Environmental Flows Recommendation Workshop Summary

Cape Fear River Sustainable Rivers Program

2019

The Nature Conservancy
Protecting nature. Preserving life.™

US Army Corps of Engineers ®

Table of Contents

Key Contributors to this Report

The Nature Conservancy took the lead in writing this report which included circling back with key stakeholders to further refine prescriptions. Julie DeMeester, Will Spoon, Danica Schaffer-Smith, and Gretchen Benjamin drafted key sections. From the Corps, John Hickey and Justin Bashaw contributed content. Ashley Hatchell conducted the RAS modeling and provided content. Additional Corps staff contributed significantly to editing drafts, including Tony Young and Dan Emerson. Many workshop participants provided thoughtful feedback and content to earlier drafts.

Sustainable Rivers Program

The Sustainable Rivers Program (SRP) is a joint nationwide effort between the United States Army Corps of Engineers (Corps) and The Nature Conservancy (TNC). The mission of the program is to improve the health of rivers by changing dam operations to enhance and protect ecosystems, while maintaining or enhancing other project benefits. The goal is to advance, implement, and incorporate environmental flow (e-flow) strategies at Corps reservoirs. Here, e-flows are considered management decisions that manipulate water and land-water interactions to achieve ecological or environmental goals. SRP launched in 2002 and now has 16 rivers in the program, representing 66 federal dams in 15 states.

The Cape Fear River Basin was added to SRP in 2016. The basin was chosen because of its complex human-ecology relationships, the expert stakeholders in the basin, and because the

Corps-owned B. Everett Jordan Dam (Jordan Dam) has potential to influence fish and wildlife habitat, water quality, and other natural resources. The Cape Fear River Basin supports 95 species of freshwater fish, 42 rare aquatic species, as well as streamside habitat containing some of the oldest trees east of the Rocky Mountains; some of which are over 2000 years old (Stahle, 2012). Natural and human environments rely on the Cape Fear River, making its water quality and water quantity of the utmost importance.

The first phase of the Cape Fear SRP was to gather experts to identify issues of concern and review the basin. The Cape Fear launch meeting occurred with basin experts in October of 2017. Following that, TNC and the Corps developed a literature review and analysis of conditions in the Cape Fear River Basin pre- and post-Jordan Dam. The literature review was completed in October of 2019 and was designed to support and inform development of flow hypotheses for the e-flows workshop involving expert stakeholders. It summarized the natural and current range of variation in low flow, high flow and flood pulses, duration and frequency of each, and the rate of change from one condition to another. Background data included ecology and biology flow needs, as well as hydrologic conditions before and after Jordan Dam construction and impoundment. Following distribution of the literature review to applicable parties, the expert e-flow workshop was held on Oct 1-2, 2019. At this meeting, experts crafted e-flow prescriptions for several reaches of the mainstem Cape Fear River between Jordan Dam and Lock and Dam Number One. This document summarizes the results of that meeting and next steps.

Summary Ecology/Flow Recommendations

Figure 1 is an example summary of ecological considerations and environmental flow targets for Reach 3 that emerged from the Oct 1-2 expert e-flow workshop. This flow prescription is specific to the Cape Fear mainstem from Lock and Dam 3 (LD3) to Lock and Dam 1 (LD1). The figure is the culmination of ideas from fish, floodplains, and water quality experts. Group assumptions in this prescription include that LD3 and LD2 can be submerged at 20,000 CFS. Based on select points of study on the river, the group assumed overbank flow happens around 25,000 CFS for several stretches of the river. Another assumption is that the potential for algal blooms occurs when the river falls below 1200 CFS, and especially below 1000 CFS based on research to-date at LD1. When converting Reach 3 of the river to CFS targets at REACH 1, we estimated reduced flows by a factor of 1.5. These assumptions are items to study through the implementation of pulses.

The rest of this report will summarize the process used to generate flow recommendations, specific flow prescriptions from individual groups, as well as the unified flow recommendations for multiple stretches of the river. The last section will summarize next steps, including modeling the enabling conditions to accomplish the flow prescriptions.

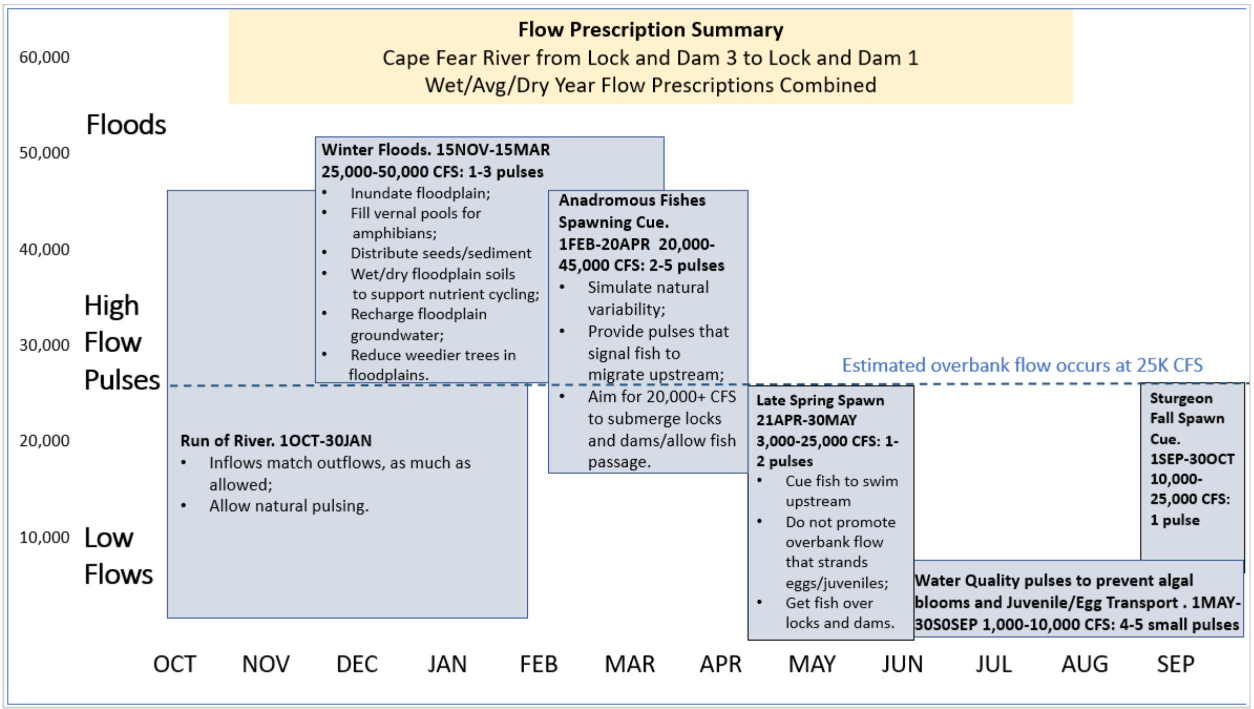


Figure 1. Unified flow prescription with ecological explanations for Reach 3. Experts assumed that 20k CFS would provide adequate flow over lock and dams to allow fish passage and assumed 25k CFS would promote overbank flow.

Workshop goals and agenda

The goal of the workshop was to develop e-flow recommendations in the Cape Fear River that could result in benefits to fish, wildlife and the ecosystem in general while minimizing conflicts with current human uses by exploring operational changes at Jordan Dam. The full agenda is included in Appendix A and a list of the 45 expert participants is included as Appendix B. Experts spanned disciplines and included representatives from federal government, state government, academics, non-governmental organizations (NGOs), private industry, utilities, and council of governments. During the Cape Fear River Basin SRP e-flows workshop, experts worked through a series of tasks and questions to draft e-flow prescriptions for specific reaches of the Cape Fear River downstream of Jordan Dam. Working groups were organized by leveraging individuals having specific expertise. Experts were broken into three different groups: fish, floodplains, and water quality. Each of the three groups were given a different sequence of reaches to address to assure all three reaches would have at least one e-flow prescription formulated to serve as a base model with which to move forward during the unification of all three reaches. Every effort was made to adhere to the assigned reach sequence, but some deviation did occur as the workshop progressed. The task of the experts was to draft desired hydrographs for their ecological target at a specific reach of the river. These recommendations included desired CFS targets in wet, dry and normal years. During the breakout sessions, experts were instructed to focus on their ecological target without consideration of current operational constraints, such as feasibility of making releases to enhance downstream overbank flooding or feasibility of water quality storage to support higher minimum flows and/or pulses during dry low-flow periods. Although USACE water management staff were part of each working group, operations were not offered as constraints to the hydrograph recommendations.

Experts in the fish group were asked to consider the suite of diadromous fishes as well as rare fishes like the Cape Fear Shiner. Flow recommendations considered spawning cues, migration needs, access to floodplains, conditions necessary for shaping appropriate spawning substrates, and velocities that support good water quality. The floodplains group was tasked with thinking about ways to create healthy, functioning floodplains. Flow recommendations considered the length of time that floodplains need to be inundated, the timing of inundation, the vegetation hydrology requirements, and other related matters. The water quality group was tasked with primarily thinking about how to reduce algal blooms. Flow recommendations considered pulsing events to flush lower velocity (pooled) areas, drought conditions, temperature improvements, and like issues.

The two-day workshop began with informal networking, followed by a welcome and formal participant introductions, then a review of the SRP process and discussion of desired workshop outcomes. Next was an overview of Corps projects in the basin followed by a presentation on hydrologic analysis and flow/ecology relationships as background for developing e-flow recommendations. The group then received an overview of the Regime Prescription Tool (RPT) software, for use in visualizing e-flow prescriptions, followed by instructions for working groups. In the afternoon of the first day, working groups were tasked with identifying e-flow hydrographs for each reach designed to improve ecological conditions associated with each group's focus area.

Working Groups break out:
Group #1 – Fish, with a focus on diadromous and rare fishes (reach order 3,1,2)
Group #2 – Water quality to prevent algal blooms (reach order 2,1,3,0)
Group #3 – Floodplain health and function, and vegetative reestablishment (reach order 1,2,3)

Reach #0 – Jordan Lake

Reach #1 – Jordan Dam to Lillington

Reach #2 – Lillington to LD3 (William O. Huske Lock and Dam)

Reach #3 – LD3 (William O. Huske Lock and Dam) to LD1 (Lock and Dam #1)

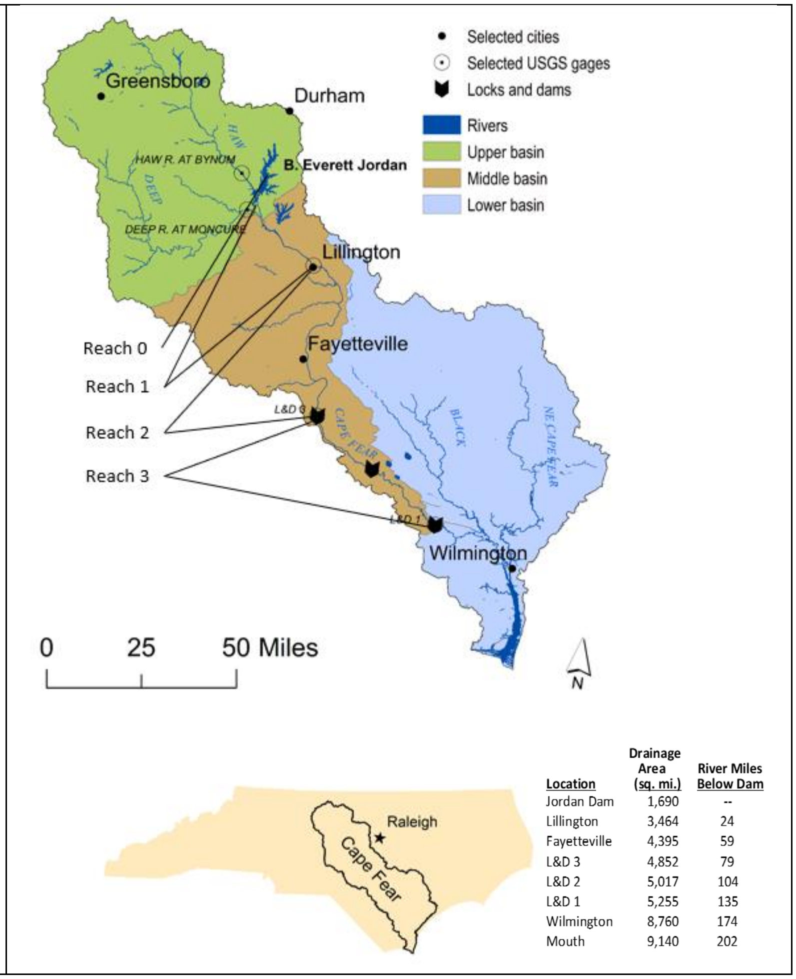


Figure 2. Focus reach description and map.

Working groups continued for the rest of the first day and first half of the second day to define flow needs in each reach and took notes on any related but non-focus issues such as further research needs or other unknowns. These issues were logged in what was referred to as the 'Parking Lot' but were not addressed at this workshop. Throughout this time, Corps specialists in project operations, SRP, RPT and River Analysis System (RAS) were available to answer any questions the working groups had. On the afternoon of the second day, following a very informative Corps-led HEC RAS mapper presentation on inundation mapping of water surface profile results, unification of flow recommendations began by the collective group. The final day ended with conclusion and parting discussion, which included remaining uncertainties, parking lot issues (discussion topics that were outside scope of the workshop, Appendix C), next steps, research and modeling needs, and concluding thoughts.

Basin characteristics and USACE operations

The Cape Fear River Basin lies entirely within North Carolina, covering 9,140 square miles and stretching across central North Carolina in a southeasterly direction and emptying into the Atlantic Ocean. The headwaters of the Cape Fear River are in the North Carolina Piedmont passing through the larger population centers of Burlington, High Point and Greensboro, and includes the Deep and Haw Rivers that join to form the Cape Fear River. Moving southeast, the basin next transitions into the Inner Coastal Plain, before ultimately reaching the Atlantic Ocean near Wilmington, North Carolina. Common physiographic features of the Inner Coastal Plain Province include step like planar terraces. The basin includes a wide variety of land uses including farming, urban and residential development, industry and manufacturing, and more. (NC Geological Survey, 2004)

The B. Everett Jordan Dam (Jordan Dam) and Lake (Jordan Lake) project is located in Chatham, Durham, Orange, and Wake Counties in North Carolina. Jordan Dam is an earth and rock fill structure with an overall length of 1,330 feet. The drainage area upstream of the project is approximately 1,690 square miles. The top of the dam as-constructed is at elevation 266.5 feet above mean sea level (m.s.l.). The total Jordan Lake project area encompasses 46,768 acres of which 13,940 acres are permanently flooded to form a reservoir (Jordan Lake) at 216 feet above mean sea level (m.s.l.). Approximately 200 miles of shoreline were created by the lake at top of conservation pool (216 feet m.s.l.), with lake waters extending five miles on the Haw River and 18 miles on New Hope Creek. The Haw joins the Deep River 4.2 miles downstream of the dam to form the Cape Fear River.

The authorized project purposes of Jordan Dam include flood control (flood risk management), water quality control, water supply, recreation, and fish and wildlife conservation. The project has been operated for those purposes since completion of construction. Jordan Dam is generally operated to maintain water levels near the top of water conservation storage as inflows allow and to maintain releases sufficient to meet downstream flow targets. No specific operations are performed for water supply, since the Town of Cary's water intake is within the lake itself. During periods of high inflow, the Jordan Dam is operated for flood risk management. Flood storage has never been exceeded, and conservation storage has never been fully depleted. Jordan Dam has a private hydropower structure physically attached to it, but this does not influence operations.

Key Findings from the Literature Review

The effects of Jordan Dam on flows in the Cape Fear River were analyzed using United States Geological Survey (USGS) water gages at Lillington, Lock and Dam 3 (LD3), and Lock and Dam Number 1 (LD1). As authorized, Jordan Dam significantly reduced large floods at Lillington. Small floods and pulse events were reduced in magnitude so that overbank flow at the Lillington gage rarely happened. Post-dam construction and impoundment, small floods were less frequent, but of longer duration. The dam also increased baseflow and low flow volumes. The rise and fall rate of the river were dampened. These effects were most noticeable in Lillington, but still remained at LD3. Despite LD1's distance downstream, Jordan Dam has the potential to influence LD1 in low flow conditions. These findings helped guide the e-flows workshop as associated ecological effects were explored including migratory cues, floodplain inundation, river-creating geomorphology, plant recruitment on streambanks, associated levels of dissolved oxygen and more.

Flow-ecology relationships for the workshop

A natural flow regime or hydrologic regime refers to the characteristic pattern of a river's flows in terms of quantity, timing, and natural variability. The natural flow regime influences many of the key characteristics of, and processes in, river systems such as physical habitat (channel structure and characteristics such as substrate), water quality (issues such as chemical and temperature regimes), energy supply in terms of nutrient input and availability, and species interactions. Flow regime ecosystem influences vary greatly depending on if the flow is low, high or flooding, but all can benefit the ecological integrity of a river system.

A dam-altered flow pattern can result in significant changes to a river's hydrologic regime with impacts to timing, duration, magnitude, frequency and rate of change. The aim of the Cape Fear SRP is to identify preferred flow regimes for fish and wildlife populations, ecosystem function, river and floodplain habitat health, and water quality that could later be explored to determine whether it is possible to modify Corps' dam operations to accommodate these flow regimes. The task was to think about environmental flows in the Cape Fear River, especially below Jordan Dam. The goal was to identify opportunities to improve congruency between hydrology and species/ habitat flow needs. The desired outcome was a set of e-flow prescriptions that create adequate conditions for all ecosystem components to the extent possible.

Throughout the workshop, additional scientific knowledge was added to the literature review to include several key assumptions. Through discussions with on-site fisheries experts, one assumption is that LD3 and LD2 can be submerged at 20,000 CFS. Based on select points of study on the river with the National Weather Service and HEC RAS results, the group assumed overbank flow happens around 25,000 CFS for several stretches of the river. Through published and unpublished literature looking at flows and algal blooms in the Cape Fear, another assumption was that the potential for algal blooms occurs when the river falls below 1200 CFS, and especially below 1000 CFS based on research to-date near LD1. These assumptions are items to study through the implementation of pulses.

Fish

Experts were tasked with considering the needs of all aquatic fauna but focused on rare species (e.g. Cape Fear Shiner) and diadromous fishes and to think about the life stages of the organisms.

Diadromous fish of the Cape Fear River considered:

- Atlantic sturgeon (*Acipenser brevirostrum*)
- Shortnose sturgeon (*Acipenser oxyrinchus*)
- Striped bass (*Morone saxatilis*)
- American shad (*Alosa sapidissima*)
- Hickory shad (*Alosa mediocris*)
- American eel (*Anguilla rostrata*)

Fish needs considered:

- Migration cues
- Spawning flows
- Egg development
- Juvenile habitat
- Adult habitat
- All life stage food supplies (i.e. detritus from the floodplain)
- Temperature needs

Floodplains

Experts were asked to think about the hydrology requirements that are linked to healthy floodplains within the study area.

Flow recommendations considered:

- Seed dispersal and vegetation establishment needs
- Tree sapling hydrology needs
- Adult tree hydrology needs
- Soil wetting and drying to stimulate nutrient processing
- Food web inputs
- Animal life needs
- Streambank stability

Within the Active River Area (the area that historically could flood) of the entire Cape Fear basin:

- 67,472 acres (5%) of impervious cover,
- 419,179 acres (29%) of forest land,
- 700,753 acres (48%) of wetlands,
- 258,452 acres (18%) of land that represents mostly agriculture and grasslands

Water Quality

The water quality group was tasked with primarily thinking about how to reduce algal blooms. For example:

- Potentially harmful algal blooms were detected five times at LD1 between June 21, 2012 and August 21, 2012.
- During this two-month period, USGS gage 02105769 CAPE FEAR R AT LOCK #1 near Kelly, NC recorded the median daily flow at 1350 CFS, the lowest flow at 498 CFS, and the highest flow at 3180 CFS.
- Flow recommendations might consider pulsing events to flush the system, temperature improvements, and using the floodplain to process nutrients,
- The groups also considered Jordan Lake, selective withdrawals, etc.

Additionally, the water quality group was asked to consider:

- Chlorophyll a impairments in several locations
- Harmful algal bloom outbreaks in Jordan Lake and behind the Locks and Dams
- Poor water quality in large storms from non-point sources and, potentially, overwhelmed WTPs
- Poor water quality in drought-NPDES sources have a higher impact

River Analysis System (HEC-RAS)

An important ecological consideration for each group was the occurrence of river overbank flow. During the workshop, the main method used for estimating overbank flow was the National Weather Service flood stage estimates at USGS gages. Yet, there were significant stretches of river between the USGS gages and these stretches flood at different CFS flow magnitudes. To give estimates to the flooding for the entire mainstem river from Jordan Dam to LD1, the Corps modeled different CFS events using a HEC RAS model. Using the HEC-RAS geometry and computed water surface profiles, inundation depth and floodplain boundary datasets were created for flows ranging from 20k-60k CFS (for an example, see Figure 3). This technology was essential to providing a visual guide to where overbank flow was and was not possible, which has important ecological implications for water quality, floodplain health, and fish habitat access. A report was produced that summarizes the imagery used during the workshop. Appendix D

Figure 3. HEC-RAS Imagery example from REACH 1 – INUNDATION AT 20,000 CFS. Representative location is approximately 15 river miles downstream of Jordan Dam.

Summary of the Regime Prescription Tool (RPT)

The Corps and TNC used a real-time software to help technical experts craft their e-flow prescriptions. The Regime Prescription Tool (HEC-RPT) is designed to facilitate entry, viewing, and documentation of flow recommendations in real-time, public settings. HEC-RPT seeks to improve 1) communications in group settings by allowing real-time recording and plotting of the recommendations as they are developed and 2) the recommendations produced by making hydrologic information more immediately accessible to scientists, engineers, and water managers during the formulation process.

The Corps and TNC displayed hydrographs of wet, dry, and average years in HEC-RPT. A description of how water years were determined is in Appendix E. The software was then used to draw hydrographs on top of the data. HEC-RPT is primarily a visualization tool and is not intended to perform the detailed quantitative analyses (e.g., statistical analyses or reservoir and river routing) already performed by other software packages. Instead, HEC-RPT seeks to complement other software by making it easier to create flow time series that other software packages can import and use in their analyses. (USACE, 2019)

Unification

Process

As previously stated, breakout groups created their flow prescriptions for Fish (Appendix G), Floodplains (Appendix H), and Water Quality (Appendix I) separately. The goal of the workshop was to create a unified flow prescription that combined each group's thinking. During the second day of the workshop, the group reconvened to combine flow prescriptions.

All the breakout groups had time to finish Reach 3 flow prescriptions, so this was the starting reach for the unification process. During the workshop, the group was able to unify Reach 3 wet and dry years during the workshop. There were some follow ups and research needs identified but the group came to consensus on the prescriptions for this reach. The group then agreed that prescriptions for Reach 1 would largely mirror those of Reach 3, but with reduction in CFS to account for the reduced watershed. TNC and the Corps followed up with workshop participants to finish Reach 1 unification prescriptions. In general, flow prescriptions at LD3 were reduced by a factor of 1.5 to estimate flows for Reach 1. Reach 2 was given lesser priority due to the incised nature of the river, lack of connection to the floodplain and minimal potential impacts possible through dam management.

When unifying reach 3, the group came to the following agreements:

- All groups agreed that a Winter Run of River flow prescription was best.
- The Winter Flood prescription became a combination of the floodplain team's Winter Flood prescription, the water quality team's Infiltration and Return Flows prescription, and the fish team's Amphibian Floodplain Filling prescription. Several of the big floods in January and February overlapped with Anadromous Fish early spawning cues, but were kept in Winter Flood.
- Anadromous Early Spring Spawn served the main purpose of fish spawning cues, but also served the floodplain team's overbank flow goal and the water quality group's infiltration and return flow goal. The Fish team was okay with overbank flow in the early spring.
- The Late Spring Spawn prescription was taken from the Fish team. Overbank flow could potentially hurt aquatic organisms, so overbank flow was minimized in this flow prescription.
- Egg/Juvenile Transport and Water Quality Pulses was taken primarily from the fish prescription. The water quality team wanted a minimum flow of 1,000 CFS at this time, or else they wanted pulses. The fish prescription pulses seemed sufficient for the water quality needs, although monitoring would further ensure this.
- The Atlantic Sturgeon Fall Spawning Period came straight from the fish prescription. The timing of the pulse should be monitored with other ecology goals to not flush other aquatic organisms.

Reach 3

Table 1 lists the prescriptions developed for all water year types in Reach 3 with the dates and CFS columns listing the full range of the water prescriptions. More exact date ranges and CFS for particular water year types can be found in the individual water year sections for this reach.

Table 1. Unified Reach 3 Flow Prescriptions with Ecological Purposes.

Flow Prescriptions	Dates	CFS	Details, Purpose and Benefits
Winter - Run of River	1OCT-30JAN	750-45,000+	• Quasi run of river • Allow natural pulsing • Inflows to Jordan Lake are quickly released downstream (without negatively impacting authorized purposes).
Winter Flood	15NOV-15MAR	25,000-50,000	• 1-3 pulses per season • Inundate floodplain, fill vernal pools for amphibians • Distribute seeds and sediment • Wet and dry floodplain soils to support nutrient cycling • Recharge floodplain groundwater • Reduce weedier trees in floodplains
Anadromous Early Spring Spawning	1FEB-20APR	20,000-46,000	• 2-5 pulses per season • Provide pulses that signal fish to migrate upstream • Aim for >20,000 CFS to adequately submerge locks and dams/allow fish passage
Late Spring Spawn	21APR-30MAY	3,000-24,000	• 1-2 pulses per season • Simulate natural variability • Cue fish to swim upstream • Do not cause overbank flow/strand eggs/juveniles (estimated at 25,000 CFS and above) • Aim for 20,000-24,000 CFS to get fish over locks and dams 2 and 3

			• Even small pulses help fish get over the rock ramp at lock and dam 1
Egg/Juvenile Transport and Water Quality Pulses	1MAY-30S0SEP	1,000-10,000	• 4-5 small pulses per season • Transport eggs downstream over dams • Minimize overbank flow and stranding • Break up instream stratification to prevent algal blooms and DO
Atlantic Sturgeon Fall Spawn	1SEP-31OCT	10,000-24,000	• 1 pulse per season • Ideally a 20,000 pulse to get fish over the locks and dams
Base flow minimums	Year round	750-4,600	• Break up instream stratification to prevent algal blooms

Unified, Reach 3, Wet

Environmental flow recommendations for Unified Reach 3 Wet are shown in Figure 19. Characteristics of each flow component are detailed below.

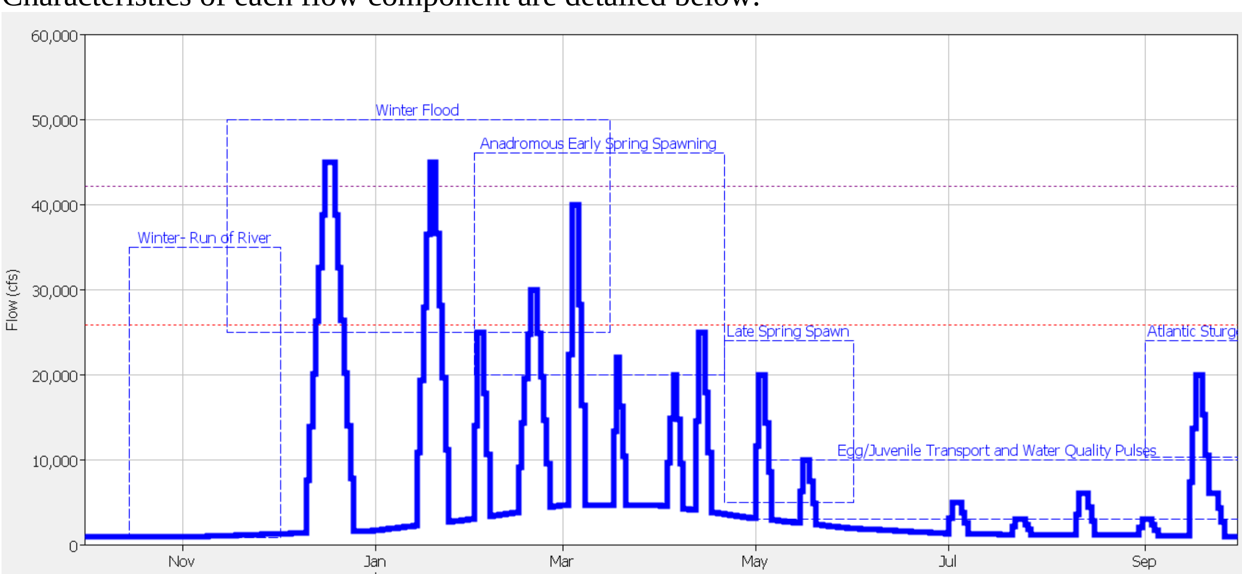


Figure 19. Flow prescription for Unified, Reach 3 Wet. Purple dotted line is NWS flood stage at LD1 and red dotted line is NWS flood stage at LD3.

Winter – Run of River (Unified, Reach 3, Wet)

Season: 15OCT-1DEC

Events per season: Variable based on natural weather patterns

Magnitude: 850-45,000+ CFS projected from historic weather patterns
Duration: Variable based on natural weather patterns
Duration of peak: Variable based on natural weather patterns

Additional Details and Caveats:
See Table 1 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without negatively impacting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (Unified, Reach 3, Wet)
Season: 15NOV-15MAR
Events per season: 3
Magnitude: 25,000-50,000 CFS
Duration: 10-15 day(s)
Duration of peak: 2-3 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
10Dec	15	45,000	3
14Jan	10	45,000	2
15Feb	10	30,000	2

Additional Details and Caveats:
Peaks should taper in magnitude as timing approaches the end of the operational window for winter floods to limit fish access to low areas on the floodplain that can be inundated- this limits predation on eggs and larval herpetofauna.

Anadromous Early Spring Spawning (Unified, Reach 3, Wet)
Season: 1FEB-20APR
Events per season: 5
Magnitude: 20,000-46,000 CFS
Duration: 4-5 day(s)
Duration of peak: 1-2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Feb	5	25,000	2
03Mar	5	40,000	2
17Mar	4	22,000	1
03Apr	5	20,000	1
12Apr	5	25,000	2

Additional Details and Caveats:
Pulses are ideally over 20,000 CFS to allow fish over the locks and dams. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The last April pulse was 20,000 CFS in the fish group, and was raised to 25,000 CFS in

unification to have an overbank event. The fish group wanted to avoid overbank flow by late April (defined as April 20th) to prevent stranding of eggs and juveniles. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (Unified, Reach 3, Wet)
Season: 21APR-30MAY
Events per season: 2
Magnitude: 5,000-24,000 CFS
Duration: 5 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	5	20,000	2
15May	5	10,000	2

Additional Details and Caveats:
Stripers and Shad are main fish species of concern that might still need a cue, but by late April the teams wanted to prevent eggs stranding on the floodplain so the goal was to stay below 25,000 CFS (estimate of overbank flow at LD3).

Egg/Juvenile Transport and Water Quality Pulses (Unified, Reach 3, Wet)
Season: 1MAY-30S0SEP
Events per season: 5
Magnitude: 3,000-10,000 CFS
Duration: 6 day(s)
Duration of peak: 3 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	6	5,000	3
21Jul	6	3,000	3
10Aug	6	6,000	3
30Aug	6	3,000	3
20Sep	6	6,000	3

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn (Unified, Reach 3, Wet)
Season: 1SEP-30OCT
Events per season: 1
Magnitude: 10,000-24,000 CFS

Duration: 7 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	7	20,000	2

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream, which is ideally 20,000 CFS to get over all three LDs. Yet, that is a big flow rate at this time of year, and even smaller pulses would help cue the fish to go upstream and at least get over LD1. The teams did not want overbank flow at this time (estimated to occur at 25,000 CFS at LD3).

Low flows/ baseflows (Unified, Reach 3, Wet)
Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	**Flow (CFS)**
31Oct	870
30Nov	1,250
31Dec	1,640
28Feb	4,600
31Jan	3,000
31Mar	4,600
30Apr	3,100
31May	1,900
30Jun	1,300
31Jul	1,100
31Aug	1,100

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In a wet year, baseflows were chosen as the 25th percentile flow values by month (Appendix F).

Unified, Reach 3, Average. Environmental flow recommendations for this reach are shown in Figure 20. Characteristics of each flow component are detailed below.

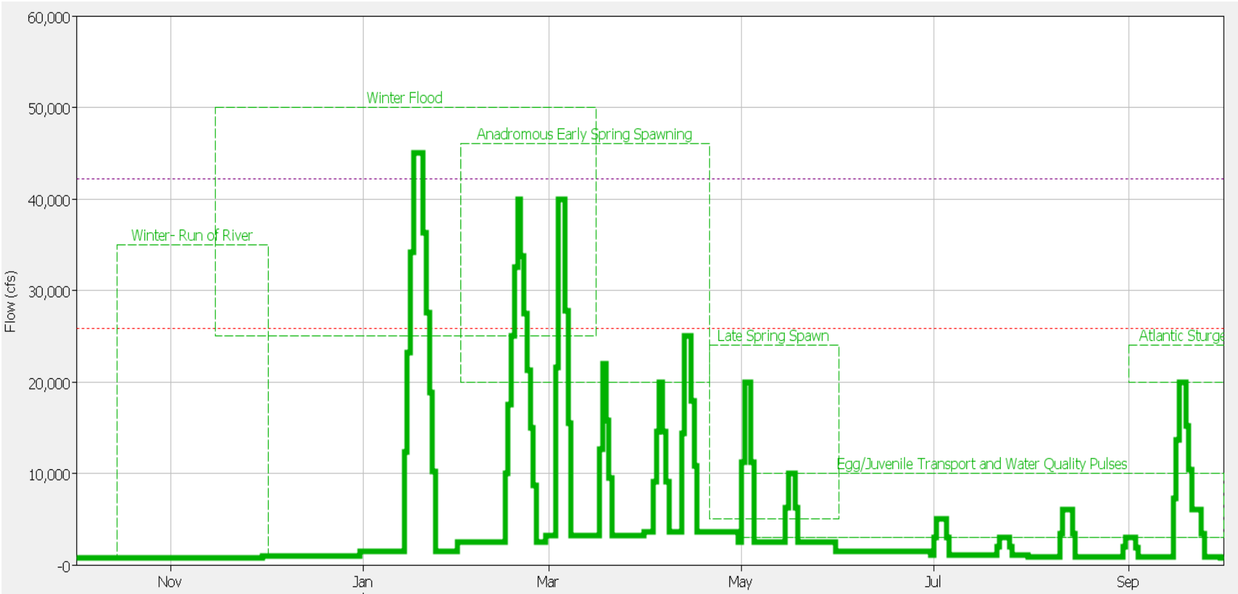


Figure 20. Flow prescription for Unified, Reach 3 Average. Purple dotted line is NWS flood stage at LD1 and red dotted line is NWS flood stage at LD3.

Winter – Run of River (Unified, Reach 3, Average)

Season: 15OCT-1DEC
Events per season: Variable based on natural weather patterns
Magnitude: 850-45,000+ CFS projected from historic weather patterns
Duration: Variable based on natural weather patterns
Duration of peak: Variable based on natural weather patterns

Additional Details and Caveats:
See Table 1 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without hurting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (Unified, Reach 3, Average)

Season: 15NOV-15MAR
Events per season: 2
Magnitude: 25,000-50,000 CFS
Duration: 10-20 day(s)
Duration of peak: 2-3 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
14Jan	10	45,000	3
15Feb	10	45,000	1

Additional Details and Caveats:
Peaks should taper in magnitude as timing approaches the end of the operational window for winter floods to limit fish access to ponded areas - this limits predation on eggs and larval herpetofauna.

