Sciences Academy
Mary	Freeman	University of GA
Cody	Hale	University of GA
Joe	Hamilton	The Nature Conservancy
Deborah	Harris	U.S. Fish and Wildlife Service
Joe	Hoke	U.S. Army Corps of Engineers
Rhett	Jackson	University of GA
Danny	Johnson	SC Department of Natural Resources
Kim	Lutz	The Nature Conservancy
Monica	Palta	University of GA
Elizabeth	Richardson	University of GA
Becky	Sharitz	University of GA
Vic	Van Sant	GA Department of Natural Resources
SHOALS	**GROUP**	
Colin	Apse	The Nature Conservancy
A.W.(Bud)	Badr	SC Department of Natural Resources
Ed	Bettross	GA Department of Natural Resources
Prescott	Brownell	National Marine Fisheries Service
Dick	Christie	SC Department of Natural Resources
Leroy	Crosby	U.S. Army Corps of Engineers
David	Hawkins	GADNR - Environmental Protection Division
Amanda	Hill	U. S. Fish and Wildlife Service
Jeff	Isely	USGS-Coop Unit
Gerritt	Jobsis	SC Coastal Conservation League
Judy	Meyer	University of GA
Ellen	Tejan	The Nature Conservancy
UNASSIGNED		
Braye	Boardman	The Nature Conservancy
Ted	Illston	The Nature Conservancy
Brian	Richter	The Nature Conservancy

Table 2. Low flow recommendations (cfs) from each working group for three reaches of the Lower Savannah River. (Changed the order here to make it match the text)

Year type	Month	Shoals *	Floodplain	Estuary
Dry	October	>2000	3000 B	6000
Dry	November	>2700	A	6000
Dry	December	>2700	A	6000
Dry	January	4000-6000	A	8000
Dry	February	4000-6000	A	8000
Dry	March	4000-6000	A	8000
Dry	April	4000-6000	3000 B	8000
Dry	May	4000-6000	3000 B	6000
Dry	June	>2700	3000 B	6000
Dry	July	>2700	3000 B	6000
Dry	August	>2000	3000 B	6000
Dry	September	>2000	3000 B	6000
Average	October	4000-5000	5000	8100
Average	November	4000-5000	A	9400
Average	December	4000-5000	A	9400
Average	January	6000-10000	A	12000
Average	February	6000-10000	A	15500
Average	March	6000-10000	A	16300
Average	April	6000-10000	5000	13600
Average	May	6000-10000	5000	9500
Average	June	4000-5000	5000	9200
Average	July	4000-5000	5000	8500
Average	August	4000-5000	5000	8600
Average	September	4000-5000	5000	8300
Wet	October	4000-5000	A	10000 C
Wet	November	4000-5000	A	10000 C
Wet	December	4000-5000	A	10000 C
Wet	January	6000-10000	A	10000 C
Wet	February	6000-10000	A	10000 C
Wet	March	6000-10000	8000	10000 C
Wet	April	6000-10000	8000	10000 C
Wet	May	6000-10000	8000	10000 C
Wet	June	4000-5000	A	10000 C
Wet	July	4000-5000	A	10000 C
Wet	August	4000-5000	A	10000 C
Wet	September	4000-5000	A	10000 C

* Flows for the Shoals are the amount of water to be flowing in Augusta Shoals. To determine water release from Thurmond Dam, water diverted to the Augusta Canal MUST be added to the values shown in this table.
A Low flows were not specified for this month in this type of year. Flow requirements of other reaches of the river should drive the low flow needs during these months.
B Flows this low are needed for a 3-year period once every 10-20 years.
C These values are median monthly low flows, with flows never dropping below 6000 cfs. Higher monthly average flows are achieved through the high pulses and floods in Table 3.

Table 3. Flow recommendations from the high pulse and flood unified working groups.

Year type	Discharge (cfs)	Number	Timing	Duration	Notes
High Pulse	**Recommendations**				
Dry	16,000 -20,000	1/month	Mar-April	3 days	if dry >3 yr need 2 wk in Apr
Average	20,000 - 40,000	1/month	Jan - April	2-3 days	rapid rise and
Average	8,000 - 12,000	1/month	May - Oct	2-3 days	gradual decline
Wet	at least 30,000	1	March	2 weeks	
	at least 30,000	1	early April	2 weeks	
	at least 30,000	3	Jan-April	2 days	
Flood	**Recommendations**				
	50,000 - 70,000	1/3 years	Jan - April	2 weeks	periodically need 3 consecutive non-flood years in April

Table 4. Final Workshop-derived flows (cfs) in Augusta Shoals. These flows do NOT include water that has been diverted to the Augusta Canal.