Anadromous Early Spring Spawning (Unified, Reach 3, Average)

Season: 1FEB-20APR
Events per season: 4
Magnitude: 20,000-46,000 CFS
Duration: 4-5 day(s)
Duration of peak: 1-2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
03Mar	5	40,000	2
17Mar	4	22,000	1
03Apr	5	20,000	1
12Apr	5	25,000	2

Additional Details and Caveats:
Pulses are ideally over 20,000 CFS to allow fish over the locks and dams. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The last April pulse was 20,000 CFS in the fish group and was raised to 25,000 CFS in unification to have an overbank event. The fish group wanted to avoid overbank flow by late April to prevent stranding of eggs and juveniles. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (Unified, Reach 3, Average)

Season: 21APR-30MAY
Events per season: 2
Magnitude: 5,000-24,000 CFS
Duration: 4 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	4	20,000	2
15May	4	10,000	2

Additional Details and Caveats:
Stripers and Shad are main fish species of concern that might still need a cue, but by late April the teams wanted to prevent eggs stranding on the floodplain so the goal was to stay below 25,000 CFS (estimate of overbank flow at LD3).

Egg/Juvenile Transport and Water Quality Pulses (Unified, Reach 3, Average)

Season: 1MAY-30S0SEP
Events per season: 5
Magnitude: 3,000-10,000 CFS
Duration: 5 day(s)
Duration of peak: 3 day(s)

Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	5	5,000	3
21Jul	5	3,000	3
10Aug	5	6,000	3
30Aug	5	3,000	3
20Sep	5	6,000	3

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn (Unified, Reach 3, Average)
Season: 1SEP-30OCT
Events per season: 1
Magnitude: 10,000-24,000 CFS
Duration: 7 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	7	20,000	2

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream, which is ideally 20,000 CFS to get over all three LDs. Yet, that is a big flow rate at this time of year, and even smaller pulses would help cue the fish to go upstream and at least get over LD1. The teams did not want overbank flow at this time (estimated to occur at 25,000 CFS at LD3).

Low flows/ baseflows (Unified, Reach 3, Average)
Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	**Flow (CFS)**
31Oct	750
30Nov	980
31Dec	1,460
31Jan	2,460
28Feb	3,230
31Mar	3,650
30Apr	2,510
31May	1,520
30Jun	1,060

31Jul	900
31Aug	820

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In an average year, baseflows were chosen as the 18th percentile flow values by month (Appendix F). If the 18th percentile flow for a month was below 750 CFS, the fish team increased the preferred flow to 750 CFS to account for 600 CFS minimum a t Lillington (which is likely to benefit fish). It is assumed that 600 CFS at Lillington translates to 750 CFS at LD3 under most hydrologic conditions.

Unified, Reach 3, Dry. Environmental flow recommendations for this reach are shown in Figure 21. Characteristics of each flow component are detailed below.

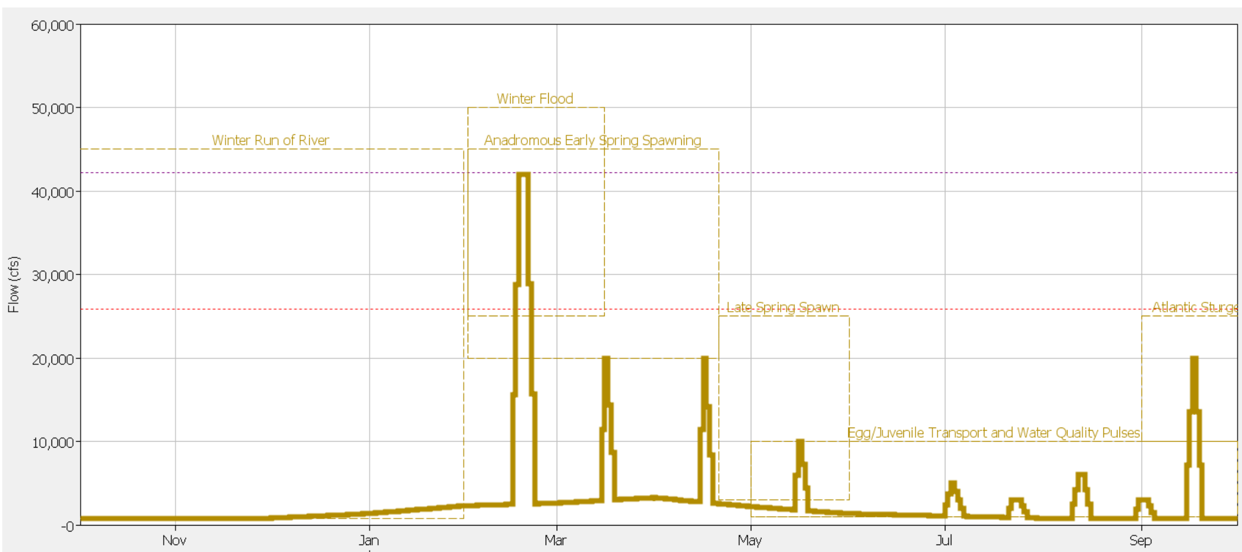


Figure 21. Flow prescription for Unified, Reach 3 Dry. Purple dotted line is NWS flood stage at LD1 and red dotted line is NWS flood stage at LD3.

Winter – Run of River (Unified, Reach 3, Dry)

Season:	1OCT-30JAN
Events per season:	Variable based on natural weather patterns
Magnitude:	750-45,000+ CFS projected from historic weather patterns
Duration:	Variable based on natural weather patterns
Duration of peak:	Variable based on natural weather patterns

Additional Details and Caveats:
See Table 1 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without hurting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (Unified, Reach 3, Dry)

Season:	1FEB-15MAR

Events per season: 1
Magnitude: 25,000-50,000 CFS
Duration: 7 day(s)
Duration of peak: 3 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Feb	7	42,000	3

Additional Details and Caveats:
With only one requested peak, the group wants to time it as late in the winter (and close to the growing season) as possible.

Anadromous Early Spring Spawning (Unified, Reach 3, Dry)
Season: 1FEB-20APR
Events per season: 2
Magnitude: 20,000-46,000 CFS
Duration: 4 day(s)
Duration of peak: 1day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Mar	4	20,000	1
15Apr	4	20,000	1

Additional Details and Caveats:
Pulses are ideally over 20,000 CFS to allow fish over the locks and dams. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (Unified, Reach 3, Dry)
Season: 21APR-30MAY
Events per season: 1
Magnitude: 3,000-24,000 CFS
Duration: 4 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15May	4	10,000	1

Additional Details and Caveats:
Stripers and Shad are main fish species of concern that might still need a cue. The 10,000 CFS is not expected to adequately submerge the locks and dams for fish passage, but would still send a cue to fish and they could be locked in the chambers to move upstream.

Egg/Juvenile Transport and Water Quality Pulses (Unified, Reach 3, Dry)
Season: 1MAY-30S0SEP
Events per season: 4
Magnitude: 1,000-10,000 CFS
Duration: 6 day(s)
Duration of peak: 1-3 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	6	5,000	1
21Jul	6	3,000	3
10Aug	6	6,000	2
30Aug	6	3,000	3

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn (Unified, Reach 3, Dry)
Season: 1SEP-31OCT
Events per season: 1
Magnitude: 10,000-24,000 CFS
Duration: 5 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	5	20,000	1

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream, which is ideally 20,000 CFS to get over all three LDs. Yet, that is a big flow rate at this time of year, and even smaller pulses would help cue the fish to go upstream and at least get over LD1. The teams did not want overbank flow at this time (estimated to occur at 25,000 CFS at LD3).

Low flows/ Baseflow minimums (Unified, Reach 3, Dry)
Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Flow (CFS)
31Oct	750
30Nov	800
31Dec	1,340

28Feb	2,600
31Jan	2,300
31Mar	3,260
30Apr	2,200
31May	1,350
30Jun	1,080
31Jul	800
31Aug	750

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In a dry year, baseflows were chosen as the 10th percentile flow values by month (Appendix F). If the 10th percentile flow for a month was below 750 CFS, the fish team increased the preferred flow to 750 CFS to account for 600 CFS minimum a t Lillington (which is likely to benefit fish). It is assumed that 600 CFS at Lillington translates to 750 CFS at LD3 under most hydrologic conditions.

Reach 1

This reach begins at Jordan Dam and ends at Lillington, NC. It includes the Haw River below Jordan Dam, the confluence of the Haw and Deep River, and the mainstem Cape Fear River from the confluence to Lillington. As a starting point for Reach 1, flow recommendations for Reach 3 were adjusted to account for decreased watershed size while largely maintaining the pattern and ecological purposes of Reach 3 recommendations. The flow was often reduced by a factor of 1.5 to estimate this reduction.

The following table lists the prescriptions developed for all water year types and the dates and CFS columns list the full range across all water year types. More exact date ranges and CFS for particular water year types can be found in the individual water year sections for this reach.

Table 2. Flow prescriptions and ecological purposes for Reach 1 of the Cape Fear River

Flow Prescriptions	Dates	CFS	Details, Purpose and Benefits
Winter - Run of River	1OCT-30JAN	750-35,000+	• Quasi run of river • Allow natural pulsing • Inflows to Jordan Lake are quickly released downstream (without negatively impacting authorized purposes).
Winter Flood	1FEB-15MAR	16,660 – 33,300	• 1-3 pulses per season • Inundate floodplain, fill vernal pools for amphibians

			• Distribute seeds and sediment • Wet and dry floodplain soils to support nutrient cycling • Recharge floodplain groundwater • Reduce weedier trees in floodplains
Anadromous Early Spring Spawning	1FEB-20APR	13,300-31,000	• 2-5 pulses per season • Provide pulses that signal fish to migrate upstream • Aim for >13,300 CFS at Lillington to adequately submerge locks and dams/allow fish passage
Late Spring Spawn	21APR-30MAY	2,000-16,000	• 1-2 pulses per season • Simulate natural variability • Cue fish to swim upstream • Do not cause overbank flow/strand eggs/juveniles (estimated at 16,600 CFS downstream) • Aim for 13,300-16,000 CFS at Lillington to get fish over the locks and dams
Egg/Juvenile Transport and Water Quality Pulses	1MAY-30S0SEP	670-6,670	• 4-5 small pulses per season • Transport eggs downstream over dams • Minimize overbank flow and stranding • Break up instream stratification to prevent algal blooms and DO
Atlantic Sturgeon Fall Spawn	1SEP-30OCT	6,670-16,000	• 1 pulse per season • Ideally 13,300 CFS at Lillington to get over the locks and dams
Base flow minimums	Year round	600-2,500	• Break up instream stratification to prevent algal blooms

Unified, Reach 1, Wet. Environmental flow recommendations for this reach are shown in Figure 22. Characteristics of each flow component are detailed below.

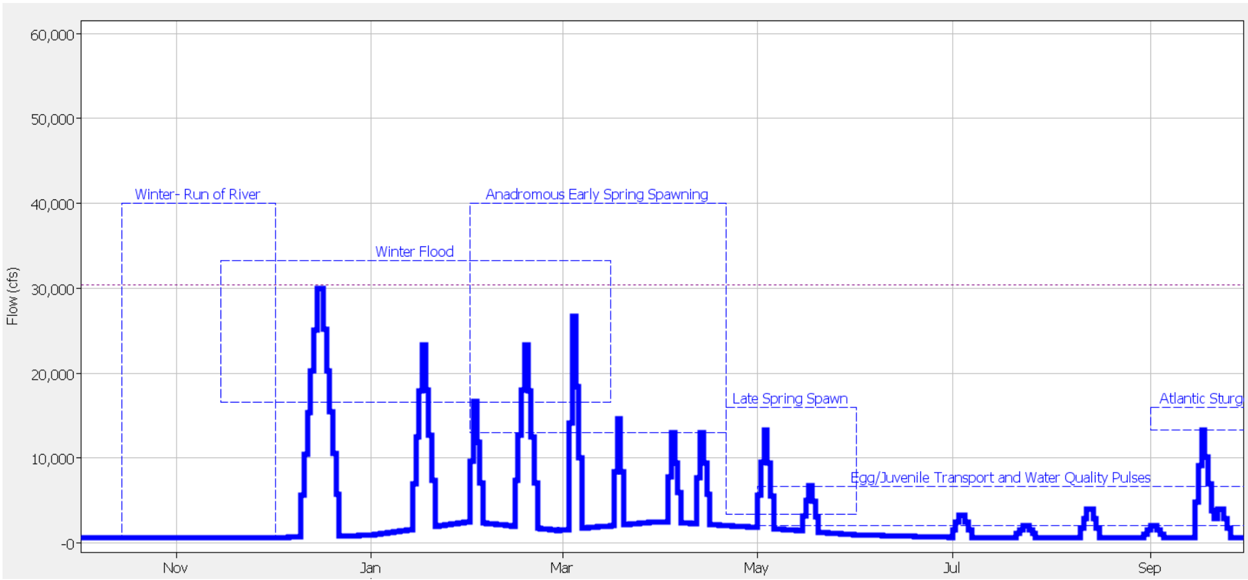


Figure 42. Flow prescription for Unified, Reach 1 Wet. Purple dotted line is NWS flood stage at Lillington. Some operation boxes altered slightly to allow text to fit, so see specifics below for numbers.

Winter – Run of River (Unified, Reach 1, Wet)

Season: 15OCT-1DEC
Events per season: Variable based on natural weather patterns
Magnitude: 850-35,000+ CFS projected from historic weather patterns
Duration: Variable based on natural weather patterns
Duration of peak: Variable based on natural weather patterns

Additional Details and Caveats:
See Table 2 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without hurting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (Unified, Reach 1, Wet)

Season: 15NOV-15MAR
Events per season: 3
Magnitude: 16,600-33,300 CFS
Duration: 7-12 day(s)
Duration of peak: 1-2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
10Dec	12	30,000	2

14Jan	7	23,300	1
15Feb	7	23,300	1

Additional Details and Caveats:
Peaks should taper in magnitude as timing approaches the end of the operational window for winter floods to limit fish access to ponded areas - this limits predation on eggs and larval herpetofauna.

Anadromous Early Spring Spawning (Unified, Reach 1, Wet)
Season: 1FEB-20APR
Events per season: 5
Magnitude: 13,000-31,000 CFS
Duration: 3-4 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Feb	4	16,670	1
03Mar	4	26,700	1
17Mar	3	14,670	1
03Apr	4	13,000	1
12Apr	4	13,000	1

Additional Details and Caveats:

Pulses are ideally over 13,300 cfs to allow fish over the locks and dams. The group estimates that 13,300 cfs in the upper reach will be approximately 20,000 cfs at the locks and dams. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The fish group wanted to avoid overbank flow by late April (approximately April 20) to prevent stranding of eggs and juveniles. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (Unified, Reach 1, Wet)
Season: 21APR-30MAY
Events per season: 2
Magnitude: 3,330-16,000 CFS
Duration: 5 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	5	13,330	1
15May	5	6,770	1

Additional Details and Caveats:

Stripers and Shad are main fish species of concern that might still need a cue, but by late April the teams wanted to prevent eggs stranding on the floodplain so the goal was to stay below 16,000 CFS. It is estimated that staying below 16,000 in reach 1 CFS will prevent overbank flooding, but this assumption needs more further investigation when looking at the full river length.

Egg/Juvenile Transport and Water Quality Pulses (Unified, Reach 1, Wet)

Season: 1MAY-30S0SEP
Events per season: 5
Magnitude: 2,000-6,670 CFS
Duration: 6 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	6	3,300	2
21Jul	6	2,000	2
10Aug	6	4,000	2
30Aug	6	2,000	2
20Sep	6	4,000	2

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn (Unified, Reach 1, Wet)

Season: 1SEP-30OCT
Events per season: 1
Magnitude: 6,670-16,000 CFS
Duration: 6 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	6	13,300	1

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream (estimated at 13,300 at this location in the upstream river). Yet, the teams want to minimize overbank flow at this time.

Low flow/ Baseflow minimums (Unified, Reach 1, Wet)

Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Flow (CFS)
31Oct	600
30Nov	600
31Dec	900
28Feb	1,470
31Jan	2,500
31Mar	2,500
30Apr	1,820
31May	940
30Jun	650
31Jul	600
31Aug	600

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In a wet year, flows were chosen as the 25th percentile flow values by month (Appendix F). If the 25th percentile flow for a month was below 600 CFS, the preferred flow was increased to the 600 CFS minimum flow requirement at Lillington (which is also likely to benefit fish and mussels). The multiplier effect of 1.5 used to adjust flows between Reach 1 and Reach 3 was not used for low flows since there was real data from the Lillington USGS gage.

Unified, Reach 1, Average. Environmental flow recommendations for this reach are shown in Figure 23. Characteristics of each flow component are detailed below.

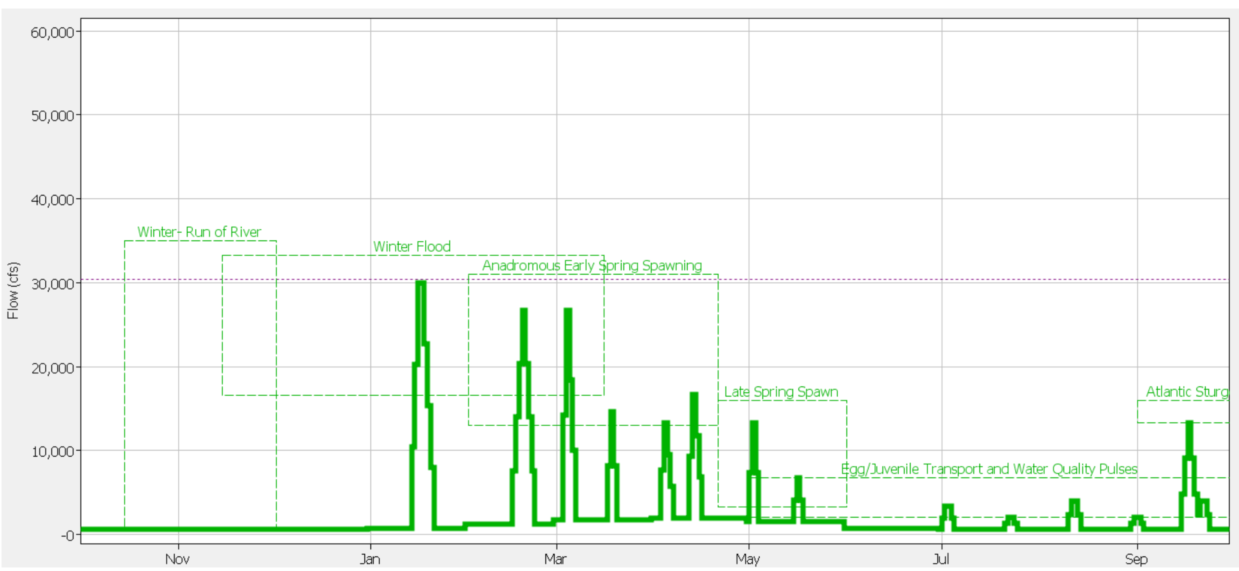


Figure 25. Flow prescription for Unified, Reach 1 Average. Purple dotted line is NWS flood stage at Lillington. Some operation boxes altered slightly to allow text to fit, so see specifics below for numbers.

Winter – Run of River (Unified, Reach 1, Average)

Season: 15OCT-1DEC

Events per season: Variable based on natural weather patterns

Magnitude: 850-35,000+ CFS projected from historic weather patterns
Duration: Variable based on natural weather patterns
Duration of peak: Variable based on natural weather patterns

Additional Details and Caveats:
See Table 2 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without hurting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (Unified, Reach 1, Average)
Season: 15NOV-15MAR
Events per season: 2
Magnitude: 16,600-33,300 CFS
Duration: 7 day(s)
Duration of peak: 1-2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
14Jan	7	30,000	2
15Feb	7	26,670	1

Additional Details and Caveats:
Peaks should taper in magnitude as timing approaches the end of the operational window for winter floods to limit fish access to ponded areas - this limits predation on eggs and larval herpetofauna.

Anadromous Early Spring Spawning (Unified, Reach 1, Average)
Season: 1FEB-20APR
Events per season: 4
Magnitude: 13,000-31,000 CFS
Duration: 3-4 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
03Mar	4	26,700	1
17Mar	3	14,670	1
03Apr	4	13,330	1
12Apr	4	16,670	1

Additional Details and Caveats:
Pulses are ideally over 16,000 CFS to allow fish over the locks and dams. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The fish group wanted to avoid overbank flow by late April to prevent stranding of eggs

and juveniles. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (Unified, Reach 1, Average)

Season: 21APR-30MAY
Events per season: 2
Magnitude: 3,330-16,000 CFS
Duration: 3 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	3	13,300	1
15May	3	6,700	1

Additional Details and Caveats:
Stripers and Shad are main fish species of concern that might still need a cue, but by late April the teams wanted to prevent eggs stranding on the floodplain, so the goal was to stay below 16,000 CFS.

Egg/Juvenile Transport and Water Quality Pulses (Unified, Reach 1, Average)

Season: 1MAY-30S0SEP
Events per season: 5
Magnitude: 2,000-6,670 CFS
Duration: 4 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	4	3,330	2
21Jul	4	2,000	2
10Aug	4	4,000	2
30Aug	4	2,000	2
20Sep	4	4,000	2

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn (Unified, Reach 1, Average)

Season: 1SEP-30OCT
Events per season: 1
Magnitude: 6,670-16,000 CFS
Duration: 5 day(s)
Duration of peak: 1 day(s)

Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	5	13,300	1

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream (estimated at 13,300 at this location in the upstream river). Yet, the teams want to minimize overbank flow at this time.

Low flow/ Baseflow minimums (Unified, Reach 1, Average)
Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Flow (CFS)
31Oct	600
30Nov	600
31Dec	674
31Jan	1,260
28Feb	1,720
31Mar	1,980
30Apr	1,480
31May	760
30Jun	600
31Jul	600
31Aug	600

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In an average year, flows were chosen as the 18th percentile flow values by month (Appendix F). If the 18th percentile flow for a month was below 600 CFS the preferred flow was increased to the 600 CFS minimum flow requirement at Lillington (which is also likely to benefit fish and mussels).

Unified, Reach 1, Dry. Environmental flow recommendations for this reach are shown in Figure 24. Characteristics of each flow component are detailed below.

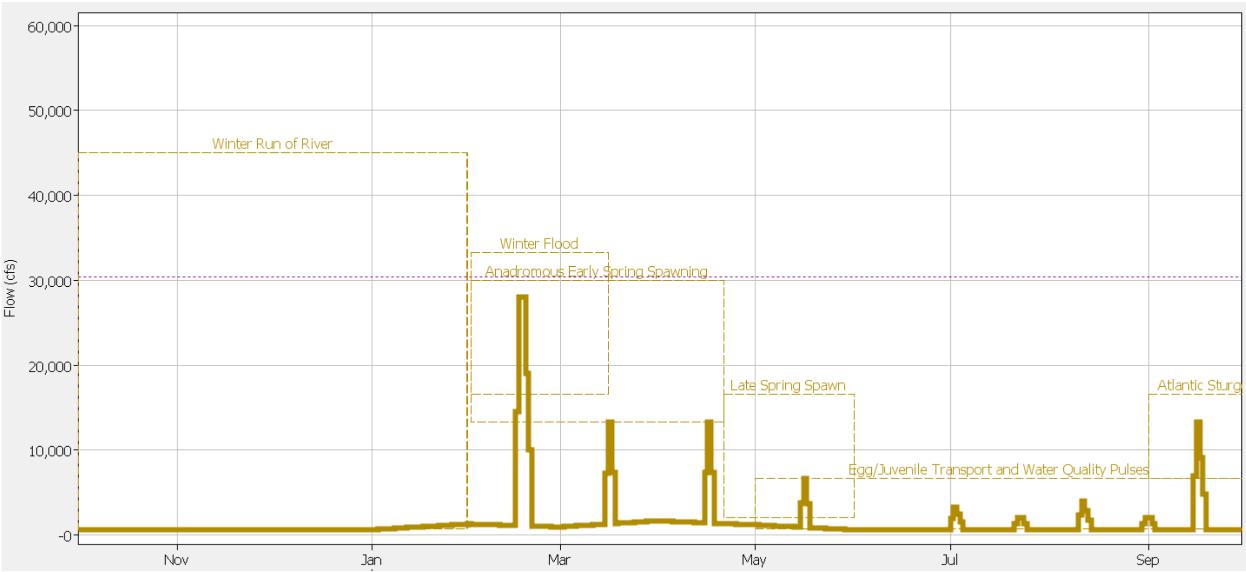


Figure 26. Flow prescription for Unified, Reach 1 Dry. Purple dotted line is NWS flood stage at Lillington. Some operation boxes altered slightly to allow text to fit, so see specifics below for numbers.

Winter – Run of River (***Unified, Reach 1, Dry)***

Season: 1OCT-30JAN
Events per season: Variable based on natural weather patterns
Magnitude: 750-35,000+ CFS projected from historic weather patterns
Duration: Variable based on natural weather patterns
Duration of peak: Variable based on natural weather patterns

Additional Details and Caveats:
See Table 2 for ecological goals. Inflows to Jordan Lake are quickly released downstream (without hurting authorized purposes) to promote natural pulsing as the river historically experienced.

Winter Flood (***Unified, Reach 1, Dry)***

Season: 1FEB-15MAR
Events per season: 1
Magnitude: 16,600-33,300 CFS
Duration: 5 day(s)
Duration of peak: 2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Feb	5	28,000	2

Additional Details and Caveats:
With only one requested peak, the group wants to time it as late in the winter (and close to the growing season) as possible.

Anadromous Early Spring Spawning (***Unified, Reach 1, Dry)***

Season: 1FEB-20APR
Events per season: 2
Magnitude: 13,300-31,000 CFS
Duration: 3 day(s)
Duration of peak: 1day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Mar	3	13,300	1
15Apr	3	13,300	1

Additional Details and Caveats:
Pulses are ideally over 13,300 CFS to allow fish over the locks and dams downstream, assuming this additional water contributions from tributaries would add to the flow and equate to approximately 20,000 CFS at LD3. Overbank flow is not a major consideration at this time of year for the anadromous fishes and will not be an issue if it occurs. The winter Feb 15 pulse meets the needs for winter flood and spring spawn, so was kept in winter pulses and removed from spring spawn.

Late Spring Spawn (***Unified, Reach 1, Dry)***

Season: 21APR-30MAY
Events per season: 1
Magnitude: 2,000-16,000 CFS
Duration: 3 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15May	3	6,600	1

Additional Details and Caveats:
Stripers and Shad are main fish species of concern that might still need a cue. The 6,000 CFS is not expected to adequately submerge the locks and dams for fish passage, but would still send a cue to fish and they could be locked in the chambers to move upstream

Egg/Juvenile Transport and Water Quality Pulses (***Unified, Reach 1, Dry)***

Season: 1MAY-30SEP
Events per season: 4
Magnitude: 670-6,670 CFS
Duration: 4 day(s)
Duration of peak: 1-2 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01Jul	4	3,300	1

21Jul	4	2,000	2
10Aug	4	4,000	1
30Aug	4	2,000	2

Additional Details and Caveats:
This prescription would provide pulses in the summer to push fry over the rock arch rapids (RARS). The fry and eggs need more stable flows and the teams were again trying to minimize overbank flooding.

Atlantic Sturgeon Fall Spawn **(*Unified, Reach 1, Dry)***

Season: 1SEP-31OCT
Events per season: 1
Magnitude: 6,670-16,000 CFS
Duration: 4 day(s)
Duration of peak: 1 day(s)
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15Sep	4	13,300	1

Further details/Caveats:
There is a second stock of sturgeon in the Cape Fear that spawns in the Fall. This prescription aims to provide adequate flow over lock and dams to help them upstream (estimated at 13,300 at this location in the upstream river). Yet, the teams want to minimize overbank flow at this time.

Base flow minimums **(*Unified, Reach 1, Dry)***

Season: Year round
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Flow (CFS)
31Oct	600
30Nov	600
31Dec	600
28Feb	940
31Jan	1,280
31Mar	1,650
30Apr	1,190
31May	610
30Jun	600
31Jul	600
31Aug	600

Further details/Caveats:
The teams were asked to input baseflows, or the regular low flows, into their hydrographs. The teams used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In a dry year, flows were chosen as the 10^{th} percentile flow values by month

(Appendix F). If the 10th percentile flow for a month was below 600 CFS the preferred flow was increased to the 600 CFS minimum flow requirement at Lillington (which is also likely to benefit fish and mussels).

Next steps in the SRP process

The Cape Fear SRP team successfully hosted a technical stakeholder e-flows workshop in October of 2019 and produced flow prescriptions for the river. There is a recognition that the flow prescriptions have ecological intentions behind them, and exact numbers and durations are guides to try to implement and study in practice. There is also a recognition that real-world conditions do not always fall within categories of "wet, average, dry" and that implementing prescriptions will be based on the opportunities the weather provides within a season. The Corps has constraints on the operation of the dam, and this will also factor into which prescriptions are possible to implement.

Further work is dependent on funding and the Cape Fear is currently under consideration for SRP funds for 2020. Depending on funding and workload availability of partners, the team plans to pursue the following next steps:

- Within the prescriptions, there are flow pulses that would help both fish and water quality that may fall within the Corp's current operational flexibility. The Wilmington District and TNC propose to run CWMS models to determine enabling hydrological conditions that would allow shad, sturgeon and other diadromous fish to spawn upstream of LD1, LD2 and LD3. The Wilmington District and TNC will also analyze the enabling hydrological conditions for late summer flow pulses that might help reduce algal blooms, along with evaluating anticipated impacts on water quality storage for such pulses.
- Concurrent with the Corps' modeling efforts, TNC will convene researchers to form a technical monitoring team to prepare a monitoring plan in case enabling conditions occur. This team will include fish tracking experts and water quality experts. The monitoring plan will include how, where, and who samples the river.
- TNC and the Corps will update stakeholders as modeling and monitoring plans are finalized.
- Throughout the spawning and growing season, there will be coordination among the Corps, TNC, and monitoring experts to watch hydrological conditions. If enabling conditions occur (and assuming water availability in Jordan Lake), the Wilmington District will conduct a test pulse and the monitoring team will sample the river.
- By late Fall 2020, work to-date will be summarized and shared to learn for future seasons.

Helpful Background Documents

ACOE. (2018). *US ARMY CORPS OF ENGINEERS WILIMINGTON DISTRICT*. Retrieved from CAPE FEAR LOCKS AND DAMS > HISTORY: http://www.saw.usace.army.mil/Locations/District-Lakes-and-Dams/Cape-Fear-Locks-and-Dams/History/

Adam Smith, N. L. (2019). *U.S. Billion-Dollar Weather & Climate Disasters 1980-2019.* Retrieved from NOAA National Centers for Environmental Information (NCEI): https://www.ncdc.noaa.gov/billions/events.pdf

Baron, J., Hall, E., Nolan, B., Finlay, J., Bernhardt, E., Harrison, J., . . . EW, B. (2013). The interactive effects of excess reactive nitrogen and climate change on aquatic ecosystems and water resources of the United States. *Biogeochemistry, 114*(1-3), 71-92. doi:10.1007/s10533-012-9788-y

Buck Engineering. (2004). *Middle Cape Fear Local Watershed Plan.* North Carolina Department of Environment and Natural Resources Ecosystem Enhancement Program.

Carter, L., Terando, A., Kow, K., Hiers, K., Kunkel, K. L., Marcy, D., . . . Schramm, P. (2018). *Southeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)].* Washington, DC, USA: U.S. Global Change Research Program. doi:10.7930/NCA4.2018.CH19

Collaboratory, N. C. (2018, October 9). *Legislative Studies*. Retrieved from North Carolina Policy Collaboratory: https://collaboratory.unc.edu/current-projects/legislative-studies/#nutrient

Commission, N. C. (2017, April 4). *files.nc.gov/ncdeq.* Retrieved 09 18, 2019, from Round 4 Jordan Lake Allocation: https://files.nc.gov/ncdeq/Water%20Resources/files/permits/jordanlake/EMC_Final_Decision_Round_4_Jordan_Lake_Allocation_2017-04-04.pdf

Conservancy, C. R. (2019). *Freshwater Mussels: an indicator species*. Retrieved from https://www.ctriver.org/freshwater-mussels-an-indicator-species/

DePoe, C. E. (1961). *The Reptiles and Amphibians of North Carolina: A Preliminary Check List and Bibliography.* Retrieved from The Reptiles and Amphibians of North Carolina: A Preliminary Check List and Bibliography.: https://dc.lib.unc.edu/cgi-bin/showfile.exe?CISOROOT=/jncas&CISO

Eanes, Z. (2018, July 18). America's fastest-growing suburb is in the Triangle. *The News & Observer*.

EPA., U. (2002). *Office of Water, U.S. Environmental Protection Agency.* Retrieved from Methods for evaluating wetland condition Using Amphibians in Bioassessments of Wetlands.: https://www.epa.gov/sites/production/files/documents/wetlands_12amphibians.pdf

Hocking, D. J. (2014). *AMPHIBIAN CONTRIBUTIONS TO ECOSYSTEM SERVICES. Herpetological Conservation and Biology, 9(1), 1–17.* Retrieved from http://www.herpconbio.org/Volume_9/Issue_1/Hocking_Babbitt_2014.pdf

Hydrologics. (2013). *Modeling the Cape Fear and Neuse River Basin Operations with OASIS.* Hydrologics.

Isaacs, J. D., Strangman, W. K., Barbera, A. E., Mallin, M. A., McIver, M. R., & Wright, J. L. (2014). Microcystins and two new micropeptin cyanopeptides produced by unprecedented Microcystis aeruginosa blooms in North Carolina's Cape Fear River. *Harmful Algae, 31*, 82-86.

James, L. A. (2013). Legacy sediment: Definitions and processes of episodically produced anthropogenic sediment. *Anthropocene, 2*, 16-26. doi:10.1016/j.ancene.2013.04.001

Keellings, D., & Engström, J. (2019). The future of drought in the Southeastern U.S.: Projections from downscaled CMIP5 models. *Water, 2019*(11), 1-9. doi:10.3390/w11020259

Kopp, R. E. (2015). Past and future sea-level rise along the coast of North Carolina, USA. *Climatic Change, 132*, 693-707.

Mallin, M. A., & McIver, M. R. (2018). Season matters when sampling streams for swine CAFO waste pollution impacts. *Water & Health, 16*(1), 78-86.

Mallin, M. A., Cahoon, L. B., McIver, M. R., Parsons, D. C., & Shank, C. G. (1999). Alternation of factors limiting pytoplankton production in the Cape Fear River Estuary. *Estuaries, 22*(4), 825-836.

Mallin, M. A., McIver, M. R., Robuck, A. R., & Kahn Dickens, A. (2015). Industrial Swine and Poultry Production Causes Chronic Nutrient and Fecal Microbial Stream Pollution. *Water, Air, & Soil Pollution, 226*(12).

Martin, K. L., Emanuel, R. E., & Vose, J. M. (2018). Terra incognita: The unknown risks to environmental quality posed by the spatial distribution and abundance of concentrated animal feeding operations. *Science of the Total Environment, 642*, 887-893.

McDonald, K. E., & Lehman, J. T. (2013). Dynamics of Aphanizomenon and Microcystis (cyanobacteria) during experimental manipulation of an urban impoundment. *Lake and Reservoir Management, 29*(2), 103-115. doi:10.1080/10402381.2013.800172

Nature Conservancy. (2008, April). *The Active River Area A Conservation Framework for Protecting Rivers and Streams.* Retrieved from https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/Documents/ED_freshwater_ARA_NE2008.pdf

NC Department of Environmental Quality. (2018, September 5). Benthos Ratings (Latest). North Carolina: NC Department of Environmental Quality. Retrieved October 16, 2018, from https://data-ncdenr.opendata.arcgis.com/datasets/501a682e188746399f6ffb62a4840a38_0

NC Department of Environmental Quality. (2018). *Final 2016 Integrated Report: All Assessed Waters.* NC Department of Environmental Quality. Retrieved October 16, 2018, from https://files.nc.gov/ncdeq/Water%20Quality/Planning/TMDL/303d/2016/NC_2016_IR_Final.pdf

NC Department of Environmental Quality. (2018, July 8). Fish Community Ratings (Latest). North Carolina. Retrieved 10 16, 2018, from https://data-ncdenr.opendata.arcgis.com/datasets?q=fish%20community%20ratings%20(latest)

NC Department of Environmental Quality. (2018, 1 30). NC Monitoring Coalition Stations. North Carolina. Retrieved 10 16, 2018, from https://data-ncdenr.opendata.arcgis.com/datasets?q=nc%20monitoring%20coalition%20stations

NC Geological Survey. (2004). *North Carolina Geological Survey.* Retrieved from http://cdm16062.contentdm.oclc.org/cdm/ref/collection/p16062coll9/id/220299

NC Policy Collaboratory. (2017). *Interim Update to the North Carolina General Assembly: UNC Nutrient Management Study.* Chapel Hill, NC: North Carolina Policy Collaboratory. Retrieved from https://collaboratory.unc.edu/

NCDEQ. (2018, November 15). *North Carolina Department of Environmental Quality.* Retrieved from Surface Water Classifications: https://deq.nc.gov/about/divisions/water-resources/planning/classification-standards/classifications#DWRPrimaryClassification

NCDEQ. (2019). Retrieved from https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/intensive-survey-branch/falls-jordan-lakes-monitoring

NCDEQ. (2019). Retrieved from https://files.nc.gov/ncdeq/Water%20Quality/Planning/TMDL/303d/2018/2018-NC-303-d--List-Final.pdf

NCPEDIA, U. o. (2006). *Cape Fear River Settlements*. Retrieved from NCPEDIA: https://www.ncpedia.org/cape-fear-river-settlements

NCWRC. (2005). *2015 Wildlife Action Plan.* Retrieved from https://www.ncwildlife.org/Plan

North Carolina Department of Environment & Natural Resources Division of Water Quality. (2005). *Cape Fear River Basinwide Water Quality Plan.* Raleigh, NC.

North Carolina Department of Environmental Quality. (2018, October 19). *Health-related resources about GenX, PFOA and PFAs.* Retrieved from North Carolina Department of Environmental Quality: https://deq.nc.gov/news/hot-topics/genx-investigation/health-related-resources-about-genx-pfoa-and-pfas

Olden, J. D., & Naiman, R. J. (2010). Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity: Incorporating thermal regimes in environmental flows assessments. *Freshwater Biology, 55*(1), 86-107. doi:10.1111/j.1365-2427.2009.02179.x

Paerl, H. W., & Paul, V. J. (2012). Climate change: Links to global expansion of harmful cyanobacteria. *Water Research, 46*(5), 1349-1363. doi:10.1016/j.watres.2011.08.002

Pierre-Louis, K. (2019, April 16). Lagoons of pig waste are overflowing after florence. Yes, that's as nasty as it sounds. *The New York Times.*

Polera, M. (2016). *MS Thesis: Microcystis in the Cape Fear River: Where, When and Why? .* University of North Carolina Wilmington.

Siegal, R. R. (2018, September 11). Moving chickens, harvesting tobacco, managing hog manure: N.C. farmers prepare for Florence. . *The Washington Post*.

Somers, K. A., Bernhardt, E. S., Grace, J. B., Hassett, B. A., Sudduth, E. B., Wang, S., & Urban, D. (2013). Streams in the urban heat island: spatial and temporal variability in temperature. *Freshwater Science, 32*(1), 309-326. doi:10.1899/12-046.1

Stahle, D. W. (2012). Tree-ring analysis of ancient baldcypress trees and subfossil wood. *Quaternary Science Reviews 34*, 1-15.

Strauss, B. H. (2012). Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters, 7: 014033*.

Strauss, B., Tebaldi, C., & Kulp, S. (2014). *North Carolina and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk.* Princeton, NJ: Climate Central. Retrieved August 8, 2019, from http://sealevel.climatecentral.org/uploads/ssrf/NC-Report.pdf

Tech, R. (2015). *Final report: Watershed scale modeling of hydrology and nutrients in the Cape Fear River, NC.*

U.S. Census Bureau. (2018, May 4). *U.S. Census Bureau.* Retrieved from Newsroom RELEASE NUMBER CB18-78: https://www.census.gov/newsroom/press-releases/2018/estimates-cities.html

USACE. (1992). WCPlan. *Water Control Manual B. Everett Jordan Dam and Lake Cape Fear River Basin, North Carolina*. North Carolina.

USACE. (2019). *Hydropower at Jordan Lake*. Retrieved from https://www.saw.usace.army.mil/Locations/District-Lakes-and-Dams/B-Everett-Jordan/Hydropower/

USACE. (2019). *US Army Corps of Engineers Hydrologic Engineering Center*. Retrieved from https://www.hec.usace.army.mil/software/hec-rpt/

USGS. (2019). *Gap Analysis Project*. Retrieved from https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap

Walsh, C. J., Roy, A., Feminella, J. W., Cottingham, P., Groffman, P. M., & Morgan II, R. P. (2005). The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society, 24*(3), 706-723. doi:10.1899/0887-3593(2005)024\[0706:TUSSCK\]2.0.CO;2

Wang, S. S.-Y., Zhao, L., Yoon, J.-H., Klotzbach, P., & Gillies, R. R. (2018). Quantitative attribution of climate effects on Hurricane. *Environmental Research Letters, 13*(5), 054014. doi:10.1088/1748-9326/aabb85

Wegmann, K. W., Osburn, C. L., Lewis, R. Q., Peszlen, I. M., & Mitasova, H. (2013). *Legacy Sediments and Stream Water Quality: Estimating Volume, Nutrient Content, and Stream Bank Erosion in 303(d)-Impaired Waterways of the North Carolina Piedmont.* Chapel Hill, NC: Water Resources Research Institute of the University of North Carolina. Retrieved 10 15, 2018, from https://repository.lib.ncsu.edu/bitstream/handle/1840.4/8190/NC-WRRI-435.pdf?sequence=1

Wiltsie, D., Schnetzer, A., Green, J., Vander Borgh, M., & Fensin, E. (2018). Algal blooms and cyanotoxins in Jordan Lake, North Carolina. *Toxins, 10*(2), 1-23.

Wyneken, J. (2013). *Proceedings Association of Reptilian and Amphibian Veternarians.* Retrieved from REPTILIAN RENAL STRUCTURE AND FUNCTION: https://cdn.ymaws.com/members.arav.org/resource/resmgr/Files/Proceedings_2013/41.pdf

Appendices

Appendix A: Agenda

Cape Fear River, Sustainable Rivers Program

Environmental Flows Workshop

October 1-2, 2019

Sanford, North Carolina
Central Carolina Community College
Meeting Room 112

AGENDA

October 1, 2019

Location: Meeting Room 112

9:00 Refreshments and networking

10:00 Welcome and introductions – *Justin Bashaw (USACE, Wilmington District), Julie DeMeester (The Nature Conservancy)*

10:20 Review of SRP process and discussion of meeting outcomes – *John Hickey (USACE, Water Resources Development Division), Gretchen Benjamin (The Nature Conservancy)*

10:50 Overview of B. Everett Jordan Reservoir and Cape Fear River Locks and Dams – *Tony Young (USACE, Wilmington District), Dan Emerson (USACE, Wilmington District)*

11:15 Hydrologic analysis and flow/ecology relationships as background for developing environmental flow recommendations – *Julie DeMeester (The Nature Conservancy),*

12:15 Lunch (provided)

1:00 Overview of Regime Prescription Tool software that will be used in Working Groups – *John Hickey (USACE, Water Resources Development Division)*

1:20 Instructions for Working Groups – *Julie DeMeester (TNC)*

1:30 Breakout groups: Working Groups have been organized by leveraging individuals having specific expertise. The aim of these Working Groups is to identify hydrographs for each reach designed to improve ecological conditions associated with each Group's focus area.

Working Groups break out:

Group #1 – Fish, with a focus on diadromous and rare fish (reach order 3,1,2)

Group #2 – Water quality to prevent algal blooms (reach order 2,1,3,0)

Group #3 – Floodplain health and function, and vegetative reestablishment (reach order 1,2,3)

Focus Reaches:

Reach #0- Jordan Lake

Reach #1 – Jordan Lake to Lillington

Reach #2 – Lillington to LD3 (William O. Huske Lock and Dam)

Reach #3 – LD3 (William O. Huske Lock and Dam) to LD1 (Lock and Dam #1)

3:15 Break

3:30 Resume working groups

4:30 Group reconvenes to address "parking lot issues" and review the tasks for Oct 2

5:00 Adjourn

<u>October 2, 2019</u>

Location: Meeting Room 112

9:00 Working groups continue to define flow needs per reaches.

10:30 Break (15min)

10:45 Working groups continue to define flow needs per reaches.

12:00 Lunch (Provided)

1:00 Each group presents its findings (~20 minutes each)

2:00 Unification of flow recommendations (~30 minutes per reach)

3:30 Break

3:45 Conclusion and parting discussion – Discussing uncertainties, parking lot issues, next steps, modeling needs, concluding thoughts

4:30 Adjourn

Appendix B: Participant List

Name	Affiliation	Break Out Group
Jenny Owens	Army Corps	Algal blooms/ Water quality
Brian Wrenn	DEQ- Water Resources	Algal blooms/ Water quality
Narayan “Raj” Rajbhandari	DEQ- Water Resources	Algal blooms/ Water quality
Nora Deamer	DEQ- Water Resources	Algal blooms/ Water quality
Patrick Beggs	DEQ- Water Resources	Algal blooms/ Water quality
Rich Gannon	DEQ- Water Resources	Algal blooms/ Water quality
Chad Ham	Fayetteville PWC	Algal blooms/ Water quality
Mick Noland	Fayetteville PWC	Algal blooms/ Water quality
Bill Kreutzberger	Fayetteville PWC- Consults to them	Algal blooms/ Water quality
Danica Schaffer-Smith	The Nature Conservancy	Algal blooms/ water quality
Will Spoon	The Nature Conservancy	Algal blooms/ water quality
Jen Schmitz	TJ COG	Algal blooms/ Water quality
Nathan Hall	UNC-Ch marine	Algal blooms/ Water quality
Ana Garcia	USGS	Algal blooms/ Water quality
Keleigh Cox	Army Corps	Fish
Frank Yelverton	Cape Fear River Watch (retired)	Fish
Casey Knight	DEQ-Division of Marine Fisheries	Fish
Steve Nebiker	Hydrologics	Fish
Judy Ratcliffe	NC Natural Heritage Program	Fish
Brena Jones	NC WRC	Fish
Chris Goudreau	NC WRC	Fish
Jeremy McCargo	NC WRC	Fish
Vann Stancil	NC WRC	Fish
Howard Schnabolk	NOAA	Fish
Julie DeMeester	The Nature Conservancy	Fish
John Ellis	USFWS	Fish
Justin Bashaw	Army Corps	Fish
Tony Young	Army Corps	Fish/ water quality
Peter Raabe	American Rivers	Floodplains
Ashley Hatchell	Army Corps	Floodplains
Dan Emerson	Army Corps	Floodplains
John Hickey	Army Corps	Floodplains
Norton Webster	Carolina Wetlands Association	Floodplains
Anjie Ackerman	DEQ- Division of Mitigation Services	Floodplains

Fred Tarver	DEQ- Water Resources	Floodplains
Neela Sarwar	DEQ- Water Resources	Floodplains
Joey Hester	NC Dept of Ag	Floodplains
Katie Martin	NCSU	Floodplains
Michele Eddy	RTI	Floodplains
Chuck Peoples	The Nature Conservancy	Floodplains
Deb Maurer	The Nature Conservancy	Floodplains
Gretchen Benjamin	The Nature Conservancy	Floodplains
Curtis Weaver	USGS	Floodplains

Appendix C: Parking Lot Issues Outside the Scope of the Workshop

Fish Team:

- If the LD2 and LD3 were not present, fish could likely get up the river to spawn at 4k CFS.
- Is Wilmington harbor deepening happening?

Floodplains Team:

- Real Operations – Wet/Avg/Dry conditions can happen in the same year. How we manage through these variations when we do not have long-term foresight?

Water Quality Team:

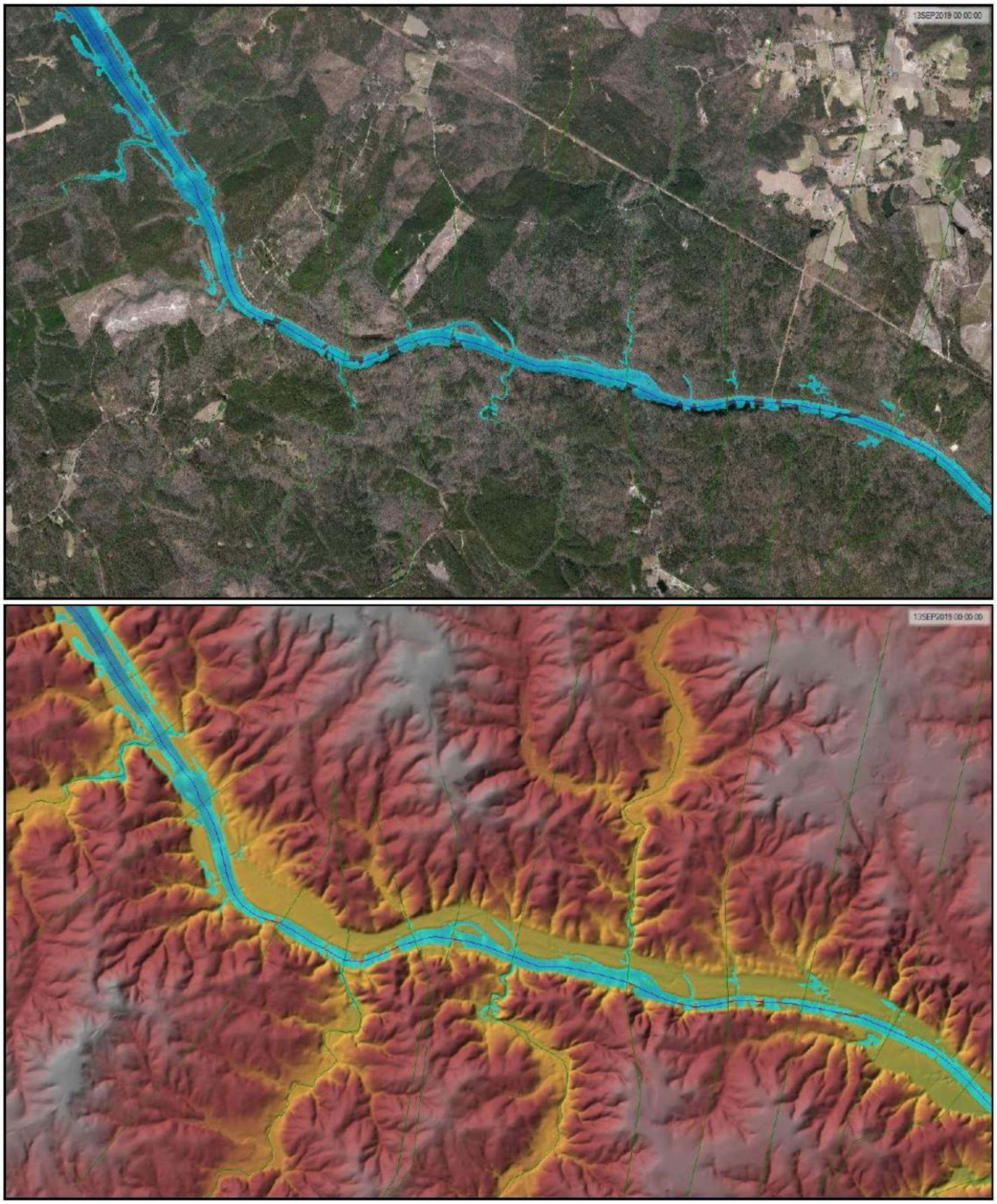
- Salt intrusion, well water condition.
- Natural low DO conditions of blackwater streams.
- In the Deep River basin, unmanaged dams and biosolids applications may be significant sources of water quality problems that affect the Cape Fear River.
- Nutrient reduction requirements downstream could pose a limitation on prescriptions generated for managing in-lake conditions at Jordan.

Appendix D: HEC-RAS Inundation Report

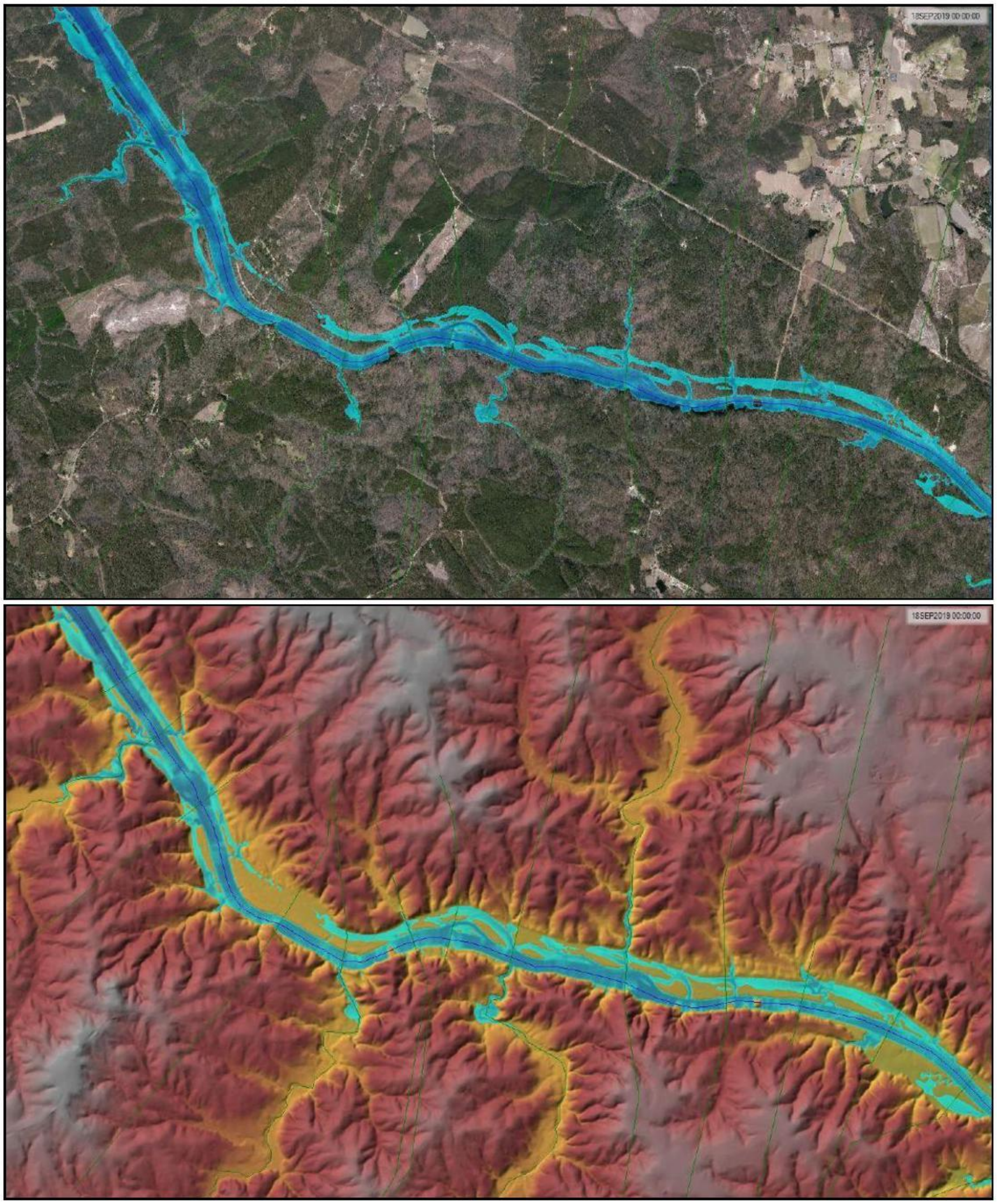
The following graphics depict the estimated inundation footprint at 3 locations on the Cape Fear River, at 5 different magnitudes of river flow. A river hydraulics model was used to route a range of flows (20k, 30k, 40k, 50k and 60k cubic feet per second (cfs)) from Jordan to Lock and Dam 1. Elevations from the hydraulic model were then applied to a terrain model to estimate the inundation footprint.

The full extent of the basin, the extent of each study reach and the locations chosen to represent each reach are shown in the image above.

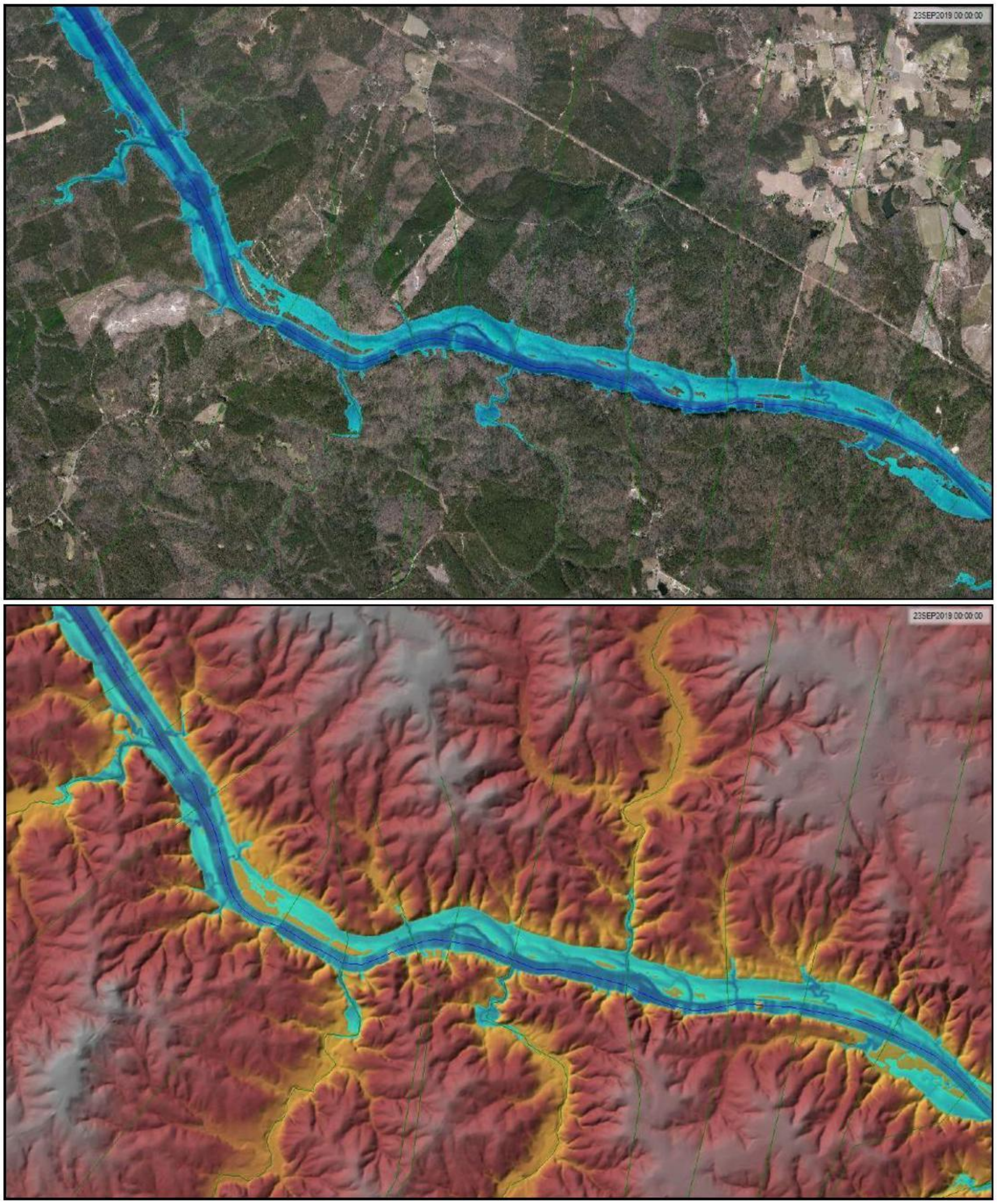
In the following graphics, inundation footprints are depicted on an aerial image and on the terrain for each flow modeled.



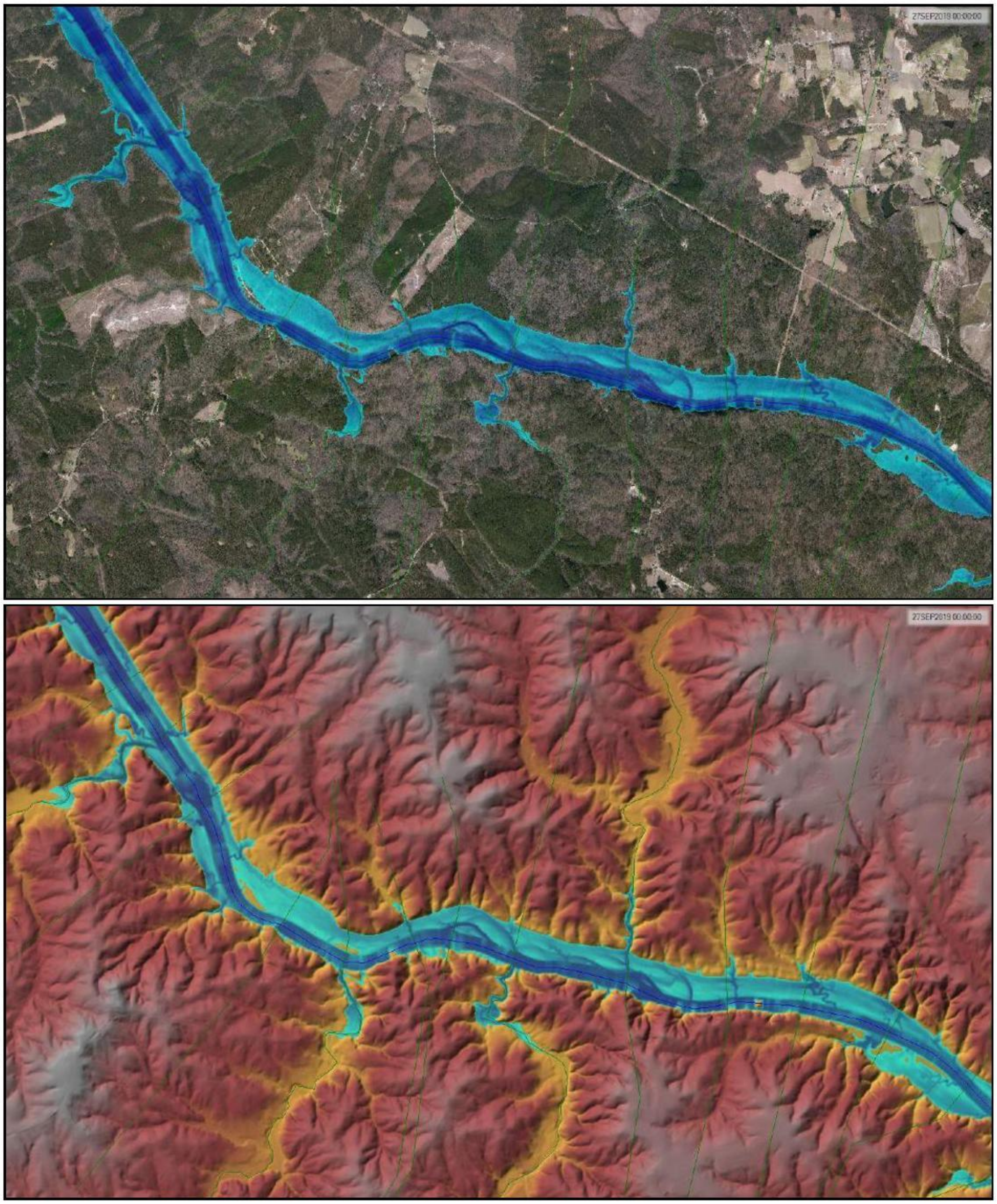
REACH 1 – INUNDATION AT 20,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



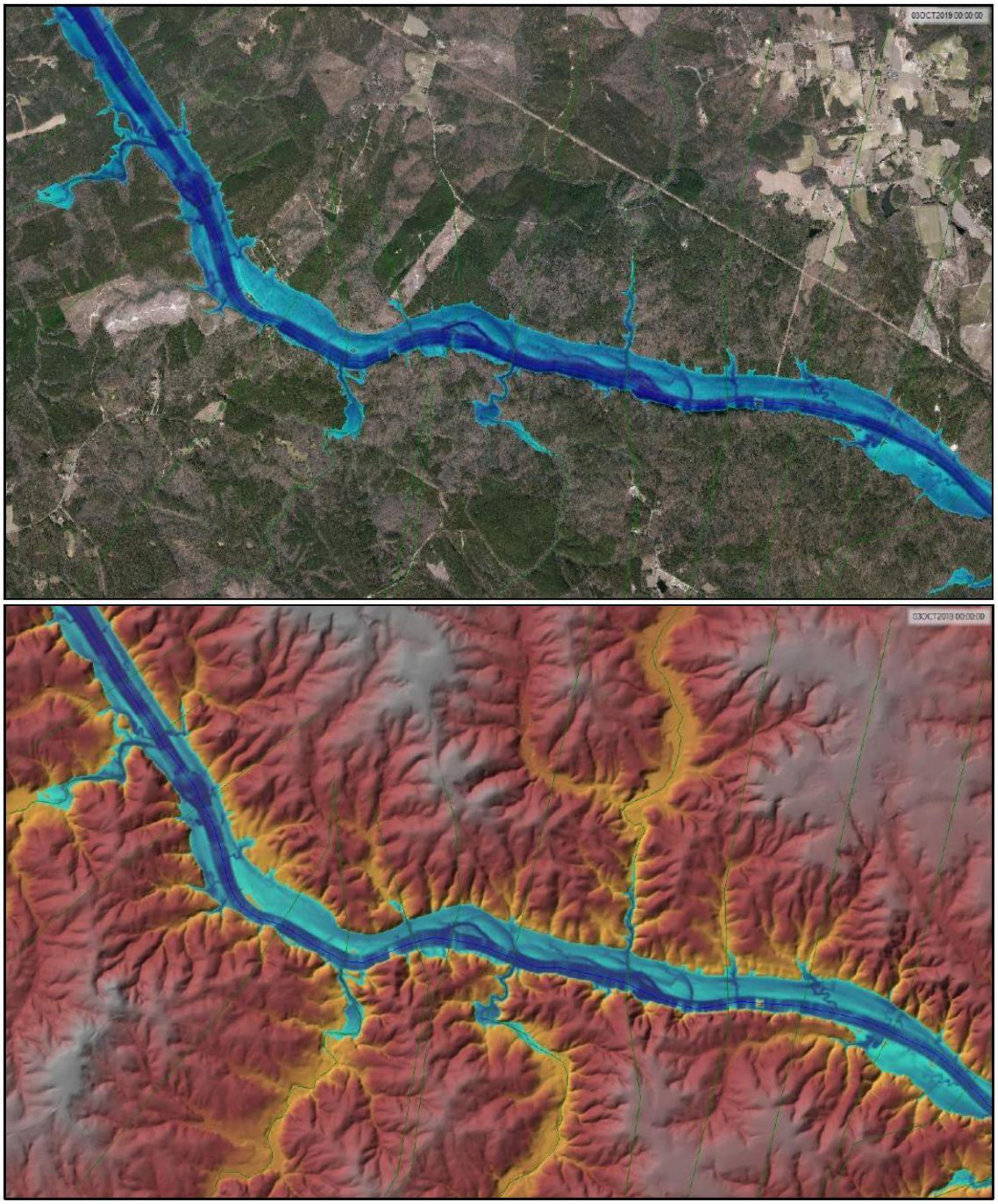
REACH 1 – INUNDATION AT 30,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



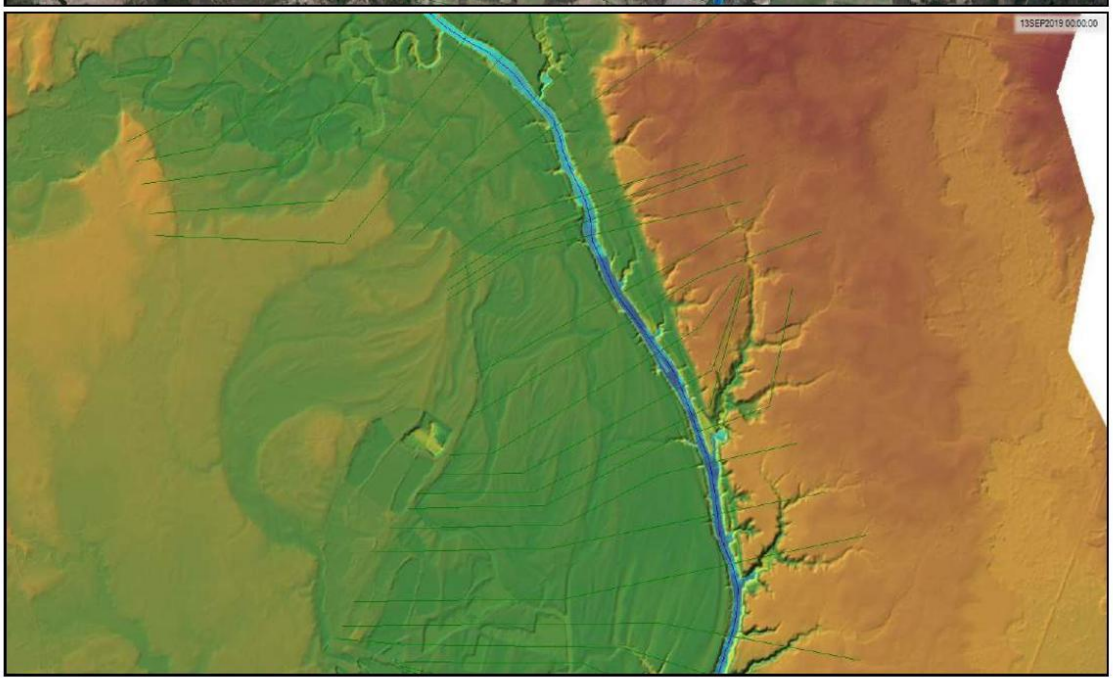
REACH 1 – INUNDATION AT 40,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



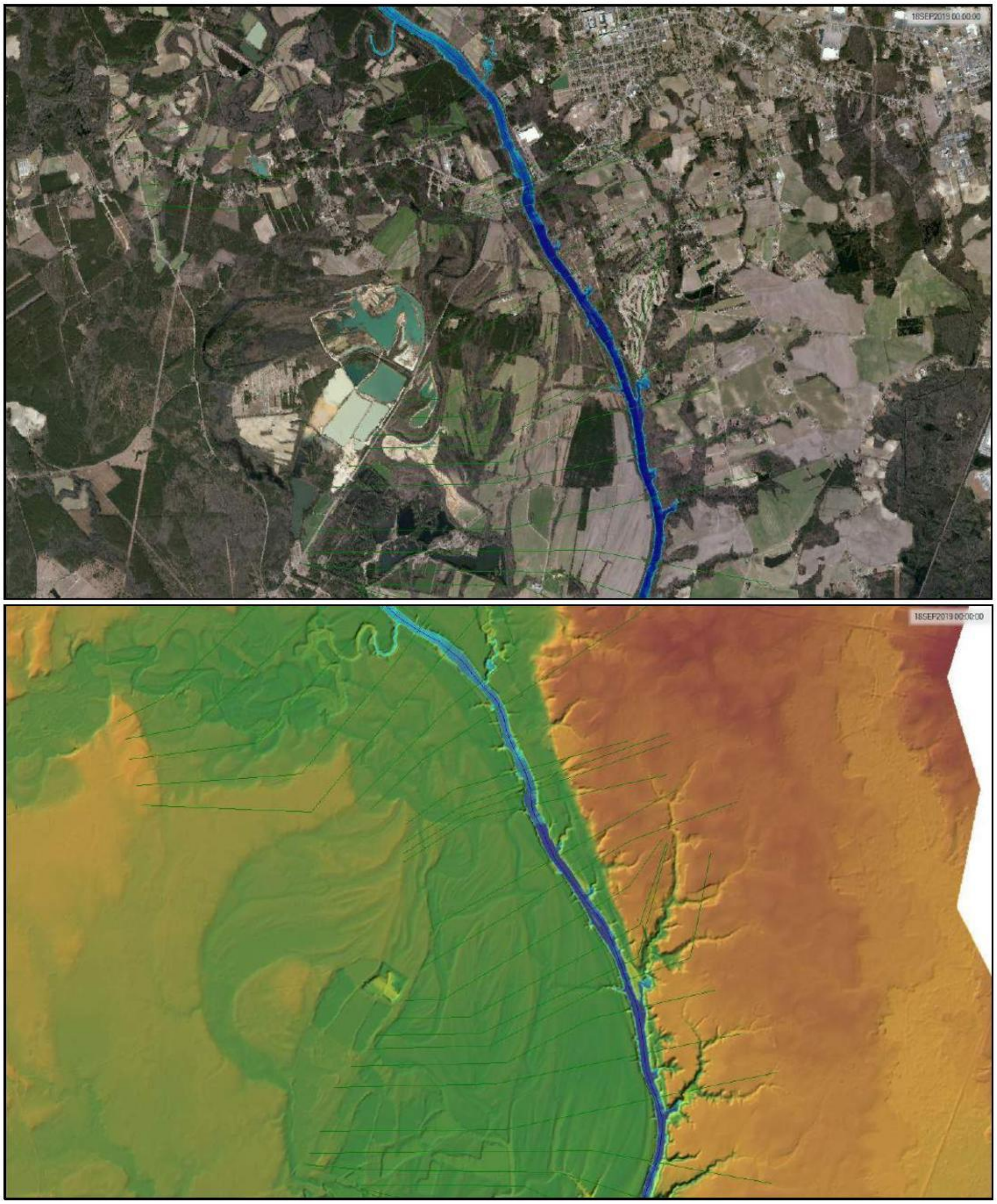
REACH 1 – INUNDATION AT 50,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