Month	Base Dry	Base Average	Base Wet	Pulse Dry	Pulse Ave.	Pulse Wet	Flood
October	2000	4000	5500				
November	2700	4000	5500				
December	2700	4000	5500				
January	4000	6000	8500		16500-36500	26500	
February	4000	7500	10000		16500-36500	26500	
March	4000	8500	10000	12500-14500	16500-36500	26500	
April	4000	6500	10000	12500-14500	16500-36500	26500	
May	2700	4500	10000				
June	2700	4500	5000				
July	2700	4000	5000				
August	2000	4000	5000				
September	2000	4000	5000				

Table 5.Final Workshop-derived flows (cfs) in floodplain reach of the Lower Savannah River. This is in the vicinity of Burton's Ferry gage.

Month	Base Dry	Base Average	Base Wet	Pulse Dry	Pulse Ave.	Pulse Wet	Flood
October	5500	7500	9000			20000	
November	6200	7500	9000				
December	6200	7500	9000				
January	7500	9500	12000		20000-40000	30000	
February	7500	11000	13500		20000-40000	30000	50000
March	7500	12000	13500	16000-18000	20000-40000	30000	
April	7500	10000	13500	16000-18000	20000-40000	30000	
May	6200	8000	13500				
June	6200	8000	8500				
July	6200	7500	8500				
August	5500	7500	8500				
September	5500	7500	8500				

Table 6. Final Workshop-derived flows (cfs) in Savannah River estuary at the Clyo gage.

Month	Base Dry	Base Average	Base Wet	Pulse Dry	Pulse Ave.	Pulse Wet	Flood
October	6000	8000	9000				
November	6200	8000	9000				
December	6200	8000	9000				
January	8000	9500	12000		20000-40000	30000	
February	8000	11000	13500		20000-40000	30000	50000
March	8000	12000	13500	16000-18000	20000-40000	30000	
April	8000	10000	13500	16000-18000	20000-40000	30000	
May	6200	8000	13500				
June	6200	8000	9000				
July	6200	8000	9000				
August	6000	8000	9000				
September	6000	8000	9000				

Figure 1. Map of the Lower Savannah River, courtesy of C. Straight and B. Freeman.