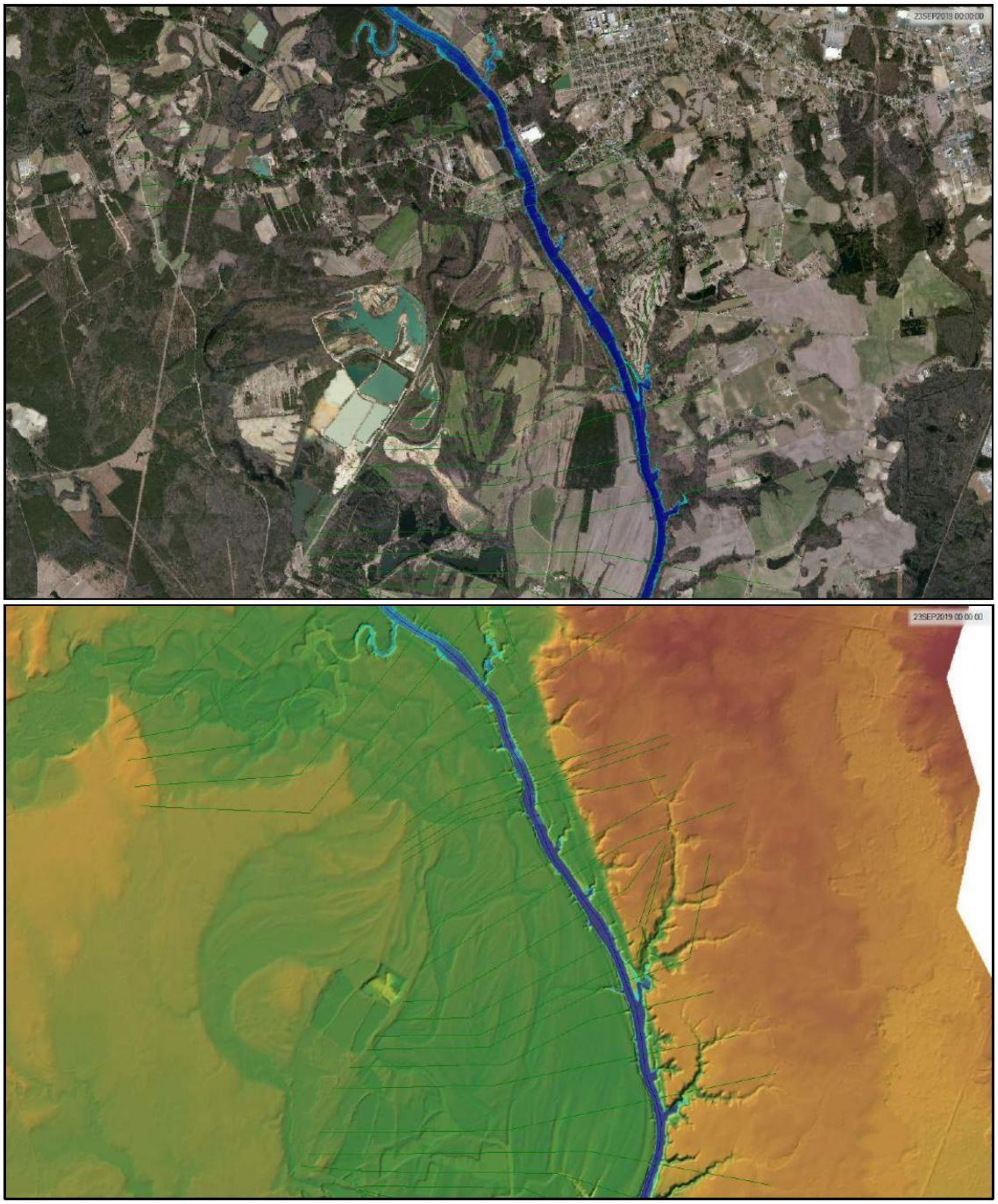
REACH 1 – INUNDATION AT 60,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



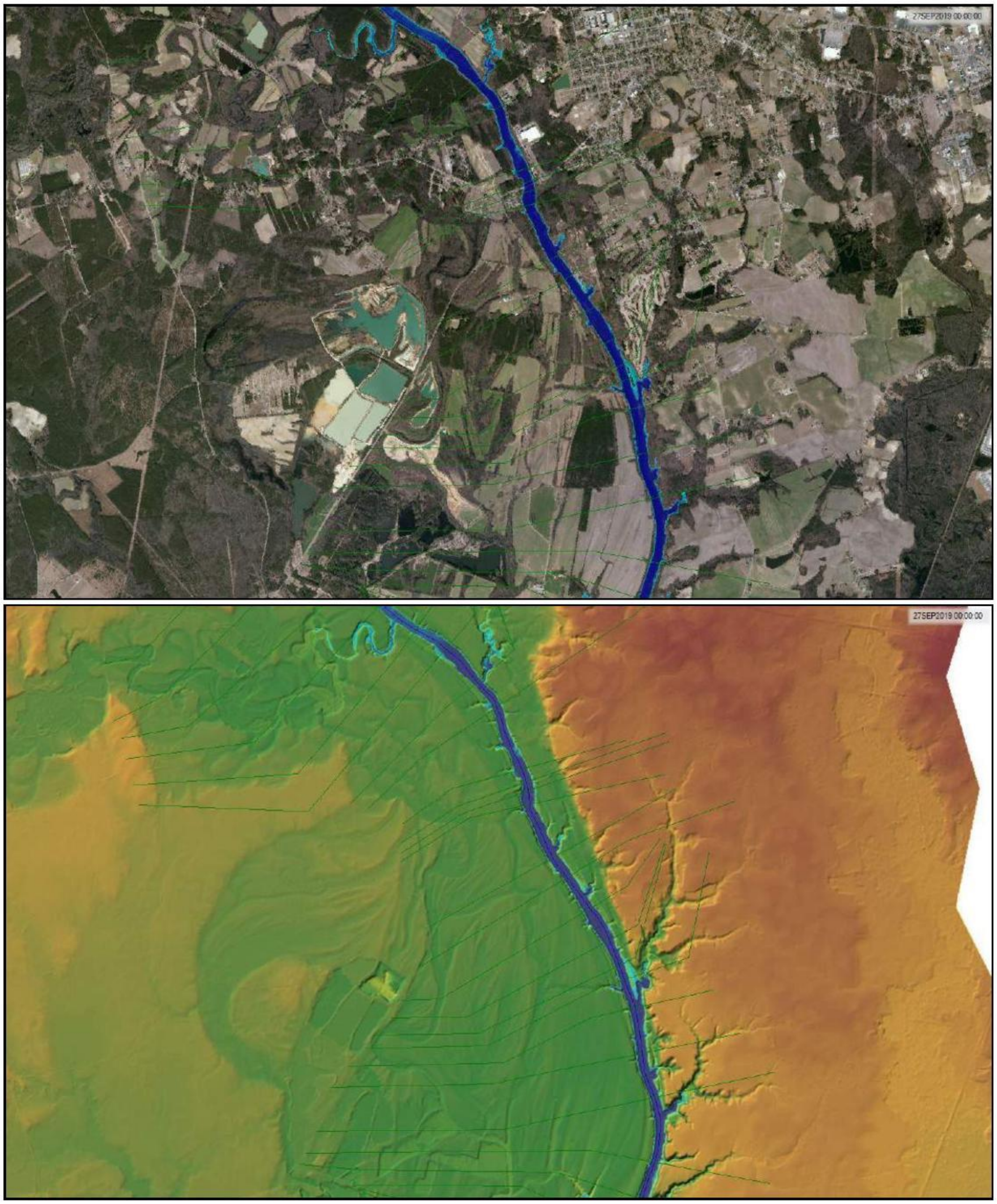
REACH 2 – INUNDATION AT 20,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



REACH 2 – INUNDATION AT 30,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



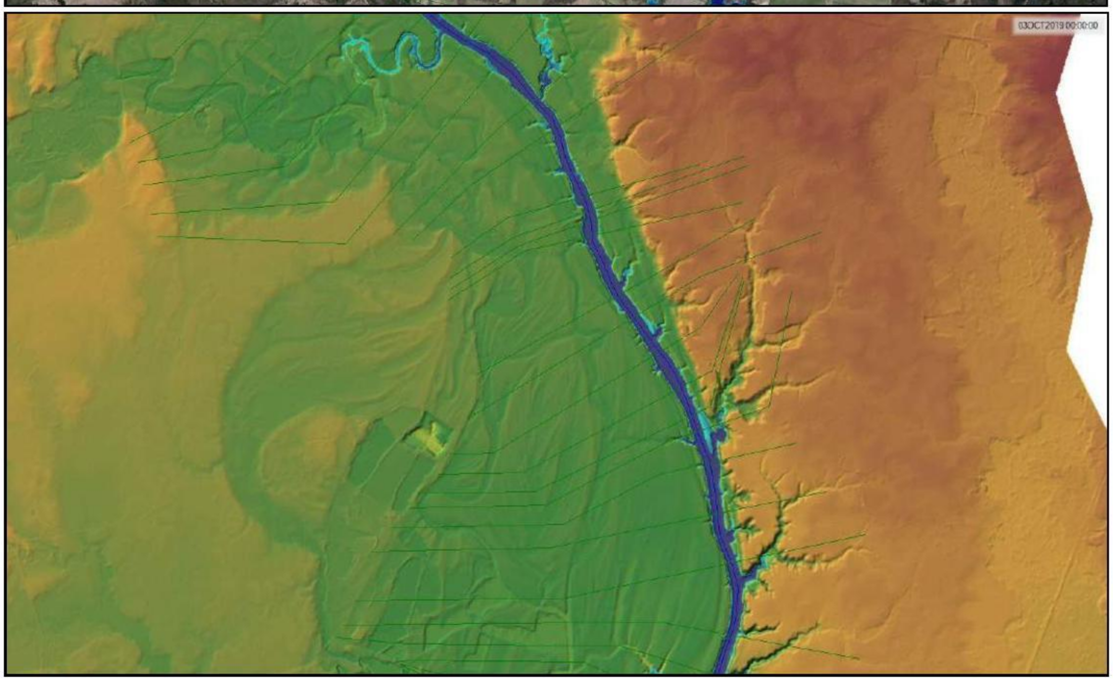
REACH 2 – INUNDATION AT 40,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



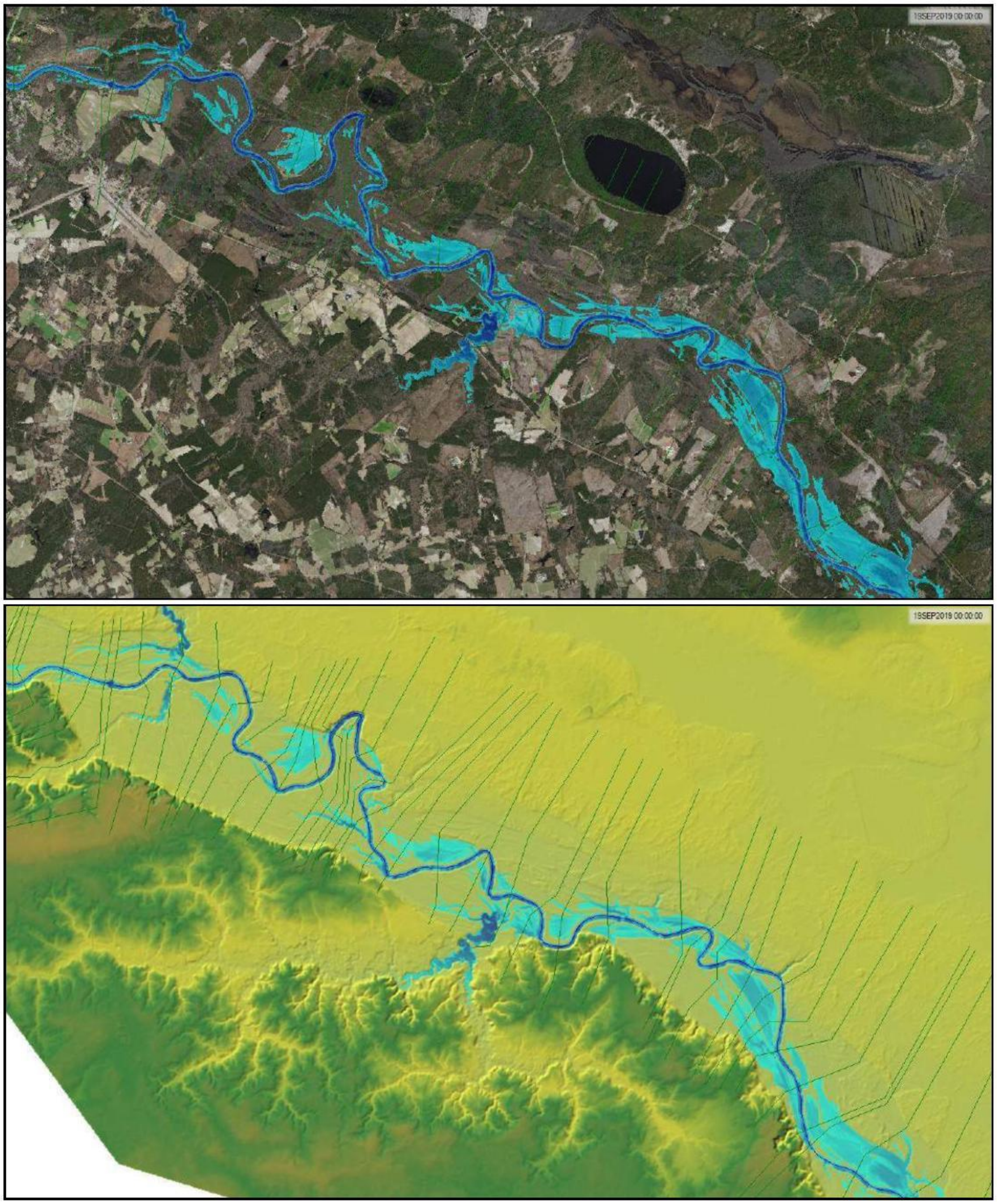
REACH 2 – INUNDATION AT 50,000 CFS

REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3

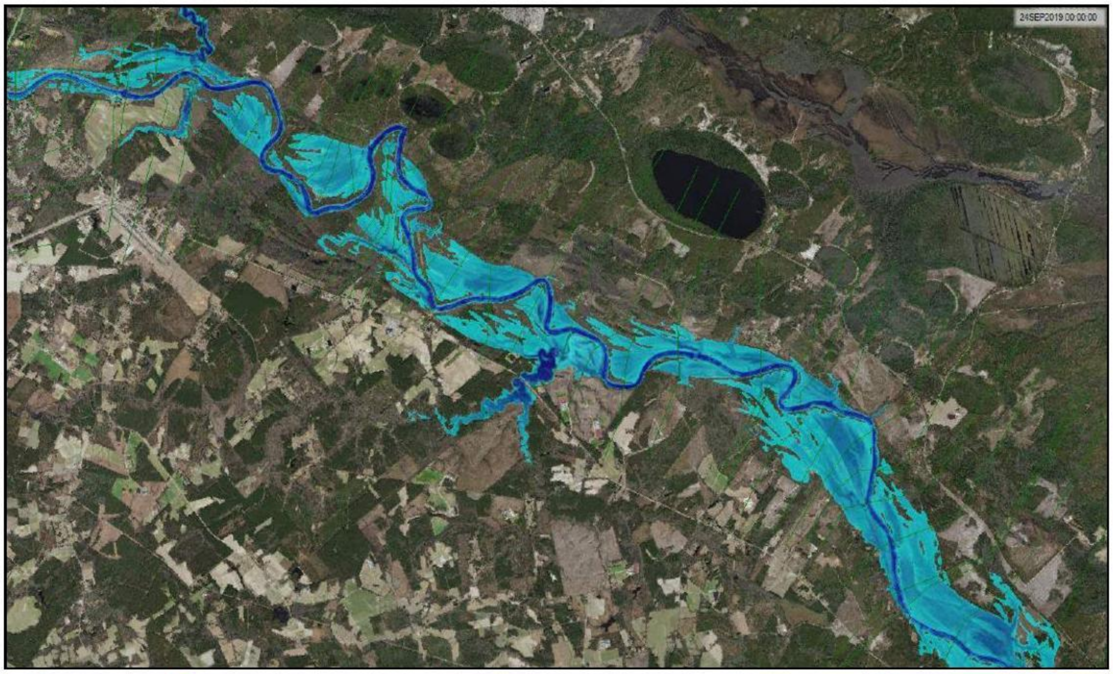
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM

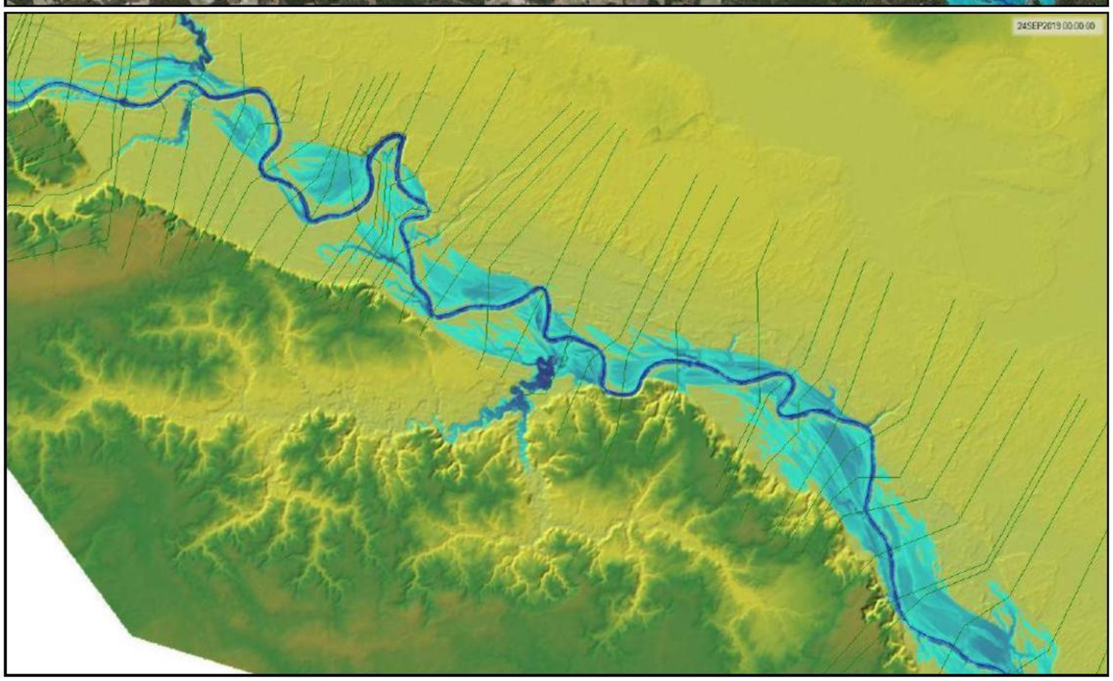


REACH 2 – INUNDATION AT 60,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM

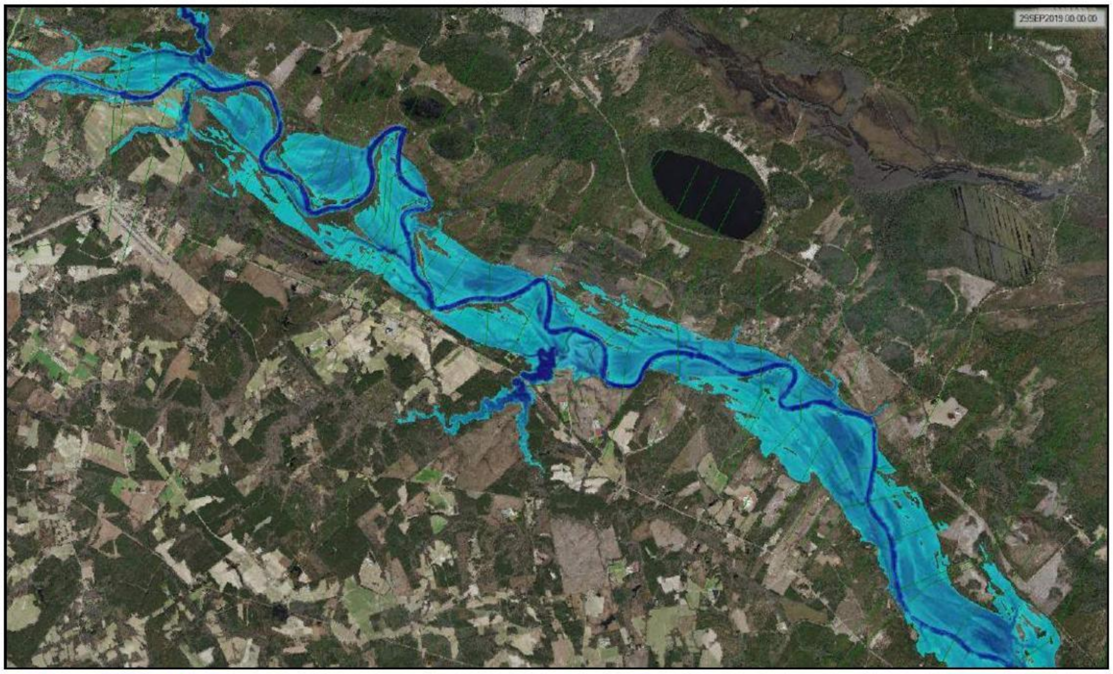


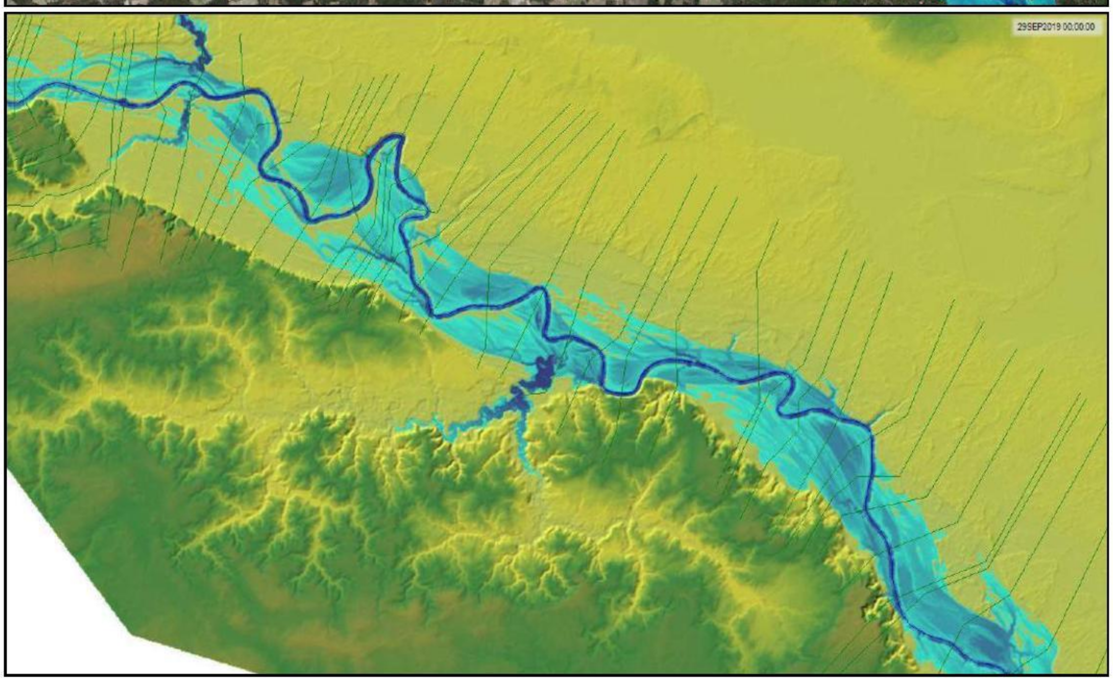
REACH 3 – INUNDATION AT 30,000 CFS
REACH 3 IS LOCATED BETWEEN LOCK AND DAM 3 AND LOCK AND DAM 1
REPRESENTATIVE LOCATION IS APPROX 90 RIVER MILES DOWNSTREAM OF JORDAN DAM



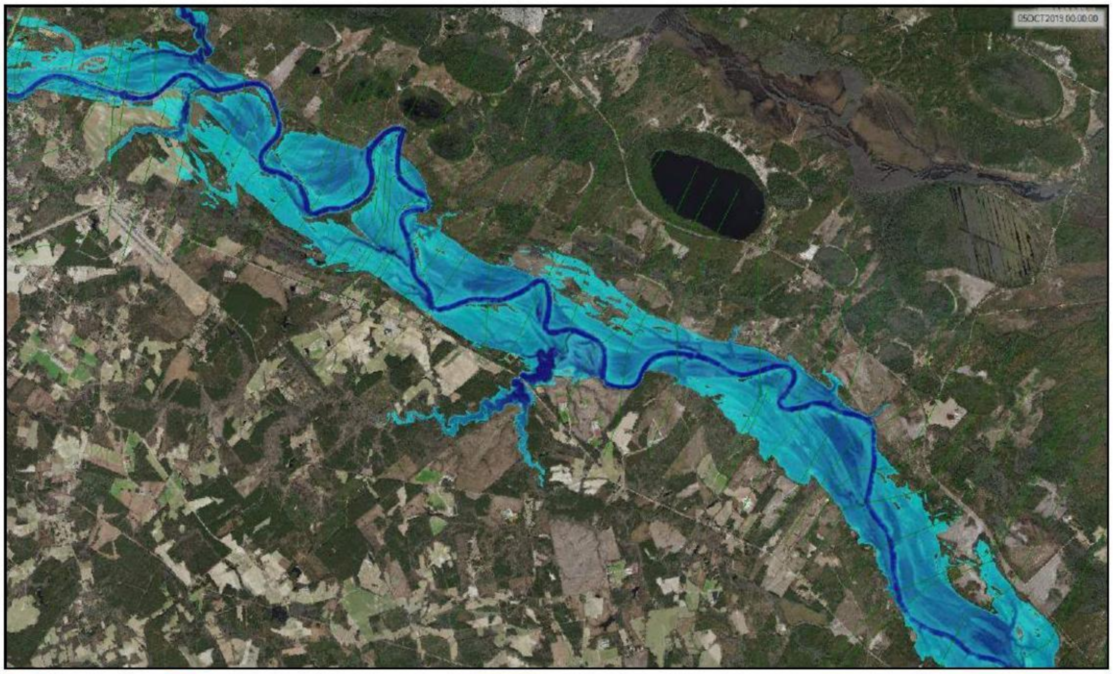


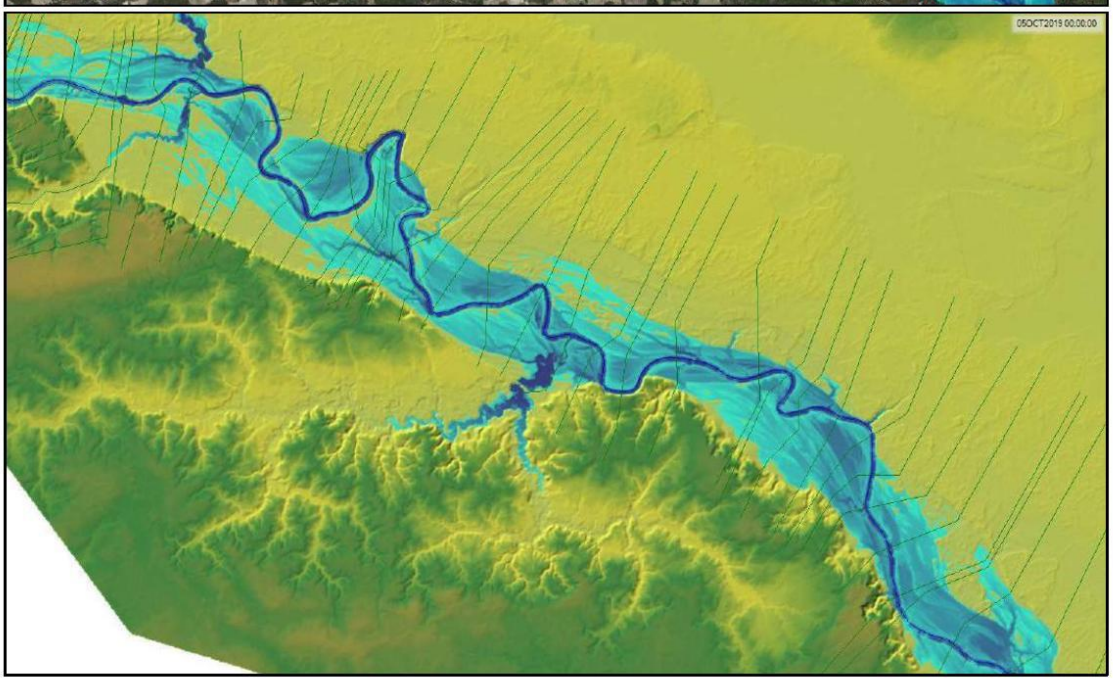
REACH 3 – INUNDATION AT 40,000 CFS
REACH 3 IS LOCATED BETWEEN LOCK AND DAM 3 AND LOCK AND DAM 1
REPRESENTATIVE LOCATION IS APPROX 90 RIVER MILES DOWNSTREAM OF JORDAN DAM





REACH 3 – INUNDATION AT 50,000 CFS
REACH 3 IS LOCATED BETWEEN LOCK AND DAM 3 AND LOCK AND DAM 1
REPRESENTATIVE LOCATION IS APPROX 90 RIVER MILES DOWNSTREAM OF JORDAN DAM





REACH 3 – INUNDATION AT 60,000 CFS
REACH 3 IS LOCATED BETWEEN LOCK AND DAM 3 AND LOCK AND DAM 1
REPRESENTATIVE LOCATION IS APPROX 90 RIVER MILES DOWNSTREAM OF JORDAN DAM

Appendix E: Water Year Type Determination Explanation

Water year type determination for
Cape Fear River Basin e-flows Workshop

September 4, 2019

This workshop aims to develop flow recommendations by evaluating how management affects flows under a variety of conditions. To aid in visualizations with RPT software for group discussions, we defined Wet, Average, and Dry years with the Cape Fear River Watershed. Our goal was to identify representative year types over the period of record.

We used the entire period of record available from USGS for the Cape Fear River at Lillington (1924-2019) as the basis of a statistical analysis to rank years according to mean daily flow. To ensure that the year type assignment reflected seasonal as well as interannual variation, we conducted the ranking assessment for the following temporal periods for each water year (October 1 - September 30):

- Entire water year (October 1 - September 30),
- Winter season (January 1 - March 31),
- Early growing season (April - 1 - July 31), and
- Tropical storm season (August 1 - September 30, October was excluded given that this is part of the next water year).

For each temporal period, we assigned the year types as follows:

- Wettest 25% --> 'Wet' (W)
- Driest 25% --> 'Dry' (D)
- All other years --> 'Average' (A)

We then assigned an overall water year type taking into account all four analysis windows, according to the following rules:

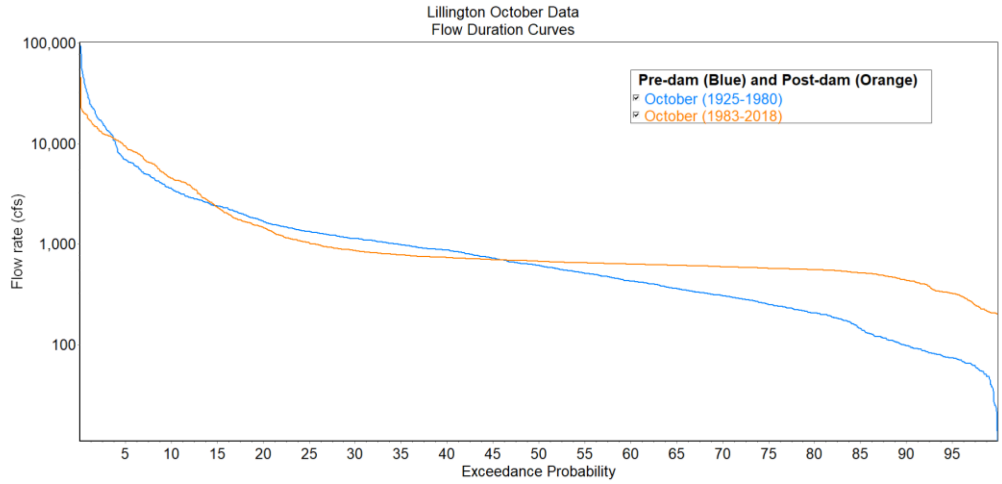
- If the type was consistent across all periods, that year was assigned that type
  - (e.g., DDDD --> 'Dry').
- If the type was consistent across 3/4 periods and the anomalous type was only off by one state level, the year was assigned the majority type.
  - (e.g., DDDA --> 'Dry', WWWA --> 'Wet')
- Other years were considered to be ambiguous and were omitted from assignment.
  - (e.g., 2007 was AADD, yet this was a year with pronounced drought, 1999 was DDDW due to Hurricane Floyd making landfall in the tropical storm season).

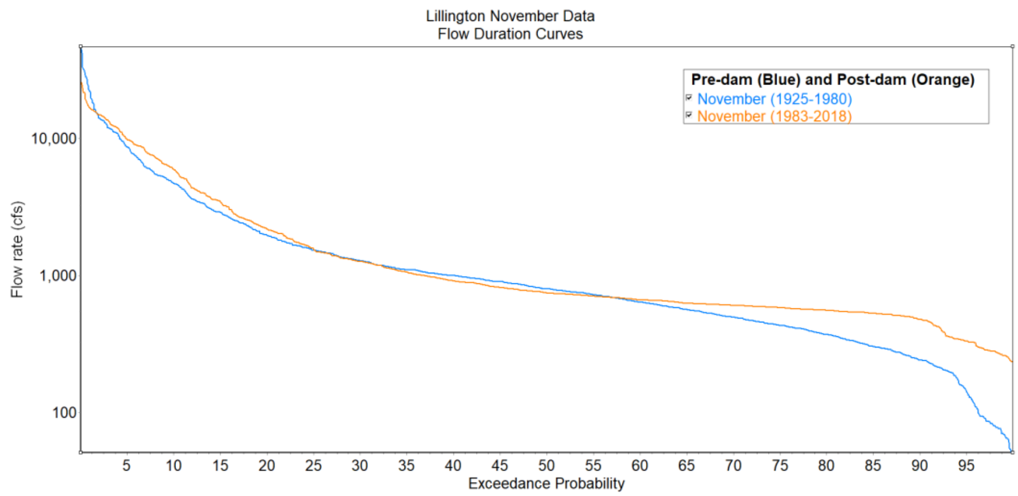
Due to RPT limitations for efficient on-the-fly hydrograph drawing, we limited the year type assignments that are represented in RPT for this workshop to 1979 (when construction of Jordan Dam occurred) to 2018. As data are currently incomplete for water year 2019, it was not included in the year assignement. For the 29 years of data considered, 7 years were assigned as 'Wet', 11 were assigned as 'Average', 11 were assigned as 'Dry' and 10 years were left undefined.

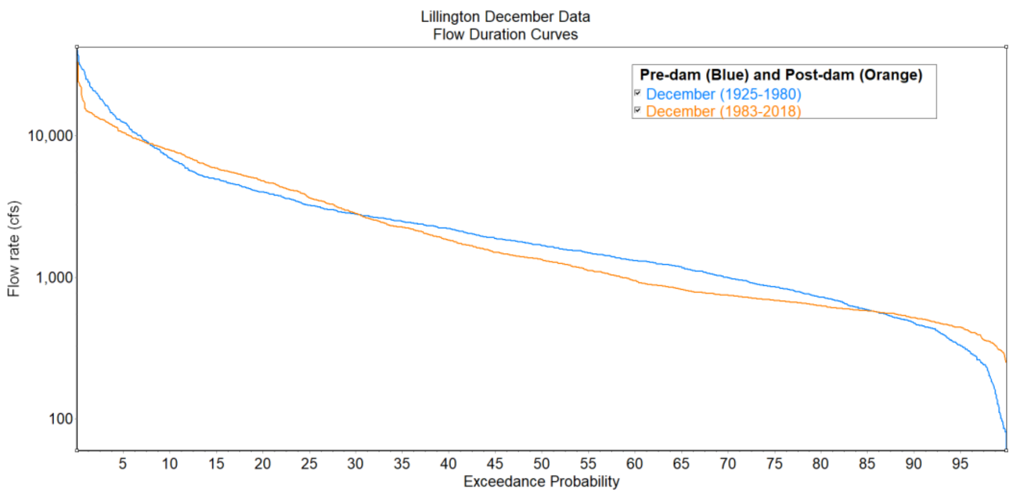
To assess whether the Lillington gage, which is centrally located in the Cape Fear River Basin, represented conditions adequately, we compared the year assignments to those generated from gages at Bynum and Lock and Dam 1. We determined that the Lillington gage is representative given that year types agreed across sites in all but 5 of 40 years considered.

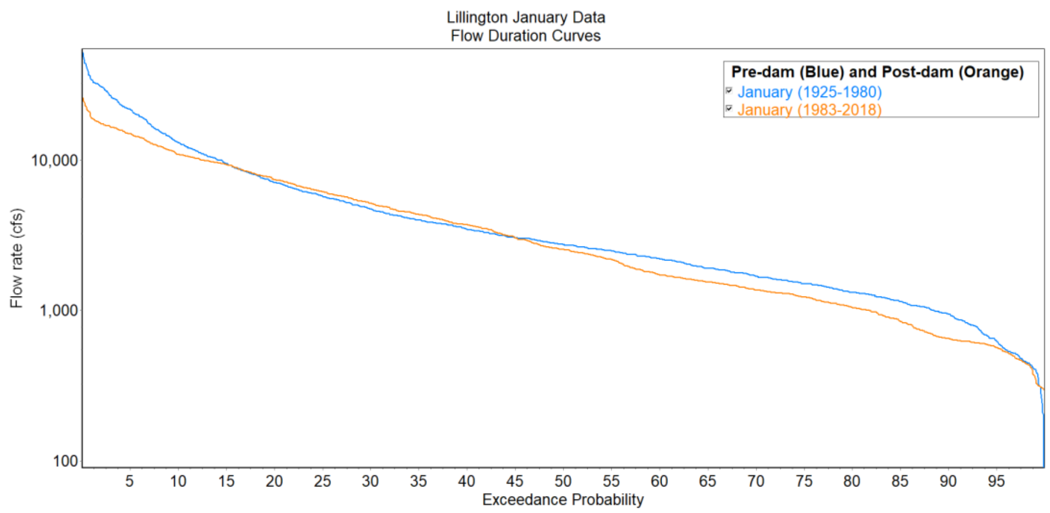
Appendix F: IHA Flow Duration Curves

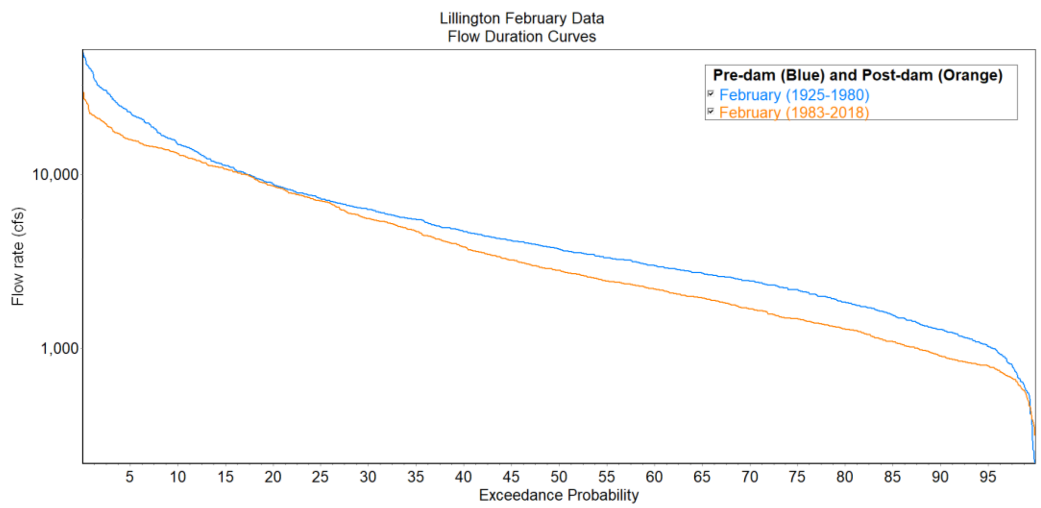
Lillington Gage:

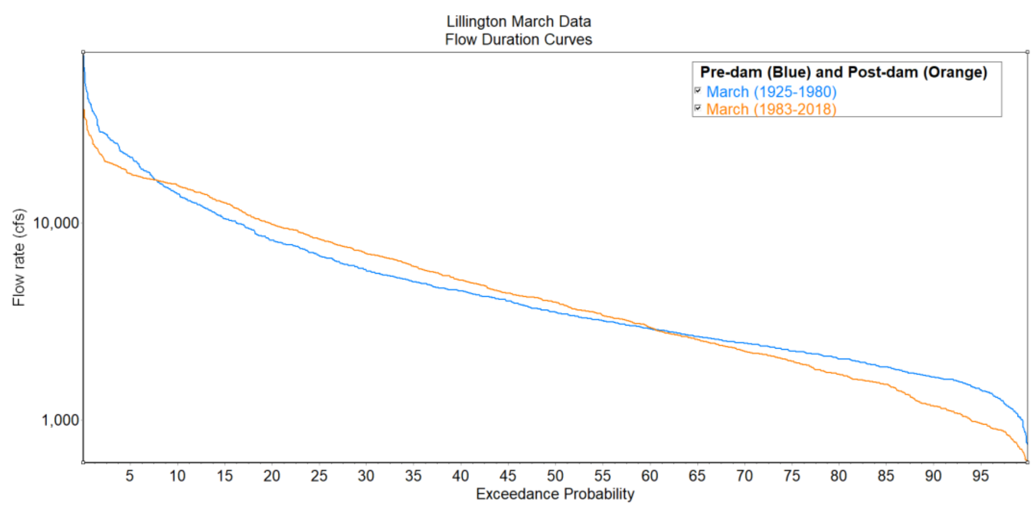


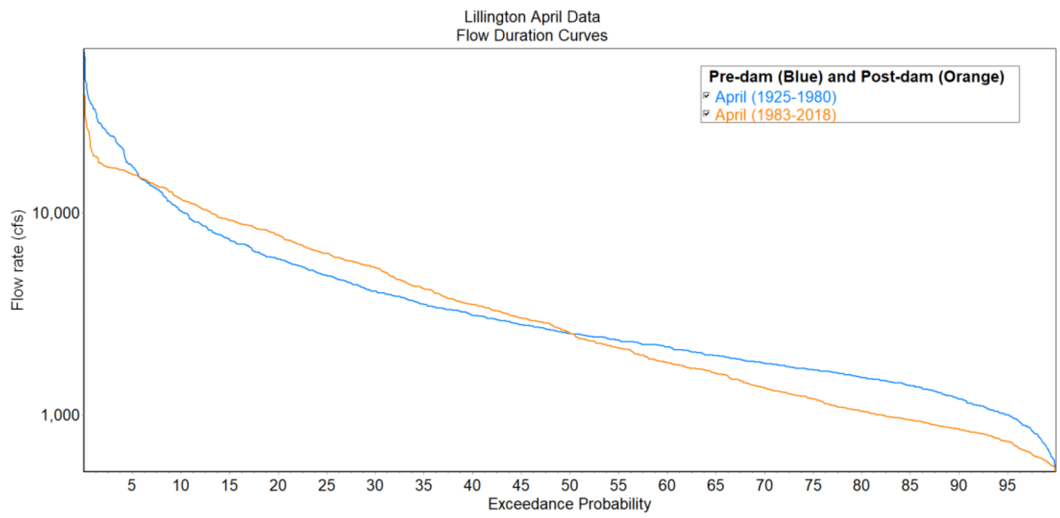


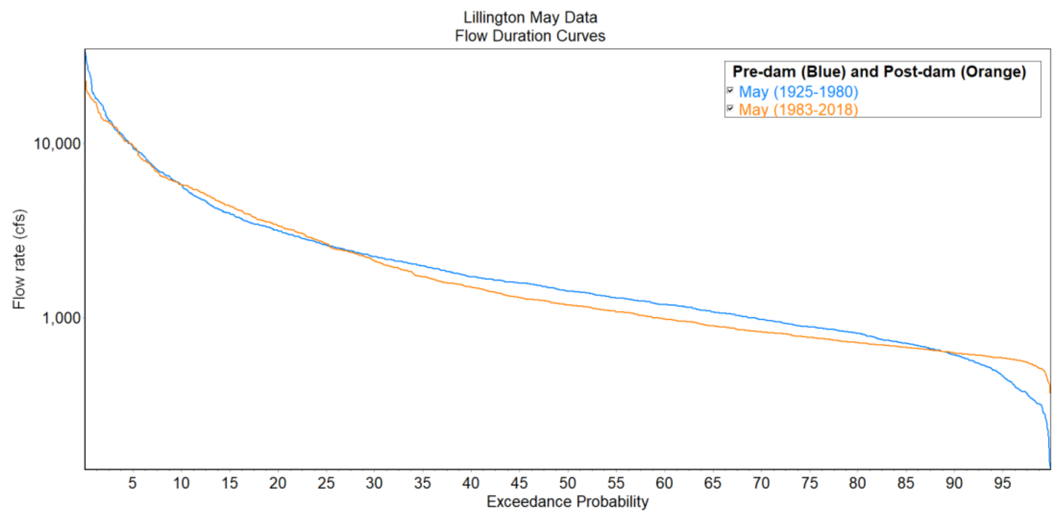


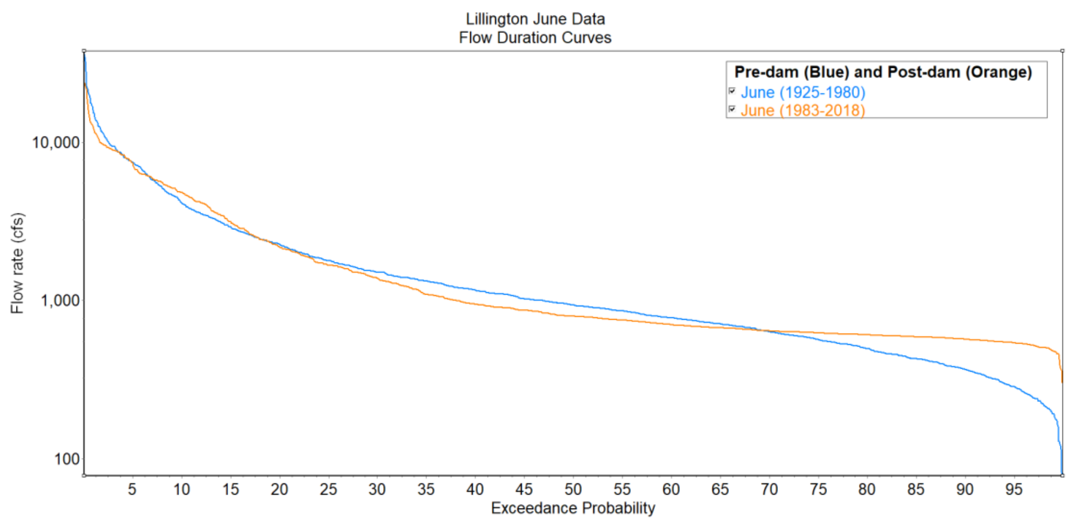

Lillington January Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
January (1925-1980)
January (1983-2018)
Flow rate (cfs)
10,000
1,000
100
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

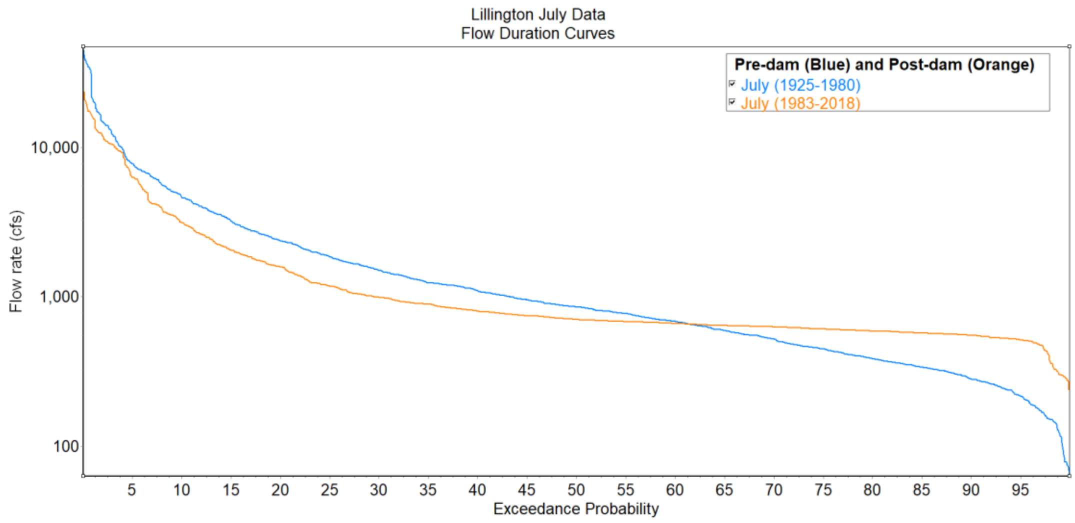

Lillington February Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
February (1925-1980)
February (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

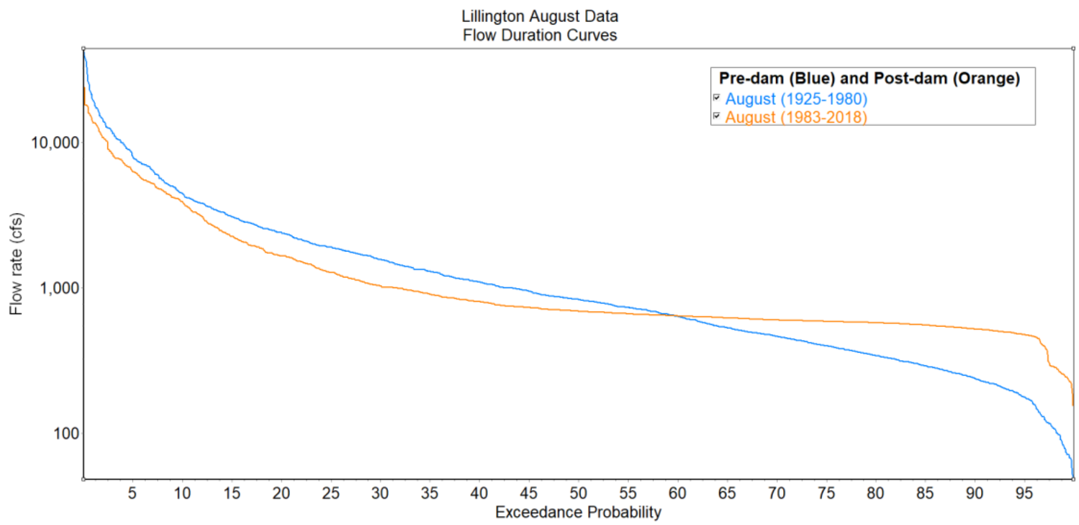

Lillington March Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
March (1925-1980)
March (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

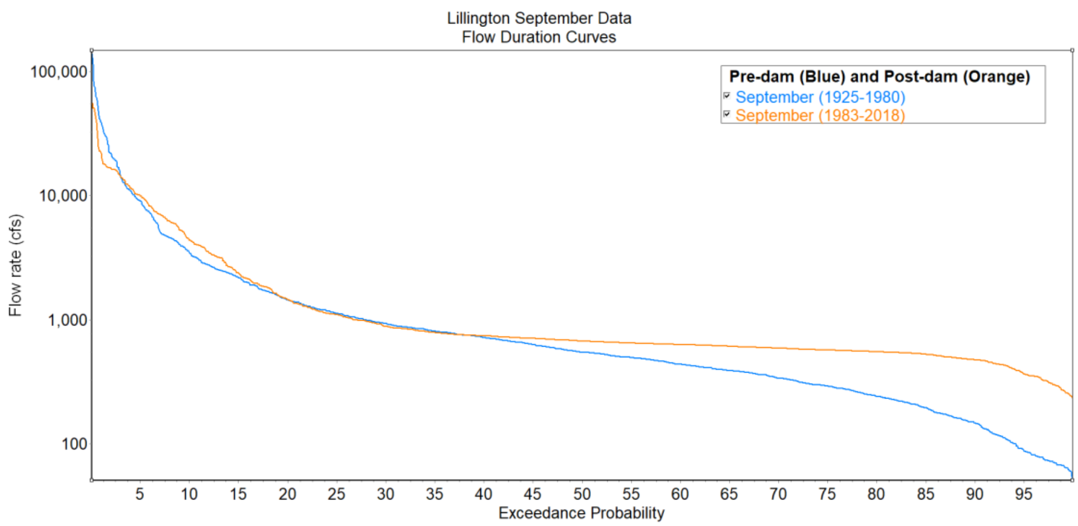

Lillington April Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
April (1925-1980)
April (1983-2018)
10,000
1,000
Flow rate (cfs)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

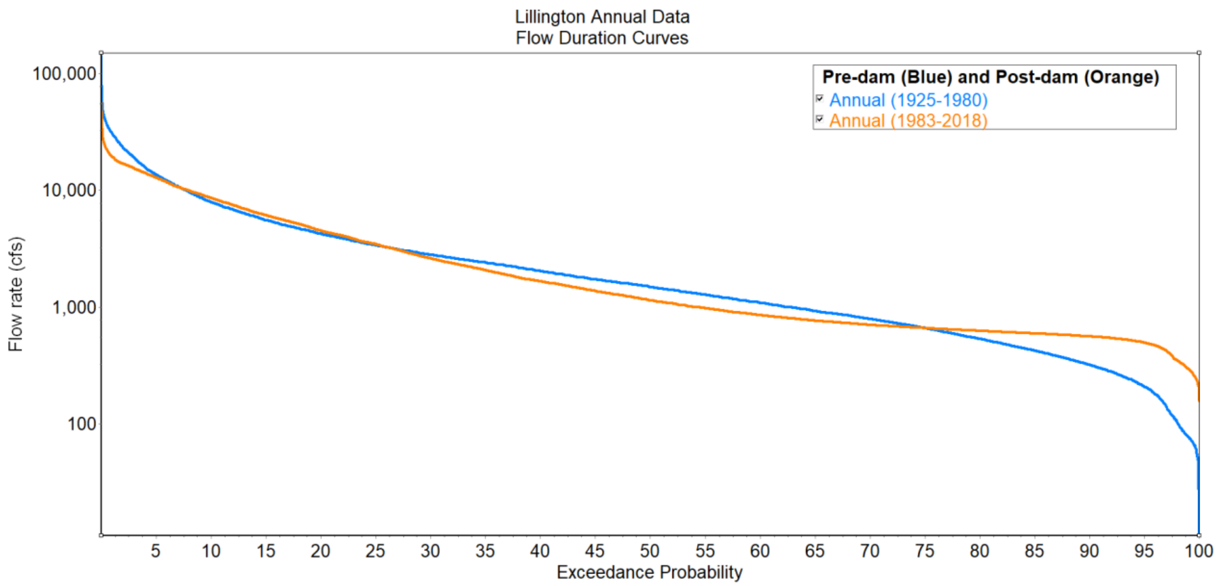

Lillington May Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
May (1925-1980)
May (1983-2018)
10,000
1,000
Flow rate (cfs)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability


Lillington June Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
June (1925-1980)
June (1983-2018)
10,000
1,000
100
Flow rate (cfs)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

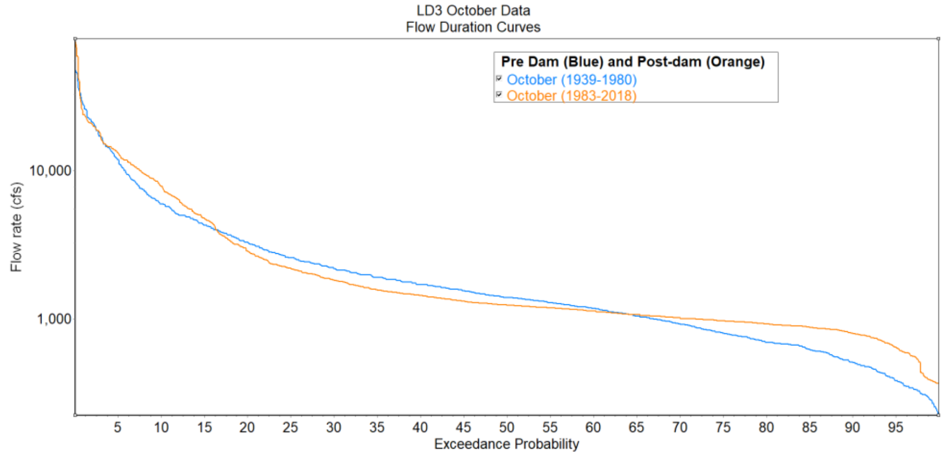

Lillington July Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
July (1925-1980)
July (1983-2018)
Flow rate (cfs)
10,000
1,000
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

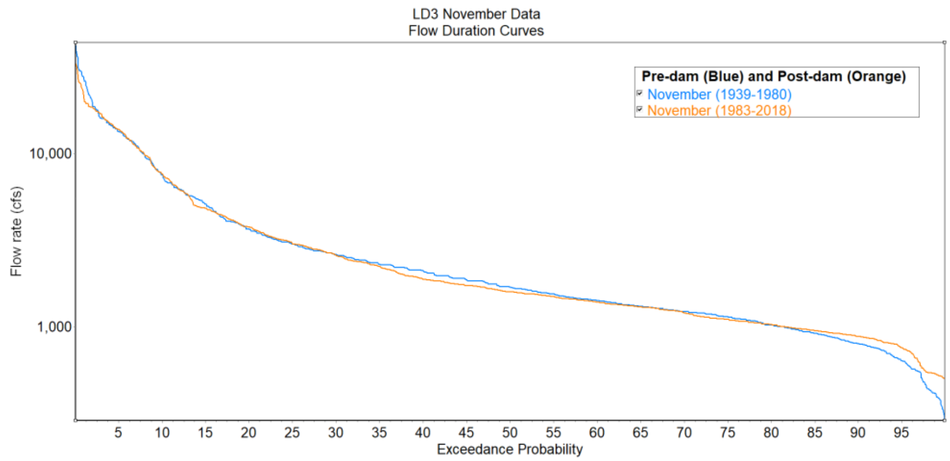

Lillington August Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
August (1925-1980)
August (1983-2018)
Flow rate (cfs)
10,000
1,000
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

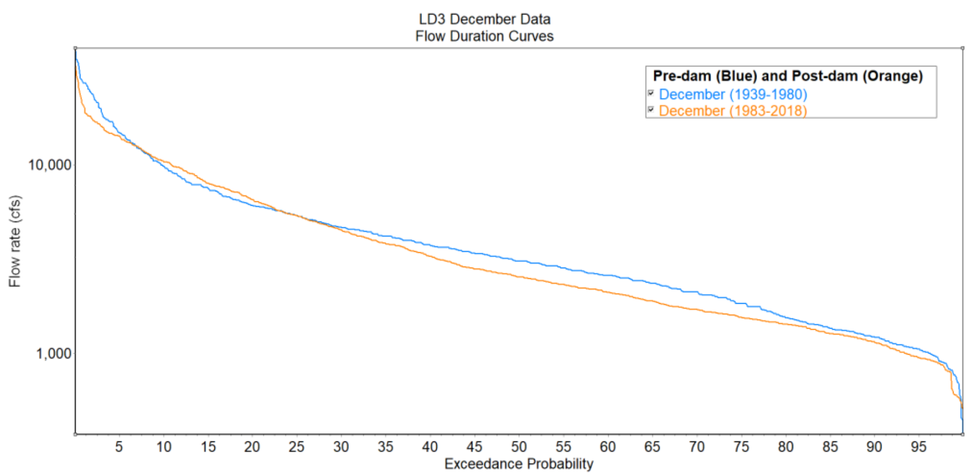

Lillington September Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
September (1925-1980)
September (1983-2018)
Flow rate (cfs)
100,000
10,000
1,000
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

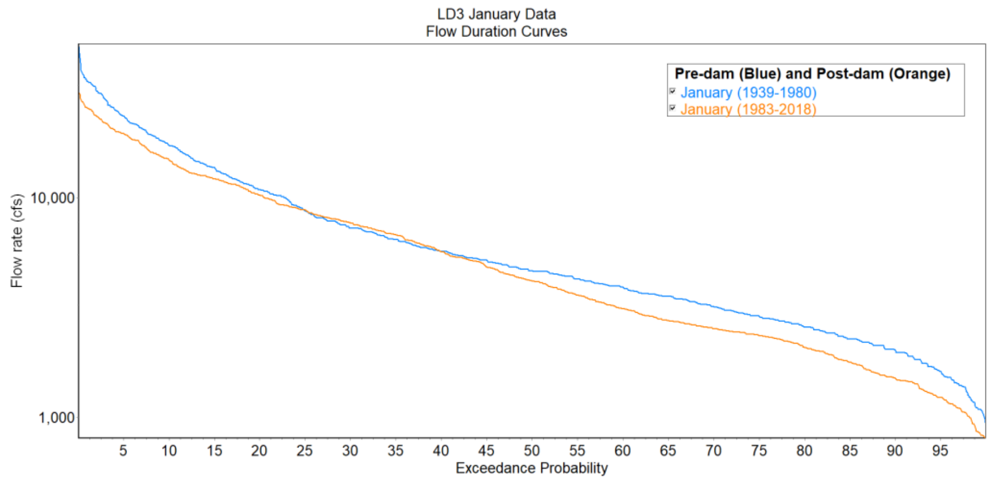

Lillington Annual Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
Annual (1925-1980)
Annual (1983-2018)
100,000
10,000
1,000
100
Flow rate (cfs)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Exceedance Probability

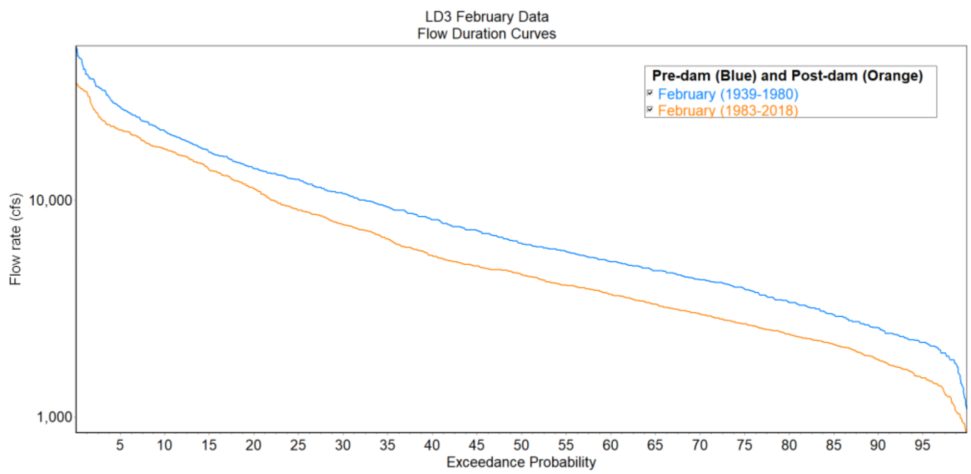
LD3 Gage

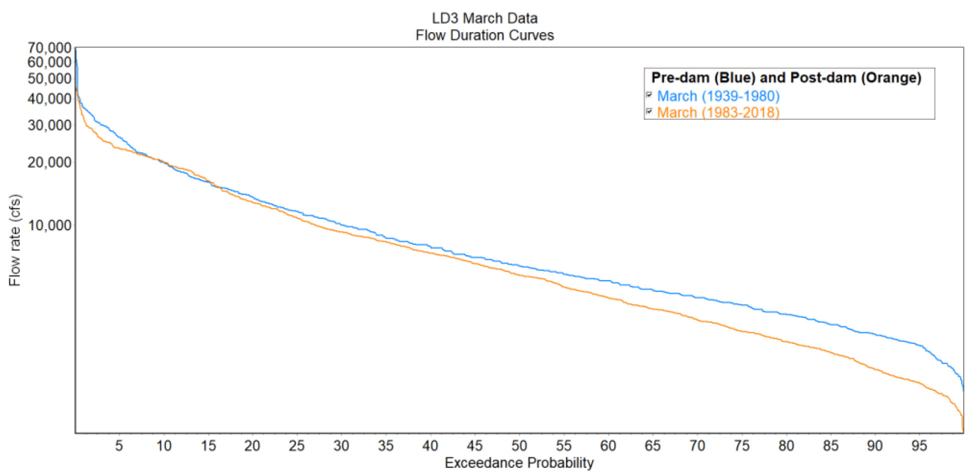

LD3 October Data
Flow Duration Curves
Pre Dam (Blue) and Post-dam (Orange)
October (1939-1980)
October (1983-2018)
10,000
1,000
Flow rate (cfs)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

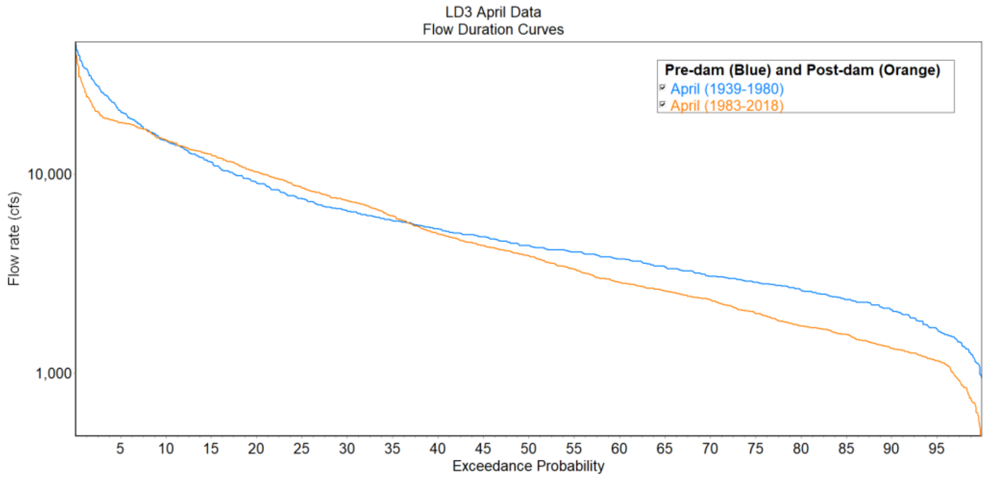

LD3 November Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
November (1939-1980)
November (1983-2018)
10,000
1,000
Flow rate (cfs)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

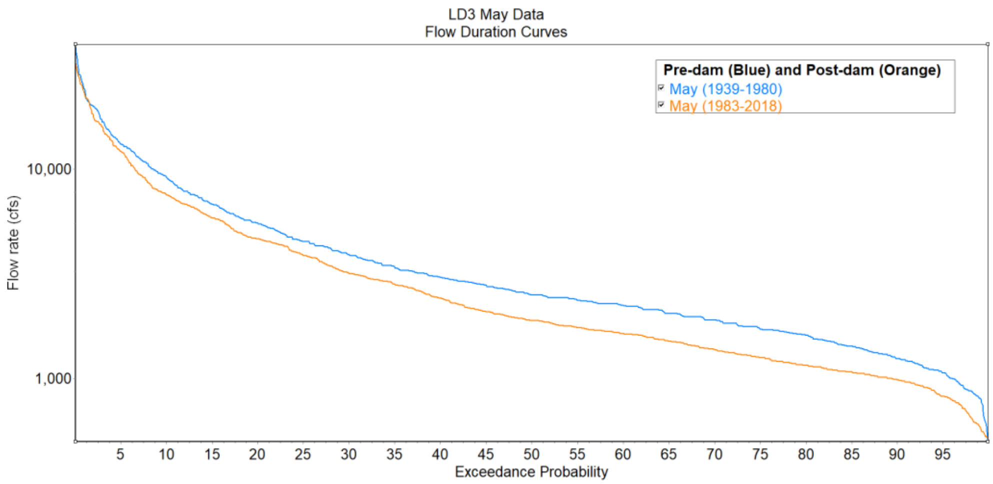

LD3 December Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
December (1939-1980)
December (1983-2018)
10,000
1,000
Flow rate (cfs)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

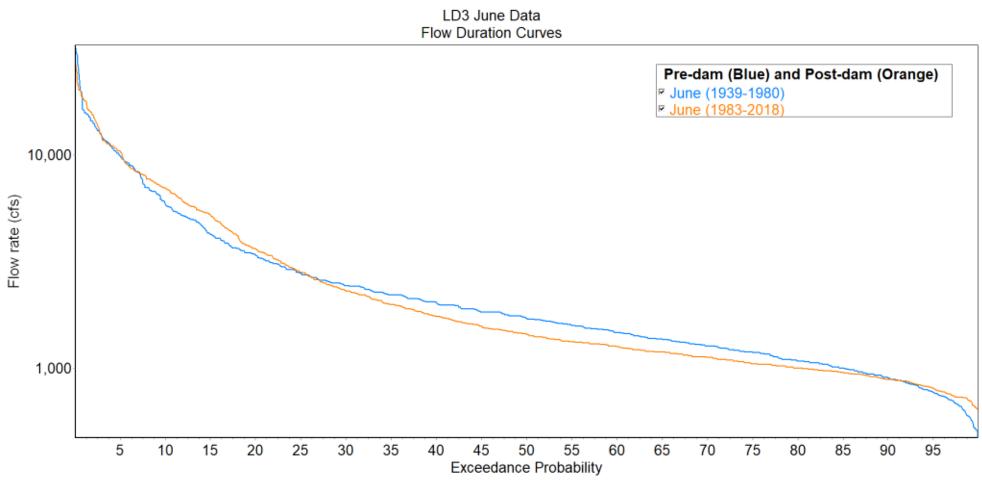

LD3 January Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
January (1939-1980)
January (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