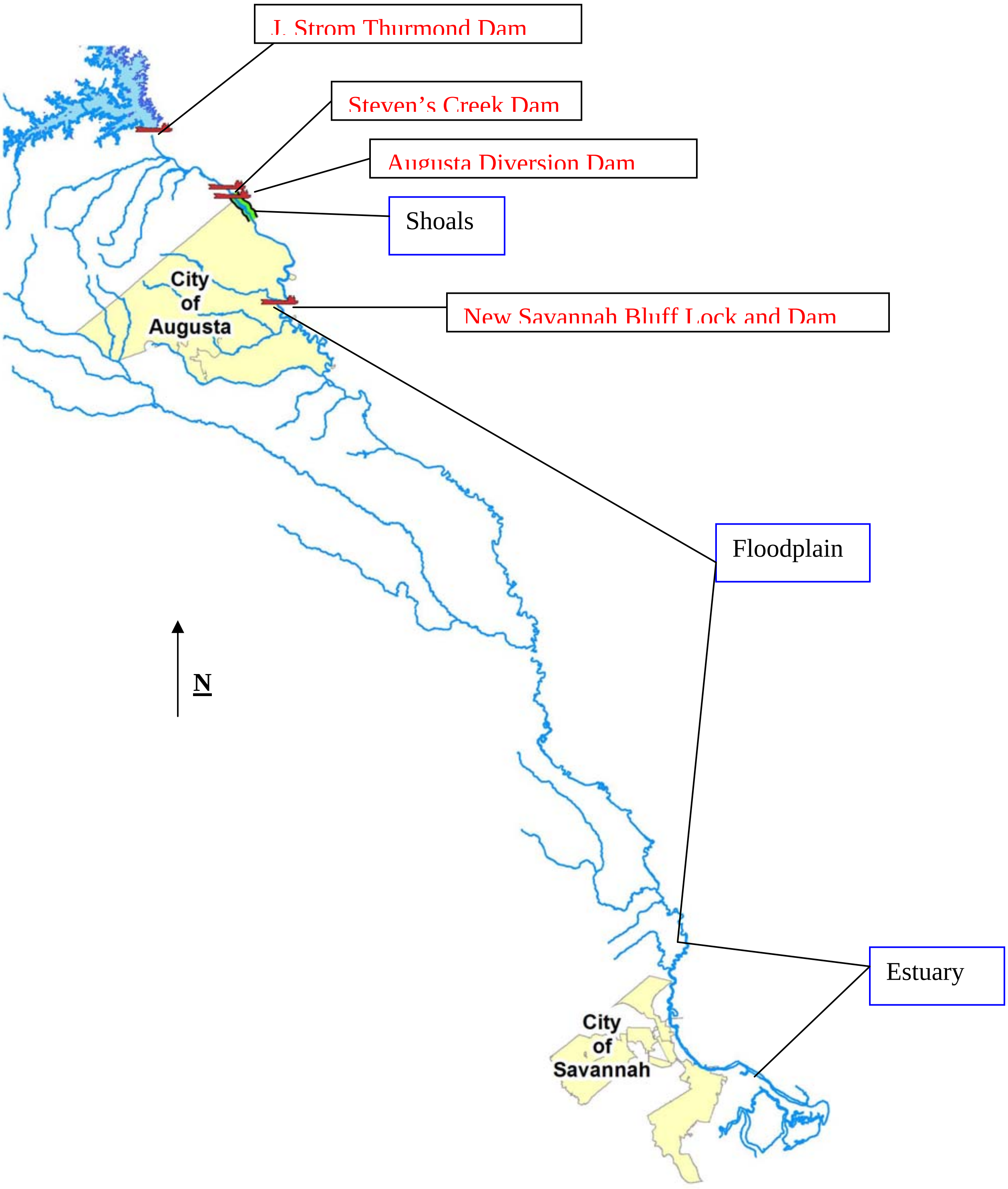

Figure 2. Map of the Augusta Shoals in the Savannah River, courtesy of C. Straight and B. Freeman.

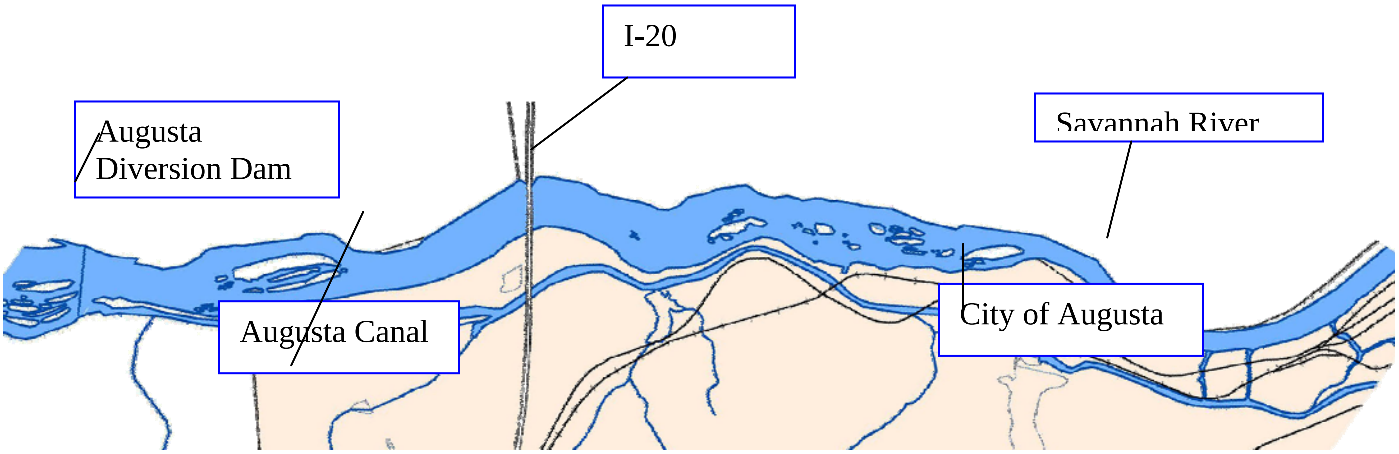

Figure 3. Example hydrographs meeting ecosystem flow recommendations during a dry (red), average (green), and wet (blue) year at Augusta Shoals. This recommended hydrograph is compared to a pre-dam hydrograph from a dry, average or wet year (gray), respectively.