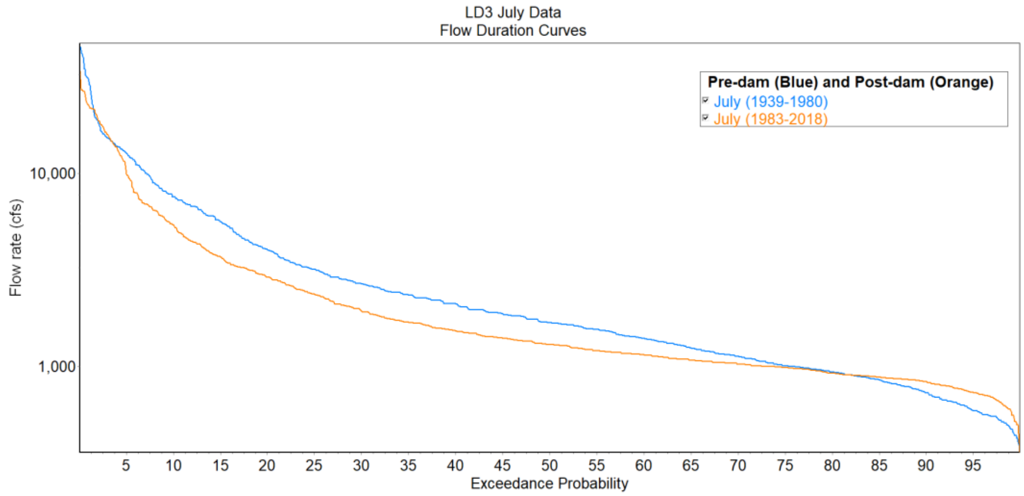

LD3 February Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
February (1939-1980)
February (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

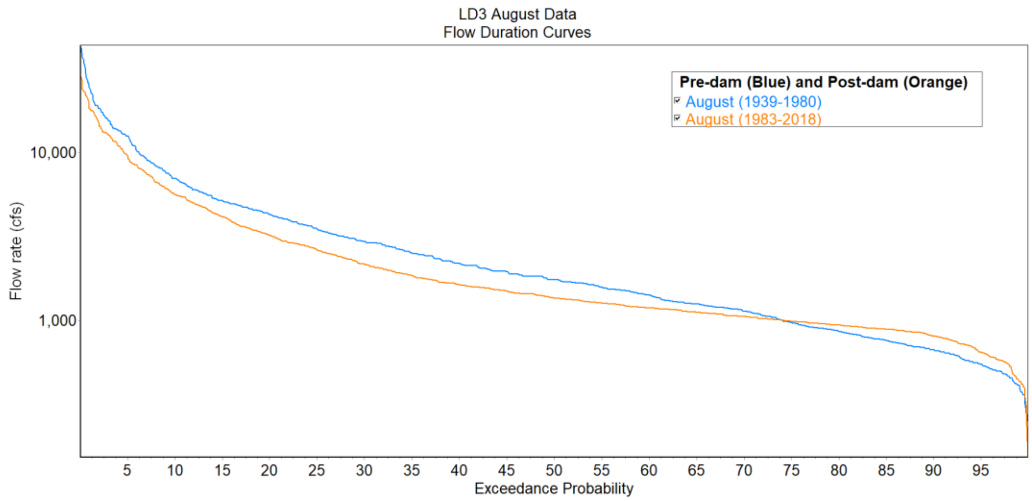

LD3 March Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
March (1939-1980)
March (1983-2018)
Flow rate (cfs)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

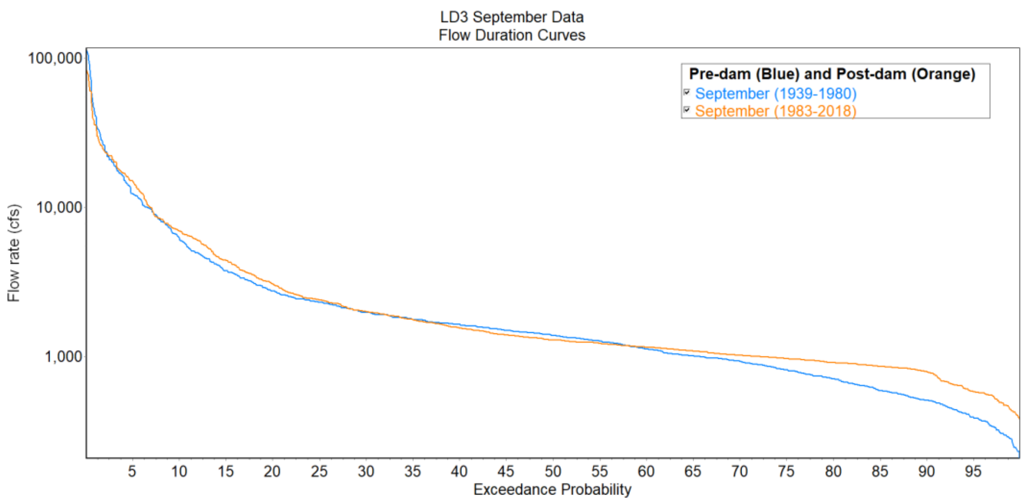

LD3 April Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
April (1939-1980)
April (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability

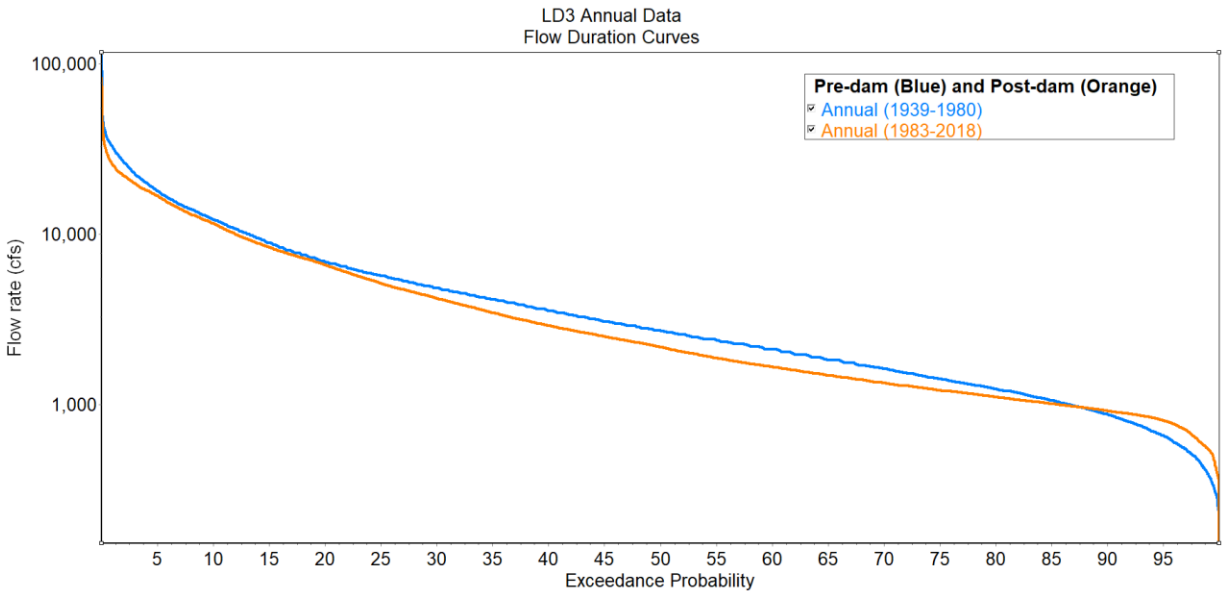

LD3 May Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
May (1939-1980)
May (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability


LD3 June Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
June (1939-1980)
June (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability


LD3 July Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
July (1939-1980)
July (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability


LD3 August Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
August (1939-1980)
August (1983-2018)
Flow rate (cfs)
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability


LD3 September Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
September (1939-1980)
September (1983-2018)
Flow rate (cfs)
100,000
10,000
1,000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Exceedance Probability


LD3 Annual Data
Flow Duration Curves
Pre-dam (Blue) and Post-dam (Orange)
Annual (1939-1980)
Annual (1983-2018)
100,000
10,000
1,000
Flow rate (cfs)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Exceedance Probability

Appendix G: Fish break-out group findings

The follow pages detail the Fish break-out group findings to include:

- Process
- General prescription goals for each year
- Flow prescriptions for fish by reach
  - Reach 3
  - Reach 2
  - Reach 1
- Research and modeling needs from the fish team

The fish team was tasked to create flow recommendations for the suite of diadromous fish (American eel, American and hickory shad, Atlantic and shortnose sturgeon, Striped bass) as well as rare resident fish like the Cape Fear Shiner. Flow recommendations considered spawning cues, migration needs, access to back floodplains, flow needs for shaping appropriate spawning substrates, flow needs for egg development, juvenile success, adult habitat, all life-stage food supplies, temperature needs, and flow levels that support good water quality. The group convened and decided that flow prescriptions would broadly consider amphibians and mussels. It was acknowledged that additional consultation should occur with amphibian experts post-workshop. TNC consulted an amphibian expert to help complete the flow prescriptions.

Process

The group was tasked with starting their flow prescription for Reach 3, from LD3 to LD1. Collectively, the group decided to start with a wet year, followed by a dry year. During the flow prescriptions, the group relied on IHA analysis of pre- and post- Jordan Dam effects at the USGS gages located at LD1 and LD3. Specifically, the pre-dam flow duration curves were used to estimate baseflows (more description below).

At the end of the group break-out time, the fish team collectively finished Reach 3 wet and dry. This write-up will follow that order. After the workshop, TNC consulted with workshop attendees and drafted Reach 3 average, as well as Reach 1 wet, dry and average. While Reach 2, from Lillington to LD3, is the most important in-stream habitat for diadromous fish (where the coastal plain switches to the Piedmont and spawning occurs), it was acknowledged that it would require a high flow to create overbank flow conditions. The prescriptions for Reaches 3 and 1 should be sufficient for Reach 2.

General prescription goals for each year

The life stages of fish and mussels were considered in crafting ecological operational windows. While the number of pulses or magnitude of the pulses might differ between a wet year, dry year, normal year, or reach of the river, the Fish Team stayed consistent on necessarily hydrologic needs during certain parts of the year for fish needs. These include:

Winter Run of River: As much as possible, the best hydrology for fish would be a run of river situation. Overbank flow is fine if it helps with floodplain health.

Amphibian floodplain filling: The Fish team made a note to consult with amphibian experts, and TNC did this post-workshop. In the late winter, a few overbank events would likely help fill vernal pools for amphibians and recharge groundwater. The predominant salamander in the floodplains of the Cape Fear is the Marbled salamander. It lays eggs in October on mostly dry ground. Water enters the floodplains and fills the vernal pools throughout the winter to help wet the eggs and prepare them for hatching. Salamanders, as well as some frogs, would benefit from overbank flow in December and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years.

Anadromous Early Spring Spawn: Many fish spawn from March-May. The fish team wanted flows to include pulses of 20k CFS. Expert opinion in the group thought 20k CFS would provide adequate flow over lock and dams to allow fish passage over LD1, LD2 and LD3. In the early spring, the team was okay if there was overbank flow.

Late Spring Spawn- There are still several species of fish that are migrating upstream to spawn in the late spring, especially striped bass and shad. Yet, there are also fish that have already spawned. In order to not strand eggs or juveniles, the fish team did not want to promote overbank flow by late April. Yet, the team still wanted to get fish over the locks and dams. The team estimates that 3-5k CFS helps fish use the rock ramp on LD1. While needing refinement on the exact CFS numbers, the group estimated that 20-25k CFS would promote fish over LD2 and LD3, but keep water within the banks of the river.

Egg/ Juvenile Transport: The team wanted small, gently rising and falling pulses throughout the summer to push fry and juvenile downstream and back over the locks and dams. Flows that are too slow will strand eggs behind the locks and dams. Yet, too much water can push the juveniles too fast. An upper limit of 10k CFS was chosen for the pulses because the team did not want to flush fish that spawned near LD1 into the ocean too fast. Most pulses ranged from 1-5k CFS.

Atlantic Sturgeon Fall Spawn: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. The exact spawning cue for the Fall-spawning sturgeon is not known. The fish team requested a pulse of 20k CFS to provide adequate flow over lock and dams to promote sturgeon to the upstream location near Smiley Falls. This request decreased if it was a low flow year.

Low flows/ baseflow: To craft "low flows" in RPT, which are essentially baseflows, the fish team relied on IHA analyses and flow-duration curves (Appendix F). The team relied on pre-dam data, figuring that pre-dam conditions represented more of the natural hydrograph. For wet years, the team used the 25th percentile flow values. The team used the 18th percentile flow values in average years and the 10th percentile flow values for dry years. Due to the minimum flow at Lillington of 600 CFS, any flow below 750 CFS was increased to 750 CFS (the group assumed a multiplier of 1.5 between reaches). These numbers were generated from the USGS gage information at LD3 for Reach 3. These numbers were generated from the USGS gage information at Lillington for Reach 1.

Flow prescriptions for fish by reach

Reach 3**:**

The team collectively finished Reach 3 Wet and Dry in the workshop. Post-workshop, TNC talked to several experts to refine the flow prescription and to finish the Average water year flow prescription.

Fish, Reach 3, Wet:

The fish team finished Reach 3 Wet during the workshop. Experts were consulted after the workshop to refine details of the prescription (Figure 4).

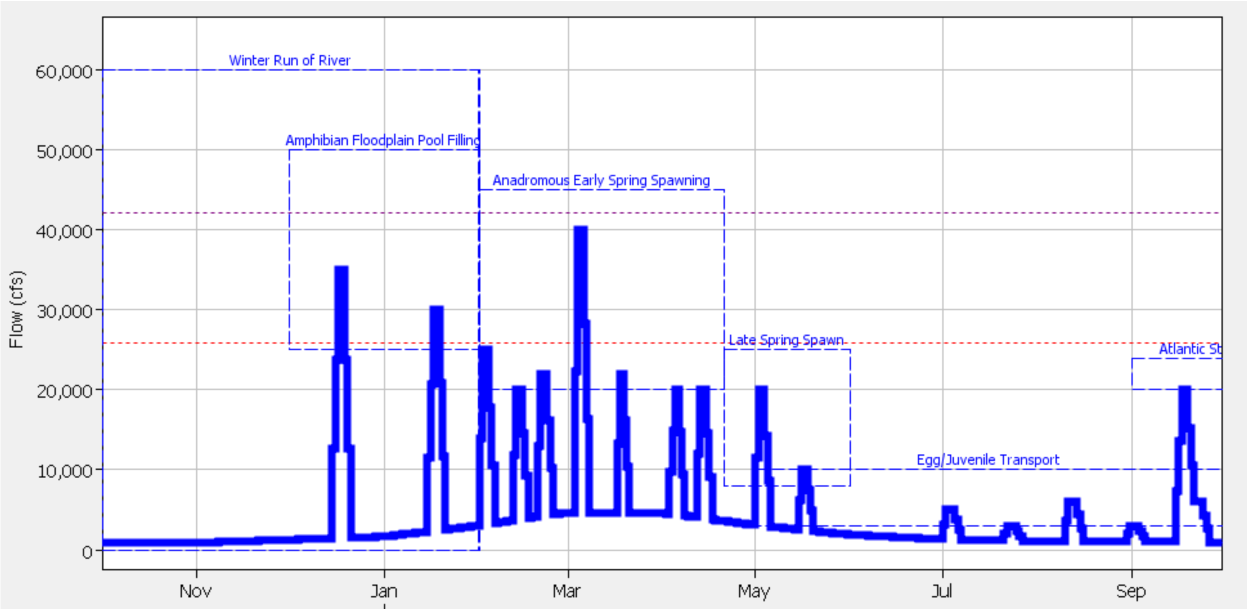


Figure 4. Flow prescription for Fish, Reach 3 Wet. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter Run of River (Fish, Reach 3, Wet): Winter is often the wettest time of year for Cape Fear flows. Fish and wildlife would benefit most from a run of river situation.

Season: 01Oct to 31Jan
Events per season: Run of river
Magnitude: 0-60,000 CFS (or the corresponding run of river condition)
Duration: Simulate natural variability
Duration of peak: Simulate natural variability

Purpose. Allow natural variability and promote the natural hydrograph to support the life cycle of aquatic organisms.

Description: The fish team did not dictate specific floods tied to ecology, but thought the natural variability of water movement in the winter would promote the general needs of aquatic organisms.

Amphibian Floodplain Filling (Fish, Reach 3, Wet):
Season: 01Dec to 31Jan
Events per season: 1-2 overbank flow events every 2 years (of approximately 30,000 CFS)
Magnitude: 25,000-50,000 CFS
Duration: ~6 days with a slow rise and fall
Duration of peak: ~2 days with a slow rise and fall
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)

15-Dec	6	35,000	2
15-Jan	6	30,000	2

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: Salamanders and frogs would benefit from overbank flow in December and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years.

Anadromous Fish Early Spring Spawn (Fish, Reach 3, Wet):
Season: 01Feb to 20Apr
Events per season: 2-3 each month for ~7 events
Magnitude: 20,000-45,000 CFS
Duration: 4-5 days
Duration of peak: 1-2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Feb	5	25,000	2
12-Feb	5	20,000	2
20-Feb	5	22,000	2
3-Mar	5	40,000	2
17-Mar	4	22,000	1
3-Apr	5	20,000	1
12-Apr	5	20,000	2

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: In a wet year, the Fish team hoped for multiple pulses of 20,000 CFS or more. The team assumed that 20,000 CFS was a threshold for LD2 and LD3 to be adequately submerged to promote fish passage. Overbank flow is fine at this time of the year. If deciding between a bigger magnitude pulse or more smaller pulses, the Fish team would prefer more fish pulses of 20,000 CFS.

Late Spring Spawn (Fish, Reach 3, Wet):
Season: 21Apr to 31May
Events per season: 2
Magnitude: 8,000-25,000 CFS
Duration: 5 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)

1-May	5	20,000	2
15-May	5	10,000	2

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: Striped bass and shad still spawn into late May. Yet, other species have already gone upstream and spawned. As of mid-April, the fish team did not want overbank flow because this could strand eggs and juveniles in the floodplains. If the Corps is still locking at the LDs, even pulses of 8,000 CFS should signal striped bass and shad to go upstream. Ideally, these pulses would be between 20,000-25,000 CFS. At this range, the group thinks LD2 and LD3 would be adequately submerged and yet there is no overbank flow.

Egg/ Juvenile Transport (Fish, Reach 3, Wet):
Season: 01May to 30Sep
Events per season: 5
Magnitude: 3,000-10,000 CFS
Duration: 6 days
Duration of peak: 3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	6	5,000	3
21-Jul	6	3,000	3
10-Aug	6	6,000	3
30-Aug	6	3,000	3
20-Sep	6	6,000	3

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The team wanted small, gently rising and falling pulses throughout the summer to push fry and juvenile downstream and back over the locks and dams. Flows that are too slow will strand eggs behind the locks and dams. Yet, too much water can push the juveniles too fast. An upper limit of 10,000 CFS was chosen for the pulses because the team did not want to flush fish that spawned near LD1 into the ocean too fast. The team did not want overbank flow at this time of year because that could strand fish. Most pulses ranged from 3,000-6,000 CFS. This operational window overlaps with the Late Spring Spawn and the Atlantic Sturgeon Spawn. If flows are promoted higher than 10,000 CFS for other ecological reasons, it is best to have a gentle rise and fall.

Atlantic Sturgeon Fall Spawn (Fish, Reach 3, Wet):
Season: 01Sep to 31Oct
Events per season: 1
Magnitude: 20,000-24,000 CFS
Duration: 7 days

Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	7	20,000	2

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The fish team requested a pulse of 20,000 CFS to provide adequate flow over lock and dams to promote sturgeon to the upstream location near Smiley Falls.

Low flows (Fish, Reach 3, Wet):

The fish team used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In a wet year, flows were chosen as the 25th percentile flow values by month.

Date	Flow (CFS)
31-Oct	870
30-Nov	1,250
31-Dec	1,640
31-Jan	3,000
28-Feb	4,600
31-Mar	4,600
30-Apr	3,100
31-May	1,900
30-Jun	1,300
31-Jul	1,100
31-Aug	1,100
30-Sep	940

Fish, Reach 3, Average:

TNC worked with experts after the workshop to draft this flow prescription. The reach 3 wet year was the starting point for the reach 3 average year prescription and magnitudes and durations were reduced. The low flow boxes in RPT were changed to the 18th percentile flow values from pre-dam duration curves at LD3. If the 18th percentile flow for a month was below 750 CFS, the fish team increased the preferred flow to 750 CFS, which is considered healthier for fish and mussel populations because it is expected to prohibit stranding. In general, the strategy was to reduce the number of pulses, the magnitude of the pulses, or the duration of the pulses (described more for each operational box below). The team used the volume of water at USGS gages to compare that the number of pulses were within reason of the water in the system.

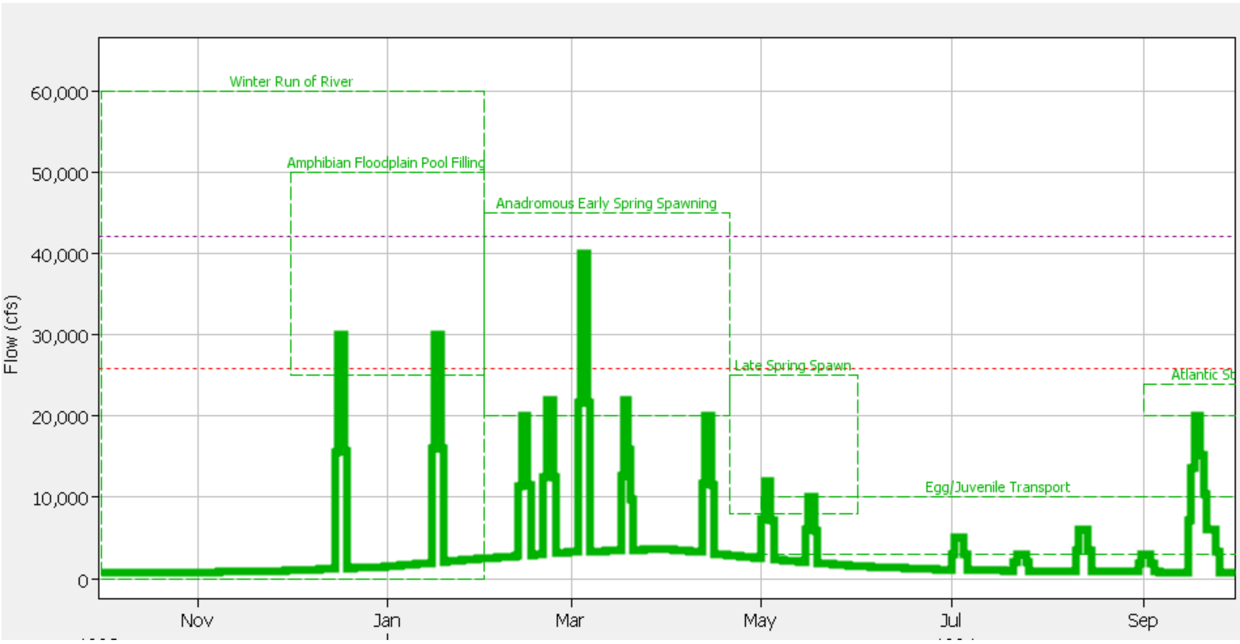


Figure 5. Flow prescription for Fish, Reach 3 Average. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter Run of River (Fish, Reach 3, Average): Same as Reach 3 Wet.

Amphibian Floodplain Filling (Fish, Reach 3, Average):
Season: 01Dec to 31Jan
Events per season: 1-2 overbank flow events every 2 years (of approximately 30k)
Magnitude: 25,000k-50,000 CFS
Duration: ~4 days with a slow rise and fall
Duration of peak: ~2 days with a slow rise and fall
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Dec	4	30,000	2
15-Jan	4	30,000	2

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: Salamanders and frogs would benefit from overbank flow in December and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years. Compared to a wet year, the duration of pulses and the peaks of pulses were reduced.

Anadromous Fish Early Spring Spawn (Fish, Reach 3, Average):
Season: 01Feb to 20Apr

Events per season: 1-2 each month for ~5 events
Magnitude: 20,000-45,000 CFS
Duration: 4
Duration of peak: 1-2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
12-Feb	4	20,000	2
20-Feb	4	22,000	2
3-Mar	4	40,000	2
17-Mar	4	22,000	1
12-Apr	4	20,000	2

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: The general goals of this flow prescription were similar to the Reach 3 Wet. Compared to a wet year, the group went from 7 pulses to 5 pulses and reduced the duration of any pulse to 4 days. The goal continued to strive for pulses of 20,000 CFS to provide adequate flow over lock and dams to promote fish passage. If the Corps had to decide between fewer pulses or a lower magnitude, the fish team prefers more pulses.

Late Spring Spawn (Fish, Reach 3, Average):

Season: 21Apr to 31May
Events per season: 2
Magnitude: 8,000-25,000 CFS
Duration: 4 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-May	4	12,000	2
15-May	4	10,000	2

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: The general goals of this flow prescription were similar to the Reach 3 Wet. The difference between a wet year and an average year is that the duration of pulses reduced from 5 days to 4 days.

Egg/ Juvenile Transport (Fish, Reach 3, Average):
Season: 01May to 30Sep
Events per season: 5
Magnitude: 3,000-10,000 CFS, most peaks in the 3,000- 6,000 CFS range

Duration: 5 days
Duration of peak: 3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	5	5,000	3
21-Jul	5	3,000	3
10-Aug	5	6,000	3
30-Aug	5	3,000	3
20-Sep	5	6,000	3

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The general goals of this flow prescription were similar to the Reach 3 Wet. The difference between a wet year and an average year is that the duration of pulses reduced from 6 days to 5 days.

Atlantic Sturgeon Fall Spawn (Fish, Reach 3, Average):
Season: 01Sep to 31Oct
Events per season: 1
Magnitude: 20,000-24,000 CFS
Duration: 7 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	7	20,000	2

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The fish team requested a pulse of 20,000 CFS to provide adequate flow over lock and dams to promote sturgeon to the upstream location near Smiley Falls. The wet year and average year recommendations are the same.

Low flows (Fish, Reach 3, Average):

The fish team used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In an average year, flows were chosen as the 18th percentile flow values by month. If the 18th percentile flow for a month was below 750 CFS, the fish team increased the preferred flow to 750 CFS to account for 600 CFS minimum at Lillington (which is likely to benefit fish). It is assumed that 600 CFS at Lillington translates to 750 CFS at LD3 under most hydrologic conditions.

Date	**Flow (CFS)**

31-Oct	750
30-Nov	980
31-Dec	1,460
31-Jan	2,460
28-Feb	3,230
31-Mar	3,650
30-Apr	2,510
31-May	1,520
30-Jun	1,060
31-Jul	900
31-Aug	820
30-Sep	750

Fish, Reach 3, Dry:

The fish team finished Reach 3 Dry during the workshop. Experts were consulted after the workshop to refine details of the prescription (Figure 6). In general, the group was more conservative with water use assuming it was a dry year. Yet, general ecological goals remained.

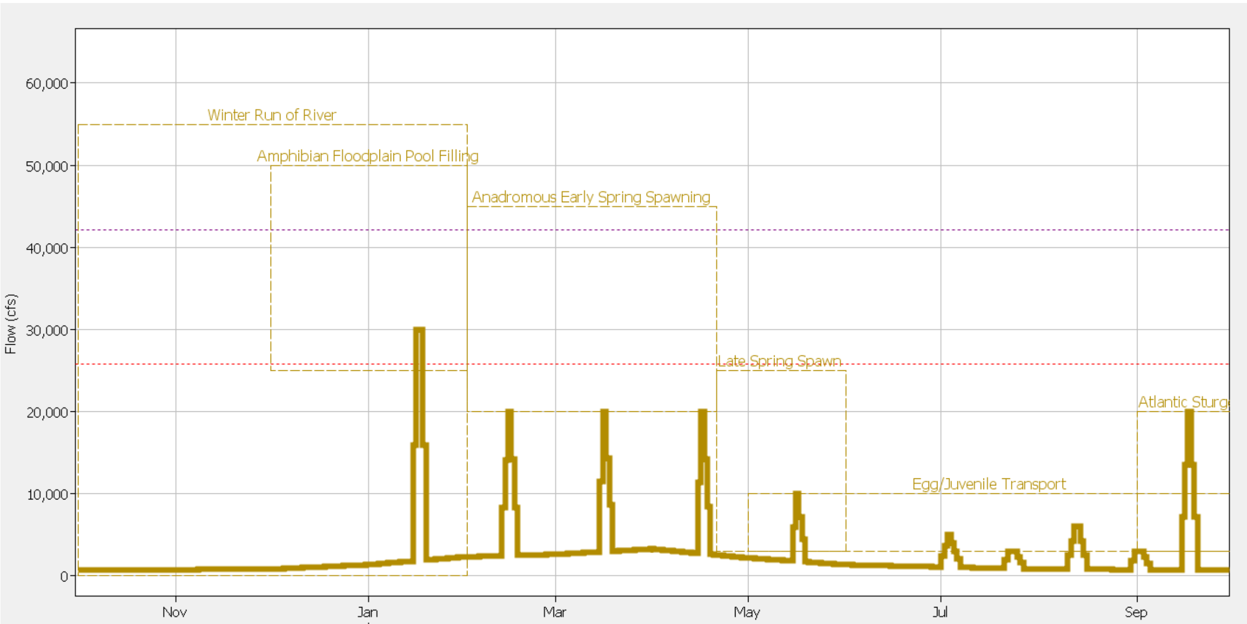


Figure 6. Flow prescription for Fish, Reach 3 Dry. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter Run of River (Fish, Reach 3, Dry): The team wants a run of river as much as possible. If water is scarce, the team does not ask for overbank flow.

Amphibian Floodplain Filling (Fish, Reach 3, Dry):
Season: 01Dec to 31Jan
Events per season: An overbank flow event every 2 years (of approximately 30,000 CFS)
Magnitude: 25,000-50,000 CFS

Duration: ~4 days with a slow rise and fall
Duration of peak: ~2 days with a slow rise and fall
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Jan	4	30,000	2

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: Salamanders and frogs would benefit from overbank flow in Dec and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years. An overbank flow event would be especially helpful in a dry year to help fill the vernal pools. Compared to wet and average years, the fish team requested just one overbank flow event.

Anadromous Fish Early Spring Spawn (Fish, Reach 3, Dry):
Season: 01Feb to 20Apr
Events per season: 1 each month for ~3 events
Magnitude: 20,000-45,000 CFS
Duration: 4-5 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
12-Feb	5	20,000	1
15-Mar	4	20,000	1
15-Apr	4	20,000	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: In a dry water year, the fish team wants three pulses to send diadromous fish upstream. Ideally, these pulses would be 20,000 CFS to provide adequate flow over lock and dams to allow fish passage. The duration and duration of peak is reduced compared to wet and average years.

Late Spring Spawn (Fish, Reach 3, Dry):

Season: 21Apr to 31May
Events per season: 1
Magnitude: 3,000-25,000 CFS, goal pulse of 10,000 CFS
Duration: 4 days
Duration of peak: 1 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-May	4	10,000	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: The general goals of this flow prescription were similar to the Reach 3 Wet and Average. The difference is the fish team only requests one pulse. Even a pulse of 10,000 CFS, if the Corps is still locking fish up the locks and dams, would benefit the spawn. The duration is 4 days and the duration at peak is 1 day.

Egg/ Juvenile Transport (Fish, Reach 3, Dry):
Season: 01May to 30Sep
Events per season: 4
Magnitude: 3,000-10,000 CFS, most peaks in the 3,000-6,000 CFS range
Duration: 5-6 days
Duration of peak: 1-3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	6	5,000	1
21-Jul	6	3,000	3
10-Aug	6	6,000	2
30-Aug	6	3,000	3

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The general goals of this flow prescription were similar to the Reach 3 Wet and Average. In a dry year, there are 4 events and the duration at peak is reduced.

Atlantic Sturgeon Fall Spawn (Fish, Reach 3, Dry):
Season: 01Sep to 31Oct
Events per season: 1
Magnitude: 3,000-20,000 CFS
Duration: 5 days
Duration of peak: 1 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	5	20,000	1

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The fish team requested a pulse of 20,000 CFS to provide adequate flow over lock and dams to promote sturgeon to the upstream location near Smiley Falls. In a dry year, even a small pulse would send a signal to the sturgeon. The duration and duration at peak were reduced compared to wet and average years.

Low flows (Fish, Reach 3, Dry):

The fish team used USGS data from the gage at LD3 and flow-duration curves (created in IHA) of pre-dam conditions. In a dry year, flows were chosen as the 10th percentile flow values by month. If the 10th percentile flow for a month was below 750 CFS, the fish team increased the preferred flow to 750 CFS to account for 600 CFS minimum at Lillington (which is likely to benefit fish). It is assumed that 600 CFS at Lillington translates to 750 CFS at LD3 under most hydrologic conditions.

Date	Flow (CFS)
31-Oct	750
30-Nov	800
31-Dec	1,340
28-Feb	2,600
31-Jan	2,300
31-Mar	3,260
30-Apr	2,200
31-May	1,350
30-Jun	1,080
31-Jul	800
31-Aug	750
30-Sep	750

Reach 2:

Reach 2, from Lillington to LD3, is the most important in-stream habitat for diadromous fish (where the coastal plain switches to the Piedmont and spawning occurs). Yet, the HEC RAS modeling demonstrated that it would require high flows to create overbank flow conditions. Thus, flow prescriptions at Reach 1 and Reach 3 should be adjusted with Corps models to apply to Reach 2, being sufficient to support good ecology at Reach 2.

Reach 1:

Workshop experts brainstormed goal conditions for Reach 1, but did not have enough time to draft flow prescriptions. Suggestions included keeping a good wetted perimeter for mussels, thinking about healthy tributaries for the Cape Fear shiner, keeping the temperature below 34 degrees C, and having releases from Jordan Dam be gentle enough not to flush organisms downstream. TNC worked with experts after the workshop to create flow prescriptions for Reach 1. In general, the flow prescriptions originated from Reach 3 and were adjusted so that the magnitudes of flows were reduced by a factor of 1.5 to account for the fact that Reach 1 is higher upstream with less flow. Durations of pulses were also reduced. The low flow numbers were generated using Lillington USGS gage information.

Fish, Reach 1, Wet:
The flow prescription for Reach 1 wet originated by using Reach 3 wet. Flows were adjusted so that the magnitudes of flows were reduced by a factor of 1.5 to account for the fact that Reach 1 is higher upstream with less flow. Durations of pulses were also reduced. The low flow numbers were generated using Lillington USGS gage information.

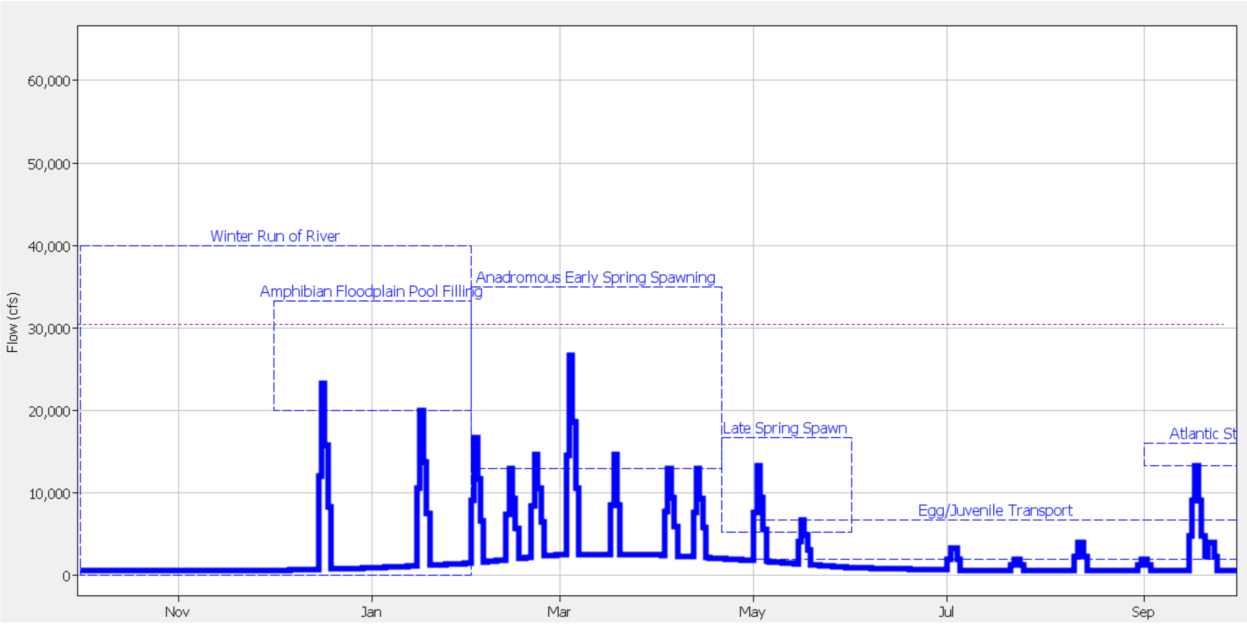


Figure 7. Flow prescription for Fish, Reach 1 Wet. Purple dotted line is NWS flood stage at Lillington.

Winter Run of Winter (Fish, Reach 1, Wet):
Season: 01Oct to 31Jan
Events per season: Run of river
Magnitude: 0-40,000 CFS (or the corresponding run of river condition)
Duration: Simulate natural variability
Duration of peak: Simulate natural variability

Purpose. Winter is often the wettest time of year for Cape Fear flows. Fish and wildlife would benefit most from a run of river situation. Allow natural variability and promote the natural hydrograph to support the life cycle of aquatic organisms.

Description: The fish team did not dictate specific floods tied to ecology, but thought the natural variability of water movement in the winter would promote the general needs of aquatic organisms.

Amphibian Floodplain Filling (Fish, Reach 1, Wet):
Season: 01Dec to 31Jan
Events per season: 1-2 overbank flow events every 2 years (of approximately 20,000 CFS)
Magnitude: 20,000-33,300 CFS

Duration: ~4 days with a slow rise and fall
Duration of peak: ~1 days with a slow rise and fall
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Dec	4	23,300	1
15-Jan	4	20,000	1

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: Salamanders and frogs would benefit from overbank flow in December and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years. This prescription was crafted by taking Reach 3 wet and reducing peaks by a factor of 1.5 as well as reducing the duration of the flood pulses.

Anadromous Fish Early Spring Spawn (Fish, Reach 1, Wet):
Season: 01Feb to 20Apr
Events per season: 2-3 each month for ~7 events
Magnitude: 13,000 – 35,000 CFS
Duration: 3-4 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Feb	4	16,670	1
12-Feb	4	13,000	1
20-Feb	4	14670	1
3-Mar	4	26,700	1
17-Mar	3	14,670	1
3-Apr	4	13,000	1
12-Apr	4	13,000	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: In a wet year, the Fish team hoped for multiple pulses of 13,000 CFS or more. The team assumed that 13,000 CFS would be approximately 20,000 CFS at LD2 and LD3, adequately submerging the locks and promoting fish passage. Coming out of the winter when flows are highest, these pulses should be possible. Overbank flow is fine at this time of the year. If deciding between a bigger magnitude pulse or more pulses, the Fish team would prefer more fish pulses of 13,000 CFS. This flow recommendation was taken by adjusting the Reach 3 wet prescription, reducing peaks by a factor of 1.5, shortening the duration to 4 days, and reducing the DOP by a day. The Cape Fear shiner needs healthy tributaries in this reach and we do not want to flush that fish by peaks that are too sharp.

Late Spring Spawn (Fish, Reach 1, Wet):
Season: 21Apr to 31May
Events per season: 2
Magnitude: 5,300-16,700 CFS
Duration: 4 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-May	4	13,330	1
15-May	4	6,770	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: Striped bass and shad still spawn into late May. Yet, other species have already gone upstream and spawned. As of mid-April, the fish team did not want overbank flow because this could strand eggs and juveniles in the floodplains. Ideally, these pulses would be between 13,330-16,700 CFS with the goal to adequately submerge the downstream LD2 and LD3, but prevent overbank flow.

Egg/ Juvenile Transport (Fish, Reach 1, Wet):
Season: 01May to 30Sep
Events per season: 5
Magnitude: 2,000-6,670 CFS
Duration: 4 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	4	3,300	2
21-Jul	4	2,000	2
10-Aug	4	4,000	2
30-Aug	4	2,000	2
20-Sep	4	4,000	2

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The team wanted small, gently rising and falling pulses throughout the summer to push fry and juvenile downstream and back over the locks and dams. Flows that are too slow will strand eggs behind the locks and dams. Yet, too much water can push the juveniles too fast. An upper limit of 6,670 CFS was chosen to correlate with a 10,000 CFS flow at LD3, and because the team did not want to flush fish that spawned near LD1 into the ocean too fast. The team did not want overbank flow at this time of year because that could strand fish. This operational window overlaps with the Late Spring Spawn and the Atlantic Sturgeon Spawn. If flows are promoted higher than 6,670 CFS for other ecological reasons, it is best to have a gentle rise and fall. This prescription was crafted by taking Reach 3 wet, reducing peaks by 1.5, reducing durations to 4, and reducing DOPs to 2.

Atlantic Sturgeon Fall Spawn (Fish, Reach 1, Wet):

Season:	01Sep to 31Oct
Events per season:	1
Magnitude:	13,300-16,000 CFS
Duration:	5 days
Duration of peak:	2 days

Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	5	13,300	1

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The fish team requested a pulse of 13,300 CFS to provide adequate flow over lock and dams to promote sturgeon to the upstream location near Smiley Falls. This prescription was crafted by taking Reach 3 wet, reducing peaks by 1.5, reducing duration to 5, and reducing DOP to 1.

Low flows (Fish, Reach 1, Wet):

The fish team used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In a wet year, flows were chosen as the 25th percentile flow values by month. Flows were increased to 600 CFS to meet minimum flow targets at Lillington, which should also benefit fish and mussels.

Date	**Flow (CFS)**
31-Oct	600
30-Nov	600
31-Dec	900
31-Jan	1,470
28-Feb	2,500
31-Mar	2,500
30-Apr	1,820
31-May	940
30-Jun	650
31-Jul	600
31-Aug	600
30-Sep	600

Fish, Reach 1, Average:

The flow prescription for Reach 1 average originated by using Reach 3 average. Flows were adjusted so that the magnitudes of flows were reduced by a factor of 1.5 to account for the fact that Reach 1 is higher upstream with less flow. Durations of pulses were also reduced. The low flow numbers were generated using Lillington USGS gage information.

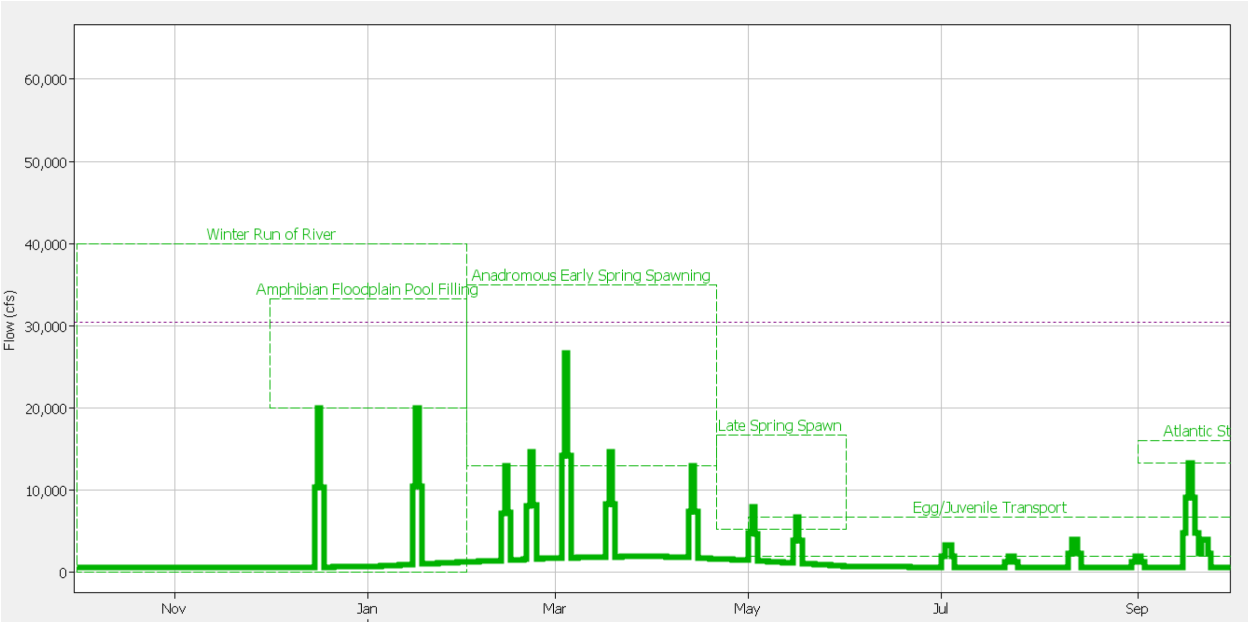


Figure 8. Flow prescription for Fish, Reach 1 Average. Purple dotted line is NWS flood stage at Lillington.

Winter Run of River (Fish, Reach 1, Average): Winter is often the wettest time of year for Cape Fear flows. Fish and wildlife would benefit most from a run of river situation.

Amphibian Floodplain Filling (Fish, Reach 1, Average):
Season: 01Dec to 31Jan
Events per season: 1-2 overbank flow events every 2 years (of approximately 20,000 CFS)
Magnitude: 20,000-33,300 CFS
Duration: ~3 days with a slow rise and fall
Duration of peak: ~1 days with a slow rise and fall
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Dec	3	20,000	1
15-Jan	3	20,000	1

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: Salamanders and frogs would benefit from overbank flow in December and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-

March, we want to reduce the amount of overbank flow. Flooding events should rise and fall as to not flush critters and eggs. Overbank flow is not required every year so the recommendation asks for events approximately every 2 years. This prescription was crafted by taking Reach 3 average and reducing peaks by a factor of 1.5 as well as reducing the duration of the flood pulses.

Anadromous Fish Early Spring Spawn (Fish, Reach 1, Average):
Season: 01Feb to 20Apr
Events per season: 1-2 each month for ~5 events
Magnitude: 13,000-35,000 CFS
Duration: 3
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
12-Feb	3	13,000	1
20-Feb	3	14,670	1
3-Mar	3	26,700	1
17-Mar	3	14,670	1
12-Apr	3	13,000	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: The general goals of this flow prescription were similar to the Reach 3 Average yet pulses were reduced by a factor of approximately 1.5, the duration of any pulse was reduced to 3 days and the duration of peak was changed to 1 day. Pulses of 13,000 CFS in this stretch of the river are assumed to provide adequate flow over lock and dams to promote fish passage. If the Corps had to decide between fewer pulses or a lower magnitude, the fish team prefers more pulses.

Late Spring Spawn (Fish, Reach 1, Average):
Season: 21Apr to 31May
Events per season: 2
Magnitude: 5,300-16,670 CFS
Duration: 3 days
Duration of peak: 1 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-May	3	8,000	1
15-May	3	6,670	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: The general goals of this flow prescription were similar to the Reach 3 Average, yet pulses were reduced by a factor of approximately 1.5, the duration of any pulse was reduced to 3 days and the duration of peak was changed to 1 day.

Egg/ Juvenile Transport (Fish, Reach 1, Average):
Season: 01May to 30Sep
Events per season: 5
Magnitude: 2,000-6,670 CFS, most peaks in the 2,000-4,000 CFS range
Duration: 4 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	4	3,300	2
21-Jul	4	2,000	2
10-Aug	4	4,000	2
30-Aug	4	2,000	2
20-Sep	4	4,000	2

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The general goals of this flow prescription were similar to the Reach 3 Average, yet pulses were reduced by a factor of approximately 1.5, the duration of any pulse was reduced to 4 days and the duration of peak was changed to 2 days.

Atlantic Sturgeon Fall Spawn (Fish, Reach 1, Average):
Season: 01Sep to 31Oct
Events per season: 1
Magnitude: 13,300-16,000 CFS
Duration: 5 days
Duration of peak: 1 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	5	13,300	1

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The fish team requested a pulse of 13,300 CFS to with the assumption that would correlate to approximately 20,000 CFS at LD3, which would provide adequate flow to promote sturgeon to the upstream location near Smiley Falls. The wet year and average year recommendations are the same.

Low flows (Fish, Reach 1, Average):

The fish team used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In an average year, flows were chosen as the 18th percentile flow values by month, listed in the below table. If the 18th percentile flow for a month was below 600 CFS, the preferred flow was increased to 600 CFS to account for minimum flow requirement at Lillington (which is likely to benefit fish).

Date	Flow (CFS)
31-Oct	600
30-Nov	600
31-Dec	674
31-Jan	1,260
28-Feb	1,720
31-Mar	1,980
30-Apr	1,480
31-May	760
30-Jun	600
31-Jul	600
31-Aug	600
30-Sep	600

Fish, Reach 1, Dry:

The flow prescription for Reach 1 dry originated by using Reach 3 dry. Flows were adjusted so that the magnitudes of flows were reduced by a factor of 1.5 to account for the fact that Reach 1 is higher upstream with less flow. Durations of pulses were also reduced. The low flow numbers were generated using Lillington USGS gage information.

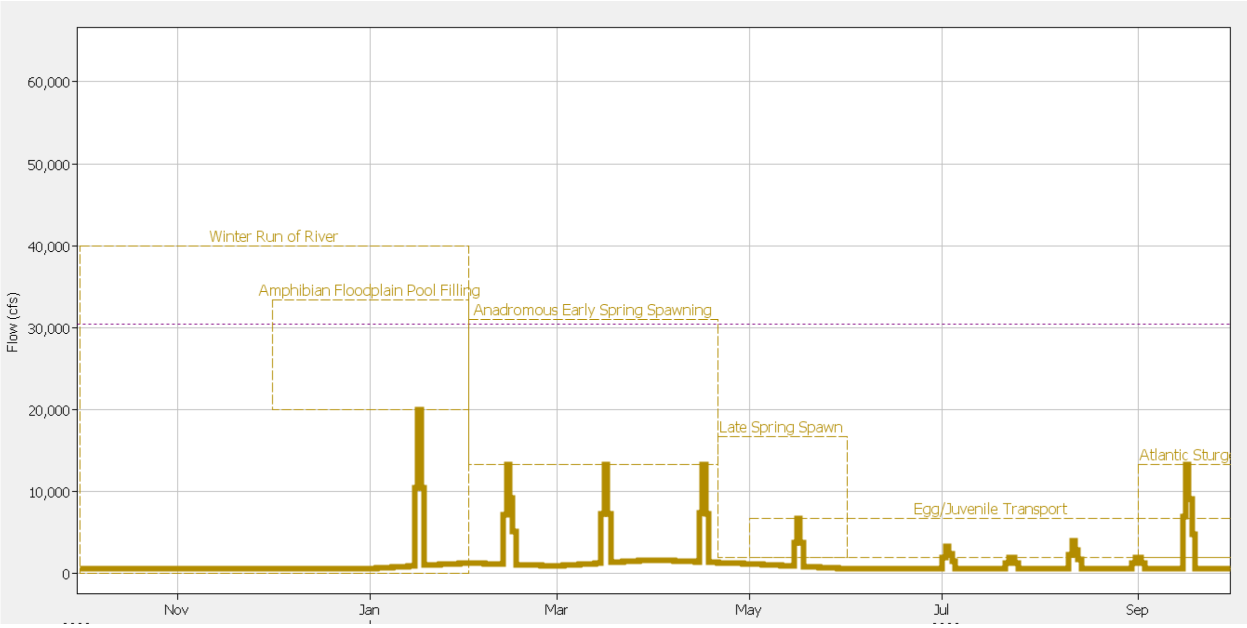


Figure 9. Flow prescription for Fish, Reach 1 Dry. Purple dotted line is NWS flood stage at Lillington.

Winter Run of River (Fish, Reach 1, Dry): The team wants a run of river as much as possible. If water is scarce, the team does not ask for overbank flow.

Amphibian Floodplain Filling (Fish, Reach 1, Dry):
Season: 01Dec to 31Jan
Events per season: An overbank flow event every 2 years (of approximately 20,000 CFS)
Magnitude: 25,000-50,000 CFS
Duration: ~3 days with a slow rise and fall
Duration of peak: ~1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Jan	3	20,000	1

Purpose: Allow overbank flow to fill vernal pools and promote amphibian development.

Description: The Fish team made a note to consult with amphibian experts, and TNC did this post-workshop. The predominant salamander in the floodplains of the Cape Fear is the Marble salamander. It lays eggs in October on mostly dry ground. Water enters the floodplains and fills the vernal pulls throughout the winter to help wet the eggs and prepare them for hatching. This amphibian, as well as some frogs, would benefit from overbank flow in Dec and January. The vernal pools will be filled by precipitation, but overbank flow also helps. By mid-March, we want to reduce the amount of overbank flow. An overbank flow event would be especially helpful in a dry year to help fill the vernal pools. Compared to wet and average years, we request just one overbank flow event. This prescription was crafted by taking Reach 3 dry and reducing peaks by a factor of 1.5 as well as reducing the duration of the flood pulses.

Anadromous Fish Early Spring Spawn (Fish, Reach 1, Dry):
Season: 01Feb to 20Apr
Events per season: 1 each month for ~3 events
Magnitude: 13,300-31,000 CFS
Duration: 3-4 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
12-Feb	4	13,300	1
15-Mar	3	13,300	1
15-Apr	3	13,300	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn.

Description: In a dry water year, the fish team wants three pulses to send diadromous fish upstream. Ideally, these pulses would be 13,300 CFS. The general goals of this flow prescription were similar to the Reach 3 dry, yet pulses were reduced by a factor of approximately 1.5, the duration of any pulse was reduced to by a day and the duration of peak was changed to 1 day.

Late Spring Spawn (Fish, Reach 1, Dry):
Season: 21Apr to 31May
Events per season: 1
Magnitude: 2,000-16,660 CFS, goal pulse of 6,670 CFS
Duration: 3 days
Duration of peak: 1 day with the assumption that would result in 20,000 CFS at the downstream lock and dams, providing adequate flow to allow fish passage.
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-May	3	6670	1

Purpose: To send a signal for diadromous fish to swim upstream and spawn without trapping already-existent eggs/juveniles in the floodplains.

Description: The general goals of this flow prescription were similar to the Reach 3 dry, yet the pulse was reduced by a factor of approximately 1.5 and the duration was reduced to by a day.

Egg/ Juvenile Transport (Fish, Reach 1, Dry):
Season: 01May to 30Sep
Events per season: 4
Magnitude: 2,000-6,670 CFS, most peaks in the 2,000-4,000 CFS range
Duration: 4 days
Duration of peak: 1-2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
1-Jul	4	3,330	1
21-Jul	4	2,000	2
10-Aug	4	4,000	1
30-Aug	4	2,000	2

Purpose: Flows to help semi-buoyant eggs and promote juvenile movement downstream

Description: The general goals of this flow prescription were similar to the Reach 3 dry, yet the pulse was reduced by a factor of approximately 1.5, the duration was reduced to by a day, and the days at peak was reduced by 1 day.

Atlantic Sturgeon Fall Spawn (Fish, Reach 1, Dry):
Season: 01Sep to 31Oct
Events per season: 1
Magnitude: 2,000-13,300 CFS
Duration: 4 days

Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Sep	4	13,330	1

Description: There are two stocks of sturgeon in the Cape Fear, and one spawns in the Fall. This pulse is to cue the Fall sturgeon to go upstream.

Purpose: The general goals of this flow prescription were similar to the Reach 3 dry, yet the pulse was reduced by a factor of approximately 1.5 and the duration was reduced by a day. The fish team requested a pulse of 13,300 CFS with the assumption that it would result in 20,000 CFS at the downstream lock and dams, providing adequate flow to promote sturgeon to the upstream location near Smiley Falls. In a dry year, even a small pulse would send a signal to the sturgeon.

Low flows (Fish, Reach 1, Dry):

The fish team used USGS data from the gage at Lillington and flow-duration curves (created in IHA) of pre-dam conditions. In a dry year, flows were chosen as the 10^{th} percentile flow values by month, as shown in the below table. If the 10^{th} percentile flow for a month was below 600 CFS, the preferred flow was increased to 600 CFS to account for minimum flow requirement at Lillington (which is likely to benefit fish).

Date	**Flow (CFS)**
31-Oct	600
30-Nov	600
31-Dec	600
28-Feb	940
31-Jan	1,280
31-Mar	1,650
30-Apr	1,190
31-May	610
30-Jun	600
31-Jul	600
31-Aug	600
30-Sep	600

Research and modeling needs from the fish team:

- What combined flows from the unregulated Deep and Jordan releases will submerge the locks and dams?
- Is 600 CFS minimum at Lillington the right low-flow standard for aquatic organisms?
- Why does the drought contingency plan go down in 50 CFS increments and how does that affect ecology?
- We need to create flow-by numbers that relate to wet, dry, and average years at each reach.
- What really stimulates the Fall Atlantic sturgeon spawn?
- Where is the saltwater wedge originating and where does it affect aquatic organisms?
- Is the sediment pool of Jordan filling in more slowly than expected?
- Could the lock chambers be used to siphon eggs downstream?
- What is the low flow minimum that still promotes a good wetted perimeter and does not strand mussels/fish?
- Can we get more specific flow-habitat relationships for the species within the Cape Fear?

Appendix H: Floodplains break-out group findings

The follow pages detail the Floodplains break-out group findings to include:

- Process
- General prescription goals for each year
- Flow prescriptions for floodplains by reach
    - Reach 3
    - Reach 2
    - Reach 1
- Research and modeling needs from the floodplains team

The Floodplain group was tasked with determining the needs of the floodplain forest and associated vegetative community. The literature review included nine forest/vegetation community types (see literature review, pages 69-81) within 300 M of the Active River Area.. After reviewing this information participants noted these vegetation communities do not represent the historic or the desired forest/vegetative community. It would be better to use measures that would support healthy and desirable floodplains composition based around more historic floodplain conditions and indicator species. The group decided to design goals and objectives that could bring about the desired states for Cape Fear floodplain vegetation communities understanding the timeframe to achieve this state could be 100-200 years.

Although the information below is not refined into classical goal and objective statements these basic conditions became the criteria for establishing the flow prescription.

Bottomland Hardwoods

Within this community there is a need for seed dispersal, seed scarification, and sediment movement with higher flows which should occur sometime between December and February. Proper soil moisture was important for seeds to germinate on the exposed substrate in March to late April timeframe. Finally, optimum conditions during the summer, May to August would include a 60-90 day window with lower stable water conditions for the saplings to grow to the point where recruited trees could survive inundation.

These conditions do not have to happen every year, but it is expected these recruitment conditions would be necessary approximately every 5 years. The group did not have specific recommendations to maintain tree health for moderate age or mature growth stands. Consulting an expert or conducting additional research to determine if the sapling recruitment flow prescription would also support mature trees is likely needed to assure all the necessary elements are included for BLH flow prescription.

Indicator Species

- Bald Cypress/Tupelo
- Overcup Oak
- Willow and Cherry bark

Natural Levee Community

This is the pioneer forest community that should not dominant forest composition but is a necessary component for woody detritus contribution to the system and creating canopy breaks. Flow prescriptions were not built for this community.

Indicator Species

- Box elder
- Ash (Green)
- Hackberry

Conditions to promote with the use of the prescription

- Sediment movement and deposition
- Nutrient cycling
- Small floodplain ponds (ephemeral ponds for herpetofauna).
- Restore more naturally occurring wetlands within the floodplain

- Can we use flow to control, minimize or even eliminate invasive species? This would be desirable.

Process

By establishing basic goals and objectives the group was able to establish basic needs to pursue for floodplain flow prescription. The Floodplain Group was assigned the reach priority sequence of Reach 1, Reach 2 and Reach 3, by workshop organizers. Each of the three groups were given a different sequence to assure all three reaches would have at least one prescription formulated as a base to move forward during the unification of all three reaches.

The Floodplain Group started with the Wet Scenario for Reach 1. Using the considerations of the goals and objectives the group defined three flood pulses in the December to February months, two smaller peaks during the March through April timeframe and a lower stable water period from May to August with the goal of 60-90 days in these conditions. This flow prescription was generated by the end of day one with the assumption that the others would be easier to define with this as the template.

Day two, the Floodplain Group was able to view additional data using the Indicators of Hydrologic Alteration (IHA) and HEC-RAS models for the Cape Fear River. With this information, the group realized the flow prescription that was formulated on day one was closer to an average scenario than a Wet scenario. The prescription was adapted to the higher flows associated with the IHA and RAS models and adjustments were made to the peaks. The highest and longest peak should occur in January to scarify and disperse seeds, redistribute sediment across the floodplain and reestablish floodplain ponds and wetlands essential to the herptiles. This early season pulse would precede the fish spawning triggers which should protect the herptiles from predation during hibernation and spawning. The remaining two flood pulses during the winter season would occur during late January and February with lower and shorter peaks and would not reach overbank. These flows would help retain soil moisture established during the first large pulse and would not provide fish access to the floodplain to eliminate the possibility of predation of herptiles. Two spring pulses were formulated primarily for fisheries but also with the purpose of maintaining soil moisture in the floodplain for seed gemination and sapling growth. These pulses were formulated for March and April with smaller height and duration than the winter pulses. Final flow considerations for the Floodplain Group were not defined as a flood pulse but designed as lower stable condition of 60-90 days during the May through August timeframe to allow sapling the ability to grow large enough to sustain larger seasonal flows that would be likely in following months. This target was represented as a box to indicate the lower range of flows that would be preferred during the summer months. The group did not define conditions beyond the August timeframe. They assumed the other two groups would have flows prescriptions during the September through November timeframe that would be incorporated into the flow prescription during the unification process.

With the agreement on the Wet Scenario, adjustments were made to the Average flow scenario developed on day one. Rather than three flood pulses in the Winter there would be only two under average conditions, retaining the highest peak in early January and follow with one smaller peak in early February. The March and April flood pulses would decrease to one pulse and would again be smaller in duration and height than the Winter flood pulses. The same target window for summer conditions was included at a lower range than identified during the Wet scenario.

The Dry scenario was limited to one flood pulse in the Winter and height did not overtop the bank as the 25% percentile did not indicate flows would be sufficient for this outcome. The same target window of lower stable water for the months of May through August was identified like the other two scenarios.

Floodplain flow prescriptions by reach:

Reach 1

This reach begins at Jordan Dam and ends at Lillington, NC. It includes the Haw River below Jordan Dam, the confluence of the Haw and Deep River, and the mainstem Cape Fear River from the confluence to Lillington. It was identified by workshop facilitators as the first reach for consideration by the floodplain group. Formulation of environmental flows was done for Wet, then Average, and then Dry hydrologic conditions. Gaged flows at Lillington and the associated IHA analysis were useful hydrologic references for Reach 1. River hydraulics models and model output informed relationships between flow and inundation. Recommendations are comprised of target flows at Lillington and are designed to support healthy, functioning, and sustained ecological communities that inhabit floodplains of the Cape Fear River.

Floodplains, Reach 1, Wet
Environmental flow recommendations for this reach are shown in Figure 10. Characteristics of each flow component are detailed below.

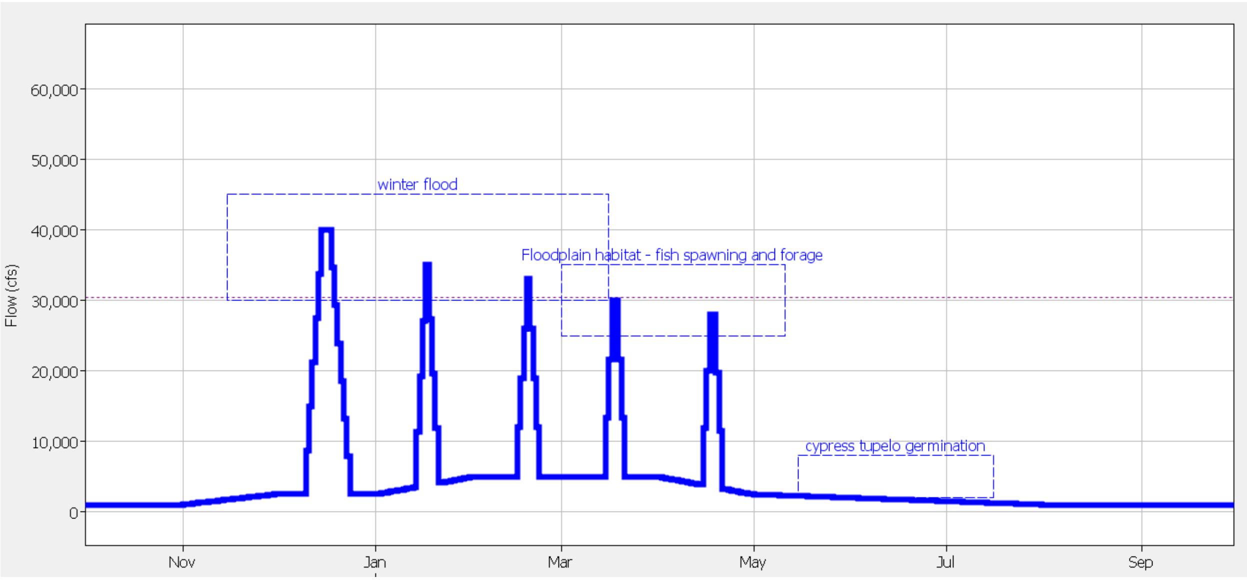


Figure 10. Flow prescription for Floodplains, Reach 1 Wet. Purple dotted line is NWS flood stage at Lillington.

Winter flood (Floodplains Reach 1, Wet). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 15Nov to 15Mar
Events per season: 2 to 4
Magnitude: 30,000-45,000 CFS
Duration: 7-14 days
Duration of peak: 1-3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
10-Dec	14	40,000	3
14-Jan	7	35,000	1
15-Feb	7	33,000	1

Purpose. Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: There should be multiple flow events within this operational window of two and four instances per season. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, rewetting of pool areas to support amphibians and reptiles, including spawning of herpetofauna in January and February. Peaks should taper in magnitude as timing approaches the end of the "Winter flood" operational window to limit fish access to ponded areas, which minimizes predation on herpetofauna eggs and larvae. The first event should be longer in duration and have a duration of peak of three days to assure significant inundation and filling of floodplain areas.

Floodplain habitat - fish spawning and forage (Floodplains Reach 1, Wet). This component supports spring spawning fish species.

Season: 01Mar to 10May
Events per season: 2 to 3
Magnitude: 25,000-35,000 CFS
Duration: 5-7 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Mar	6	30,000	2
15-Apr	6	28,000	2

Purpose. Provides access and inundation for spring spawning fishes. Cycles nutrients in floodplain areas. Shad spawn in April (early to mid-month) in the upper section on rocky areas near the fall line. Maintains soil moisture into spring season.

Description: Need multiple events to provide access and inundation for fishes as well as an opportunity to move from floodplain areas to the main channel. This component is related to the "Cypress tupelo germination" component such that in wet periods "Floodplain habitat - fish" is likely to be more successful and in dry periods "Cypress tupelo germination" is likely to be more successful.

Cypress tupelo germination (Floodplains, Reach 1, Wet). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season: 15May to 15Jul
Events per season: none
Magnitude: n.a.
Duration: n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses some aquatic invasive plants.

Description: This component only relevant when preceded by implementation of the "Winter flood" component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is ok - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) 2-3 dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is appropriate and important to repeat and initiate the cycle opportunistically as often as possible. This component is also related to the "Floodplain habitat - fish" component such that, following a successful "Winter flood", "Floodplain habitat - fish" is likely to be more successful in wet periods and "Cypress tupelo germination" is likely to be more successful in dry periods.

Low flows (Floodplains, Reach 1, Wet). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected.

Date	Flow (CFS)
1-Oct	1,000
31-Oct	1,000
30-Nov	2,500
1-Jan	2,500
1-Feb	5,000
31-Mar	5,000
30-Apr	2,500
1-Aug	1,000
30-Sep	1,000

Floodplains, Reach 1, Average

Environmental flow recommendations for this reach are shown in Figure 11. Characteristics of each flow component are detailed below. Recommendations for "Average" hydrologic conditions are similar to those for "Wet", catering to the life history needs of the same floodplain communities.

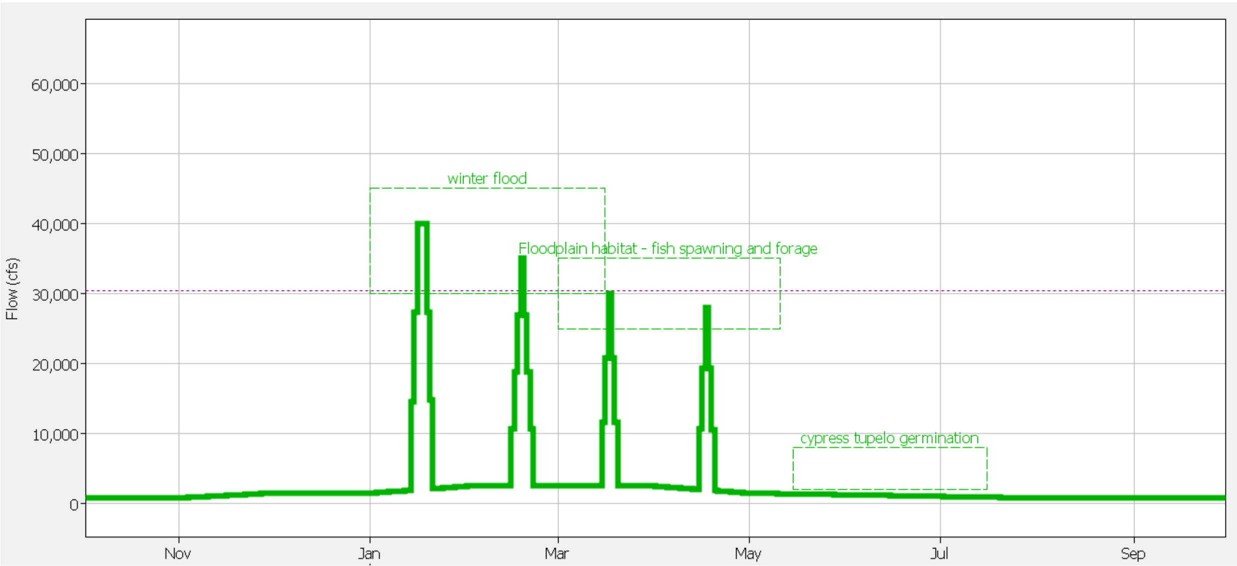


Figure 11. Flow prescription for Floodplains, Reach 1 Average. Purple dotted line is NWS flood stage at Lillington.

Winter flood (Floodplains Reach 1, Average). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 01Jan to 15Mar
Events per season: 2 to 3
Magnitude: 30,000-45,000 CFS
Duration: 7-10 days
Duration of peak: 1-3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
14-Jan	7	40,000	3
15-Feb	7	35,000	1

Purpose: Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: There should be multiple flow events within this operational window - two to three instances per season are needed. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, rewetting of pool areas to support amphibians and reptiles, including spawning of herpetofauna in January and February. Peaks should taper in magnitude as timing approaches the end of the "Winter flood" operational window to limit fish access to ponded areas, which minimizes predation on herpetofauna eggs and larvae. The first event should be longer in duration and have a duration of peak of 3 days to assure significant inundation and filling of floodplain areas.

Floodplain habitat - fish spawning and forage (Floodplains Reach 1, Average). This component supports spring spawning fish species.

Season: 01Mar to 10May
Events per season: 2 to 3
Magnitude: 25,000-35,000 CFS
Duration: 5 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Mar	5	30,000	1
15-Apr	5	28,000	1

Purpose. Provides access and inundation for spring spawning fishes. Cycles nutrients in floodplain areas. Shad spawn in April (early to mid-month) in the upper section on rocky areas near the fall line. Maintains soil moisture into spring season.

Description: Need multiple events to provide access and inundation for fishes as well as an opportunity to move from floodplain areas to the main channel. This component is related to the "Cypress tupelo germination" component such that in wet periods "Floodplain habitat - fish" is likely to be more successful and in dry periods "Cypress tupelo germination" is likely to be more successful.

Cypress tupelo germination (Floodplains Reach 1, Average). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season: 15May to 15Jul
Events per season: none
Magnitude: n.a.
Duration: n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses some aquatic invasive plants.

Description: This component only relevant when preceded by implementation of the "Winter flood" component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is ok - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) two to three dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is ok and important to repeat/initiate cycle opportunistically as often as possible. This component is also related to the "Floodplain habitat - fish" component such that, following a successful "Winter flood", "Floodplain habitat - fish" is likely to be more successful in wet periods and "Cypress tupelo germination" is likely to be more successful in dry periods.

Low flows (Floodplains Reach 1, Average). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected.

Date	Flow (CFS)
1-Oct	800
31-Oct	800
30-Nov	1,500
1-Jan	1,500
1-Feb	2,500
31-Mar	2,500
30-Apr	1,500
1-Aug	800
30-Sep	800

Floodplains, Reach 1, Dry

Environmental flow recommendations for this reach are shown in Figure 12. Characteristics of each flow component are detailed below. Recommendations for "Dry" hydrologic conditions are significantly reduced from "Average".

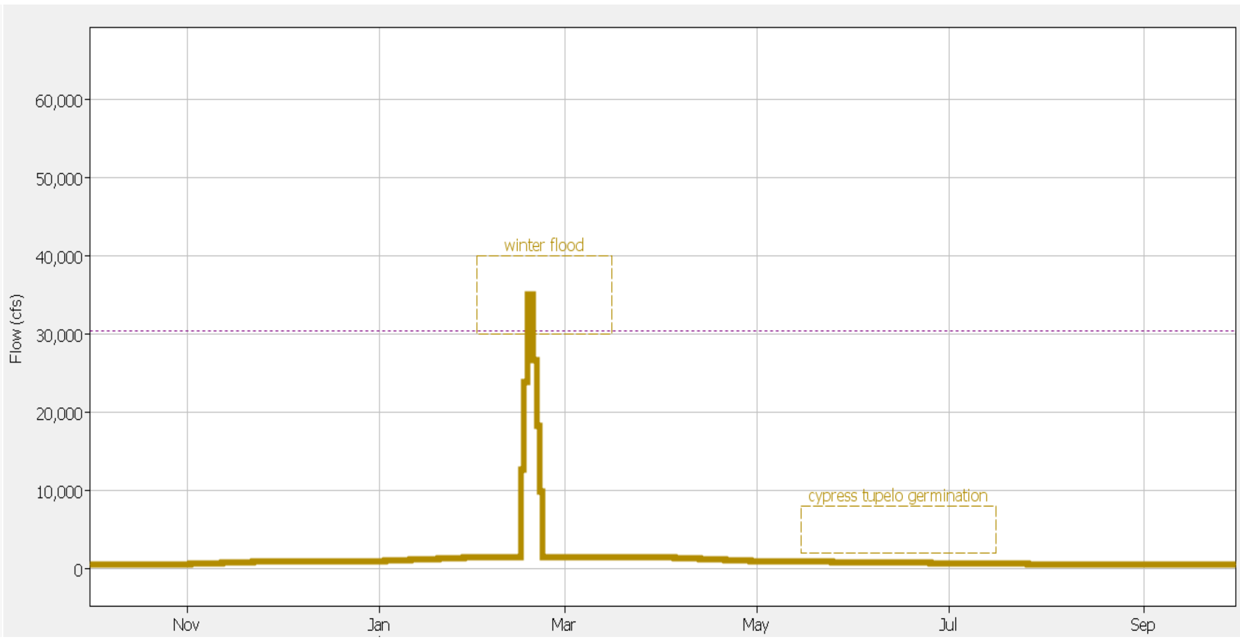


Figure 12. Flow prescription for Floodplains, Reach 1 Dry. Purple dotted line is NWS flood stage at Lillington.

Winter flood (Floodplains, Reach 1, Dry). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 01Feb to 15Mar
Events per season: 1
Magnitude: 30,000-40,000 CFS
Duration: 7 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Feb	7	35,000	2

Purpose. Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: One flow event within this operational window. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks in consecutive dry winters should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, and wetting of different pool areas to support amphibians and reptiles, including spawning of herpetofauna. Event should have a duration of peak of 2 days to generate as much inundation and filling of floodplain areas as possible.

Cypress tupelo germination (Floodplains, Reach 1, Dry). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season:	15May to 15Jul
Events per season:	none
Magnitude:	n.a.
Duration:	n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses some aquatic invasive plants.

Description: This component only relevant when preceded by implementation of the “Winter flood” component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is okay - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) two to three dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is ok and important to repeat/initiate cycle opportunistically as often as possible. This component is also related to the “Floodplain habitat - fish” component such that, following a successful “Winter flood”, “Floodplain habitat - fish” is likely to be more successful in wet periods and “Cypress tupelo germination” is likely to be more successful in dry periods.

Low flows (Floodplains, Reach 1, Dry). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected.

Date	Flow (CFS)
1-Oct	600

31-Oct	600
30-Nov	1,000
1-Jan	1,000
1-Feb	1,500
31-Mar	1,500
30-Apr	1,000
1-Aug	600
30-Sep	600

Reach 2

This reach begins at Lillington and ends at LD3. Fayetteville, NC, is located just downstream of half reach. Reach 2 was identified by workshop facilitators as the second reach for consideration by the floodplain group. Gage records at Fayetteville and LD3 were useful hydrologic references for Reach 2. Mean flows between 01October1974 and 30September2018 were computed for Lillington, Fayetteville, LD3, and LD1 based on daily gaged flows. Ratios between Lillington and each of the downstream gages were also computed and can be seen in the below table. Mean flows and flow ratios for the Cape Fear River at Lillington, Fayetteville, LD3, and LD1, water years 1975-2018.

Location	Mean Flow (CFS)	Ratio (with Lillington)
Lillington	3,137	--
Fayetteville (USGS stage, River Forecast Center rating)	4,206	1.34
LD3	4,567	1.46
LD1	5,153	1.64
Reach 3 (mean average, LD3 and LD1)	4,860	1.54

Floodplain group participants concurred that Reach 2 shared many of the same ecological needs as Reach 1. As a starting point for Reach 2, the floodplain group compared flow and inundation for Reaches 1 and 2 with the initial premise that if dynamics in the reaches were comparable and proportional, then the flow recommendations for Reach 1 might be adjusted to account for increased watershed size while largely maintaining the pattern and ecological purposes of the Reach 1 recommendations.

Hydrologically, the Cape Fear River near Fayetteville conveys about 130% of the flow at Lillington. Output from the river hydraulics model was consulted to determine whether proportionally higher flows (i.e., Reach 2 - Fayetteville versus Reach 1 - Lillington) would generate inundation dynamics in Reach 2 comparable to those in Reach 1, which had already been considered as part of the flow recommendations formulation process for that reach. It was determined that inundation dynamics are not similar; flow-inundation relationships in Reach 2 are remarkably different than in Reach 1. HEC RAS modeling shows that much of Reach 2 rarely flood until flows are much greater than other reaches—perhaps as high as 60,000 CFS. Additional maps for different flow rates are provided in Appendix D.

Inundation in Reach 2 was very limited, even in areas whose topography showed evidence of legacy flow paths of the Cape Fear River. Inspection of model topography (developed from Light Detection and Ranging (LIDAR) data collected by State of North Carolina in 2001) indicated that the current channel is significantly incised. The floodplain group was uncertain about cause, but group members who had visited this reach corroborated that the river was deeply incised in this reach with the active channel bounded by high bluffs (more than 30 feet) on both sides. Functionally, this isolates the river from its historic floodplain in Reach 2. Interestingly, Reach 3 had inundation dynamics that were comparable to Reach 1. The floodplain group speculated that this may be related to the presence of the Lock and Dams, but this was also uncertain and the basic question about Reach 2 incision and potential connections for the Lock and Dams was acknowledged as a research need.

In summary, output from the river hydraulics model suggested that flows in Reach 2 would need to be significantly higher than flows in both Reaches 1 and 3 to achieve the same ecological purposes related to floodplain communities, which would create flow continuity issues. Due to this discovery, the floodplain group did not create flow recommendations for Reach 2.

Reach 3

This reach begins at LD3 and ends at LD1 near Kelly, NC. LD2 is located near the midpoint of the reach. Reach 3 was identified by workshop facilitators as the third reach for consideration by the floodplain group. Gage records at LD3 and LD1 were useful hydrologic references for Reach 3.

Comparisons of flow and inundation showed that Reach 3 was similar to Reach 1. As a starting point for Reach 3, flow recommendations for Reach 1 were adjusted to account for increased watershed size while largely maintaining the pattern and ecological purposes of Reach 1 recommendations. A simple multiplier of 1.5 (based on the ratio of mean flow at LD1 and LD3 versus mean flow at Lillington was used to adjust the Reach 1 flow recommendation magnitudes. Results were reviewed and further modified by the group to cater flow recommendations to the ecological needs of floodplain communities in Reach 3.

Floodplains, Reach 3, Wet

Environmental flow recommendations for this reach are shown in Figure 13. Characteristics of each flow component are detailed below.

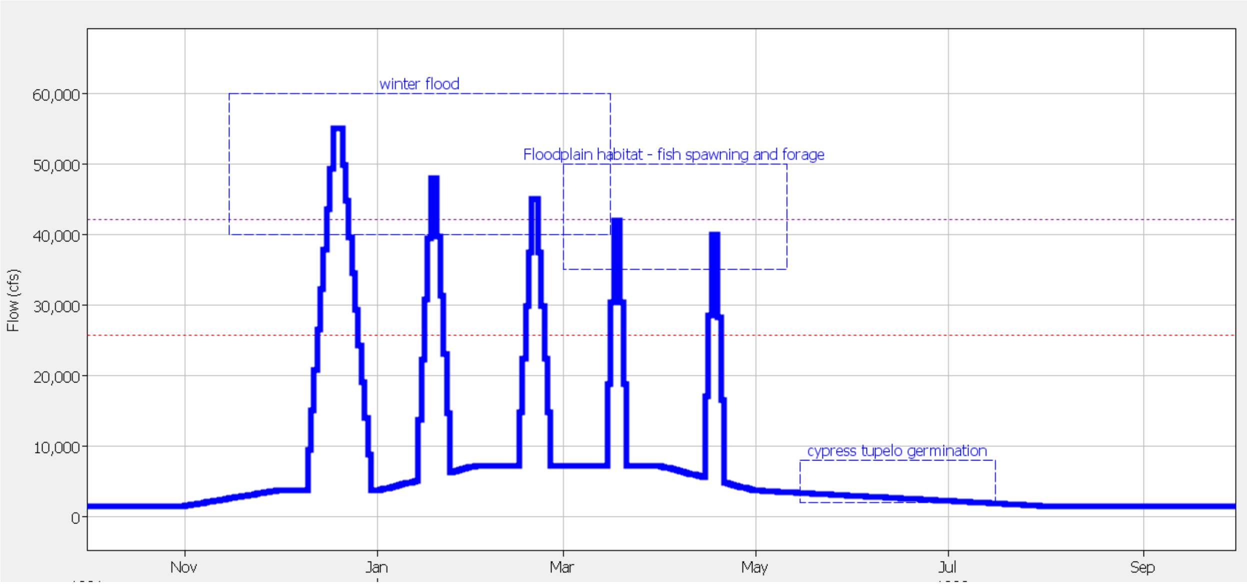


Figure 13. Flow prescription for Floodplains, Reach 3 Wet. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter flood (Floodplains Reach 3, Wet). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 15Nov to 15Mar
Events per season: 2 to 4
Magnitude: 40,000-60,000 CFS
Duration: 10-20 days
Duration of peak: 2-3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
10-Dec	20	55,000	3
14-Jan	10	48,000	2
15-Feb	10	4,5000	2

Purpose: Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: There should be multiple flow events within this operational window of two to four instances per season. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, rewetting of pool areas to support amphibians and reptiles, including spawning of herpetofauna in January and February. Peaks should taper in magnitude as timing approaches the end of the "Winter flood" operational window to limit fish access to ponded areas, which minimizes predation on herpetofauna eggs and larvae. The first event should be longer in duration and have a duration of peak of three days to assure significant inundation and filling of floodplain areas. Subsequent events should have a duration of peak of two days.

Floodplain habitat - fish spawning and forage (Floodplains Reach 3, Wet). This component supports spring spawning fish species.

Season: 01Mar to 10May
Events per season: 2 to 3
Magnitude: 35,000-50,000 CFS
Duration: 6-8 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Mar	6	42,000	2
15-Apr	6	40,000	2

Purpose. Provides access and inundation for spring spawning fishes. Cycles nutrients in floodplain areas. Shad spawn in April (early to mid-month) in the upper section on rocky areas near the fall line. Maintains soil moisture into spring season.

Description: Need multiple events to provide access and inundation for fishes as well as an opportunity to move from floodplain areas to the main channel. This component is related to the "Cypress tupelo germination" component such that in wet periods "Floodplain habitat - fish" is likely to be more successful and in dry periods "Cypress tupelo germination" is likely to be more successful.

Cypress tupelo germination (Floodplains, Reach 3, Wet). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season: 15May to 15Jul
Events per season: none
Magnitude: n.a.
Duration: n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses some aquatic invasive plants.

Description: This component only relevant when preceded by implementation of the "Winter flood" component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is okay - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) two to three dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is ok and important to repeat/initiate cycle opportunistically as often as possible. This component is also related to the "Floodplain habitat - fish" component such that, following a successful "Winter flood", "Floodplain habitat - fish" is likely to be more successful in wet periods and "Cypress tupelo germination" is likely to be more successful in dry periods.

Low flows (Floodplains, Reach 3, Wet). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected. Low flows for Reach 3 are equal to Reach 1 low flows multiplied by 1.5.

Date	Flow (CFS)
1-Oct	1,500
31-Oct	1,500
30-Nov	3,750
1-Jan	3,750
1-Feb	7,250
31-Mar	7,250
30-Apr	3,750
1-Aug	1,500
30-Sep	1,500

Floodplains, Reach 3, Average

Environmental flow recommendations for this reach are shown in Figure 14. Characteristics of each flow component are detailed below. Recommendations for "Average" hydrologic conditions are similar to those for "Wet", catering to the life history needs of the same floodplain communities.

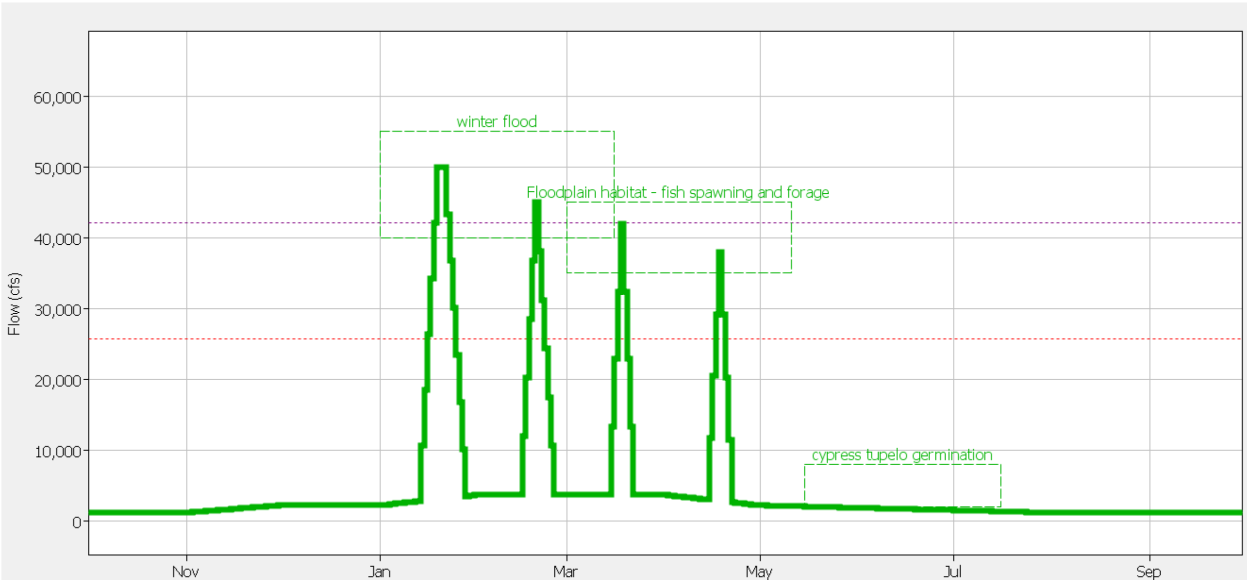


Figure 14. Flow prescription for Floodplains, Reach 3 Average. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter flood (Floodplains, Reach 3, Average). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 01Jan to 15Mar
Events per season: 2 to 3
Magnitude: 40,000-55,000 CFS
Duration: 10-14 days
Duration of peak: 1-3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
14-Jan	14	50,000	3
15-Feb	10	45,000	1

Purpose. Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: There should be multiple flow events within this operational window of two to three instances per season. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, rewetting of pool areas to support amphibians and reptiles, including spawning of herpetofauna in January and February. Peaks should taper in magnitude as timing approaches the end of the "Winter flood" operational window to limit fish access to ponded areas, which minimizes predation on herpetofauna eggs and larvae. The first event should be longer in duration and have a duration of peak of three days to assure significant inundation and filling of floodplain areas.

Floodplain habitat - fish spawning and forage (Floodplains Reach 3, Average). This component supports spring spawning fish species.

Season: 01Mar to 10May
Events per season: 2 to 3
Magnitude: 35,000-45,000 CFS
Duration: 7 days
Duration of peak: 1 day
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Mar	7	42,000	1
15-Apr	7	38,000	1

Purpose. Provides access and inundation for spring spawning fishes. Cycles nutrients in floodplain areas. Shad spawn in April (early to mid-month) in the upper section on rocky areas near the fall line. Maintains soil moisture into spring season.

Description: Need multiple events to provide access and inundation for fishes as well as an opportunity to move from floodplain areas to the main channel. This component is related to the "Cypress tupelo germination" component such that in wet periods "Floodplain habitat - fish" is likely to be more successful and in dry periods "Cypress tupelo germination" is likely to be more successful.

Cypress tupelo germination (Floodplains, Reach 3, Average). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season: 15May to 15Jul
Events per season: none
Magnitude: n.a.
Duration: n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses aquatic invasive plants such as alligator weed.

Description: This component only relevant when preceded by implementation of the "Winter flood" component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is ok - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) two to three dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is ok and important to repeat/initiate cycle opportunistically as often as possible. This component is also related to the "Floodplain habitat - fish" component such that, following a successful "Winter flood", "Floodplain habitat - fish" is likely to be more successful in wet periods and "Cypress tupelo germination" is likely to be more successful in dry periods.

Low flows (Floodplains, Reach 3, Average). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected.

Date	Flow (CFS)
1-Oct	1,200
31-Oct	1,200
30-Nov	2,250
1-Jan	2,250
1-Feb	3,750
31-Mar	3,750
30-Apr	2,250
1-Aug	1,200
30-Sep	1,200

Floodplains, Reach 3, Dry

Environmental flow recommendations for this reach are shown in Figure 15. Characteristics of each flow component are detailed below. Recommendations for "Dry" hydrologic conditions are significantly reduced from "Average".

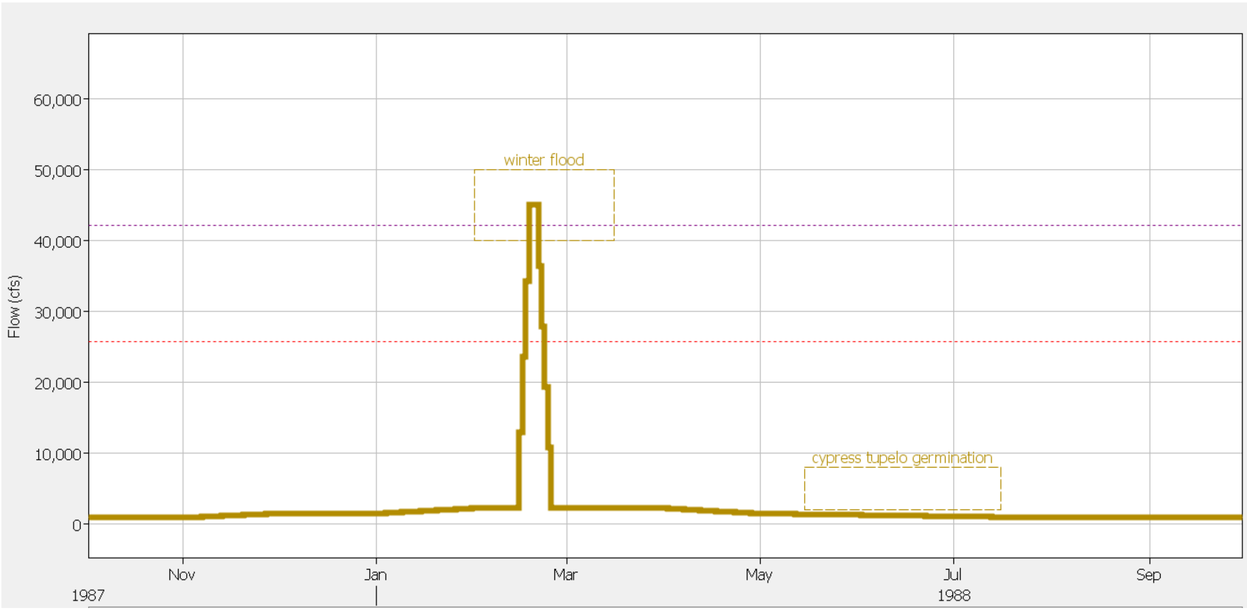


Figure 15. Flow prescription for Floodplains, Reach 3 Dry. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Winter flood (Floodplains, Reach 3, Dry). An integral part of the floodplain group recommendations, this component supports floodplain plant communities as well as fishes and herpetofauna (amphibians and reptiles).

Season: 01Feb to 15Mar
Events per season: 1
Magnitude: 40,000-50,000 CFS
Duration: 10 days
Duration of peak: 3 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
15-Feb	10	45,000	3

Purpose. Distribution of fall-produced seeds of bald cypress and tupelo. Promote nutrient cycling. Recharge shallow groundwater. Discourage encroachment of upland terrestrial and invasive species. Maintain soil condition characteristic of floodplain areas, including soil moisture content.

Description: One flow event within this operational window. Duration should be sufficient to inundate floodplain areas and fill any associated ponds. Peaks in consecutive dry winters should be variable to encourage distribution of sediments throughout floodplain areas, wetting and drying of detritus in different areas to support nutrient cycling, and wetting of different pool areas to support amphibians and reptiles, including spawning of herpetofauna. Event should have a duration of peak of three days to generate as much inundation and filling of floodplain areas as possible.

Cypress tupelo germination (Floodplains, Reach 3, Dry). This component is different in that it recommends an absence of flow events - a prolonged dry period to promote establishment of bottomland hardwood seedlings.

Season:	15May to 15Jul
Events per season:	none
Magnitude:	n.a.
Duration:	n.a.

Purpose. 60-90 days of exposed soils with no inundation. Lack of inundation supports germination and initial establishment of cypress and tupelo seedlings. Dry period also advantageous for ground-nesting birds. Suppresses aquatic invasive plants such as alligator weed.

Description: This component only relevant when preceded by implementation of the "Winter flood" component. This component is about establishing new cohorts of long-lived plant species. Following high winter flows with a prolonged dry period may be a rare occurrence, which is ok - it's only needed occasionally – given the longevity of the target species. The full establishment sequence is 1) successful winter flood and then 2) successful germination period occurs and then 3) two to three dry years to support establishment. This cycle is increasing the odds of seedling survival, which is low (ecologically). Thousands of seedlings lead to establishment of a few individuals, which ultimately leads to a mixed age stand of bottomland hardwoods. Because this component is just designed to tilt the odds in favor of cypress and tupelo establishment, it is ok and important to repeat/initiate cycle opportunistically as often as possible. This component is also related to the "Floodplain habitat - fish" component such that, following a successful "Winter flood", "Floodplain habitat - fish" is likely to be more successful in wet periods and "Cypress tupelo germination" is likely to be more successful in dry periods.

Low flows (Floodplains Reach 3, Dry). Low flows were not viewed as strongly connected to floodplain ecosystems, which are more influenced by high flows that inundate floodplain areas. Soil moisture maintenance and riverine habitat for fish that utilize floodplain areas opportunistically were discussed. An important caveat is, given that higher flow events are departures from low flows, if low flows are significantly different than those recommended by the floodplains group, the other floodplain components should be reviewed to assure that the amount (duration and magnitude) of river-floodplain engagement is unaffected.

Date	Flow (CFS)
1-Oct	900
31-Oct	900
30-Nov	1,500
1-Jan	1,500
1-Feb	2,250
31-Mar	2,250
30-Apr	1,500
1-Aug	900
30-Sep	900

Research and modeling needs from the floodplain team

1. There are two reaches within Reach 1. Jordan to Buckhorn and Buckhorn to Lillington. What is the flow relationship for management in Reach 1? USGS has data that will help us figure this out as well as the Corps knowledge from long term management of flows from both Jordan and the Deep River. *We did talk extensively about this as we discussed flow management for high peaks. We need the flow from the Deep River to supplement the flows from Jordan in order to get to some of the desirable CFS for peaks.* Corps has indicated that flows from Jordan flow over Buckhorn Dam and Buckhorn is run of river. There may be local flow, but it is minor.
2. What inundation do we need to create the right soil moisture in the floodplain (is overtopping required)? Groundwater / well monitoring will be necessary to understand this dynamic better.
3. What are the ecological connections to fall tropical storm events? (Are there positive benefits from the substantial fall flood pulses provided by tropical storms/hurricanes?)
4. What are the implications of water pulses in the channel for the floodplain plus instream biota and habitats? (Beyond spawning triggers)
5. Why is Reach 2 so incised? (Is it only geologic or is it also anthropogenic?) LiDAR indicates flowing channels in the grasslands adjacent to the incised channel. Why does Reach 3 rebound so significantly from Reach 2?
6. Do we know how often Cypress/Tupelo Recruit into the Forest Component (help to determine how often we need floodplain inundation and recruitment conditions for saplings to maintain this forest composition)?

Appendix I: Water quality break-out group findings

The follow pages detail the Water quality break-out group findings to include:

- Process
- General prescription goals for each year
- Water quality prescriptions for fish by reach
  - Reach 3
  - Reach 2
  - Reach 1
- Research and modeling needs from the Water quality team

Process

The Water Quality group was tasked with making flow recommendations that can improve water quality and reduce the incidence of harmful algal blooms. The literature review included a summary of the publicly available information related to water quality status and trends across the Cape Fear Basin (see literature review, pages 36-40). After reviewing this information, participants came prepared with their expert knowledge as well as additional information regarding recent and ongoing studies that were not available at the time the literature review was written. While the focus of the group was water quality, group participants shared the view that flow prescriptions needed for fish or floodplains would likely also provide water quality benefits.

By establishing basic goals and objectives the group was able to establish basic needs to pursue for water quality flow prescription. The Water Quality Group was assigned the reach priority sequence of Reach 2, Reach 1 and Reach 3, Reach 0, by workshop organizers. Each of the three groups were given a different sequence to assure all three reaches would have at least one prescription formulated as a base to move forward during the unification of all three reaches. Every effort was made to adhere to the assigned reach sequence, but some jumping around did occur as the sessions progressed.

General prescription goals for each year

The following overarching ecosystem objectives became the criteria for establishing water quality flow prescriptions for each of the reaches and year types.

Infiltration and Return Flows

Overbank flooding promotes water infiltration through floodplain soils, which can improve water quality by removing nutrients and other contaminants, recharge groundwater, and provide return flows to the stream that may elevate base flow and reduce in-stream temperatures. Yet, Jordan Dam alone has limited release capacity to produce very large pulses that produce overbank flood events. Jordan Dam releases could potentially be opportunistically timed to coincide with high Deep River inflows in the spring to cause larger overbank flooding (CFS varies by reach), when conditions are suitable. The appropriate time for these flows would be February 1 through June 1, when conditions are suitable; the group expected that taking advantage of floodplain infiltration during these months would help to raise baseflow during the summer and fall, which would also aid in preventing in-stream stratification. The group arrived at six pulses per spring but was flexible on timing, duration and event numbers as long as the end benefit of reducing nutrients and increased infiltration was accomplished. Conditions permitting, operating the dam to approximate run-of-river flows may accomplish the desired outcomes as well. These pulses could also have the added benefit of removing nutrients from Jordan Lake/Reach 0. Additional monitoring data to compare the effectiveness of these alternatives would aid in refining this prescription.

Break Up In-stream Stratification

Recent and ongoing studies are providing mounting evidence that in-stream stratification is a major driver of algal blooms. High retention time, when water stays in a particular reach of the stream for an extended period of time, is a problem from a water quality standpoint because it can promote stratification, accumulation of high nutrient and contaminant concentrations, and low dissolved oxygen. Stratification, or the division of the water column into layers due to differences in temperature, is not common in unimpaired stream environments, but is well documented in lake environments and can occur in stream pools particularly during low flows.

The group proposed that to prevent algal blooms and low dissolved oxygen conditions from forming, higher minimum flows or pulses (CFS vary by reach) in the late spring, summer and fall each year could be used to break up in-stream stratification. The appropriate time for these flows would be May 1 through October 31 and the group expects that these flow prescriptions would be useful across wet, dry and average water years. Periodic pulses may be able to achieve the same goals as minimum flows, while also supporting fish and floodplain objectives and requiring less water; although the group is optimistic that this could be a viable alternative, there is no available data comparing the effectiveness of these prescriptions. Monitoring algal blooms and dissolved oxygen levels under experimental minimum flows and pulse combinations would provide additional data to help refine this prescription.

Nutrient Removal out of Jordan Lake

Jordan Lake is a nutrient source for downstream reaches of the Cape Fear River, with higher nutrient concentrations at depth; strategically sending high nutrient-load waters downstream and into the floodplain in the spring each year could help to reduce the amount of nutrients within Jordan Lake. The anticipated benefit is to reduce nutrients in Jordan Lake overall, but especially within the New Hope Arm of Jordan Lake. The appropriate time for these flows would be February 1 through June 1 and this flow prescription is expected to be beneficial in wet, dry and average water years. The group arrived at six release pulses per spring but was flexible on timing, duration and even number as long as the end benefit of reducing nutrients was accomplished. The pulses in this description are directly at the dam. When combined with the flows from the Deep River, this prescription should be similar to the Infiltration and Return Flows prescription, and should support both objectives. A caveat for this flow prescription was to not send water with low dissolved oxygen downstream, particularly during the warm season.

Water quality flow prescriptions by reach

Reach 2

Reach 2 is characterized by extreme channel incision with high bluffs bounding both banks of the river, which limits potential for flows to interact with the floodplain except under life-threatening flood events; therefore, the group determined that the only practical water quality flow prescription for Reach 2 would be to break up in-stream stratification May 1 through October 31. The CFS recommendations are outlined below and were the same for wet, average and dry years.

Break Up In-stream Stratification (Water Quality, Reach 2, Wet, Average and Dry are the same):

Season:	1May to 31Oct
Events per season:	1 or possibly weekly pulses
Magnitude:	1,000 CFS
Duration:	150 days
Duration of peak:	150 days

Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	150	1,000	150

Purpose. Prevent algal blooms and low dissolved oxygen.

Description: The appropriate time for these flows would be 1May to 31Oct and this flow prescription would be useful in wet, dry and average water years. The group agreed that if natural flow events occurred that accomplished the same goals, there was not a need to adhere strictly to the schedule of prescribed flows. The group recommended a sustained minimum flow of 1,000 but theorized that weekly pulses could have a similar benefit and were willing to experiment with timing, duration and number as long as the end benefit of breaking up instream stratification to prevent algal blooms and prevent low dissolved oxygen was accomplished. Caveat: pulse frequency suggestions are rough estimates with more research required.

Reach 1

The bulk of the group's discussion centered on developing prescriptions for Reach 1, and the majority of the water quality needs elaborated below were developed at this time. The main water quality concerns highlighted included: harmful algal blooms, nutrients and low dissolved oxygen levels. Experts in the group volunteered unpublished relevant research observations that were not included in the literature review, yet were crucial to the group's discussion—for example, group members provided data regarding flow conditions during known algal bloom occurrences within the Cape Fear River basin. For Reach 1, an 800 CFS low flow minimum was also established and 1200 CFS was preferred. The team drafted a prescription for the river that was based on opportunities with the weather. The idea is that the Corps would do their best to achieve the ecological purposes within a given operational window. The timing, frequency, and difference in water years are further detailed below.

Water Quality, Reach 1, Dry

Environmental flow recommendations for this reach are shown in Figure 16. Characteristics of each flow component are detailed below.

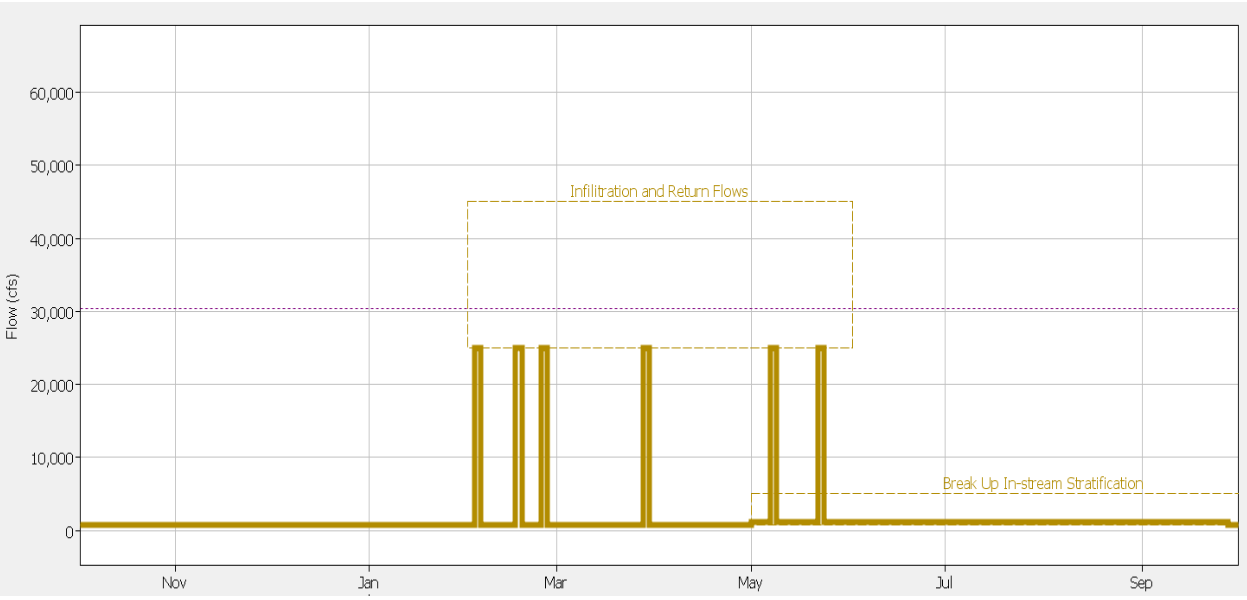


Figure 16. Flow prescription for Water Quality, Reach 1 Dry. Purple dotted line is NWS flood stage at Lillington.

Infiltration and Return Flows (Water Quality Reach 1, Dry): The goal was to team Jordan Dam releases with Deep River flows in the spring each year to cause overbank flooding where possible.

Season: 1Feb to 1Jun
Events per season: 6
Magnitude: 25,000-45,000 CFS
Duration: 2 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
03Feb	2	25,000	2
16Feb	2	25,000	2
24Feb	2	25,000	2
28Mar	2	25,000	2
07May	2	25,000	2
22May	2	25,000	2

Purpose. Facilitate infiltration and return flows later in the year.

Description: The appropriate time for these flows would be 1Feb to 1Jun and this flow prescription would be useful in wet, dry and average water years. The group agreed that if a natural flow events occurred that accomplished the same goals, there was not a need to adhere strictly to the schedule of prescribed flows. The group arrived at six pulses per spring but was flexible on timing, duration and even number as long as the end benefit of reducing nutrients and supporting infiltration was accomplished. Because the Nutrient Removal flow prescription for Reach 0 was of similar CFS, timing and frequency as those needed for the Infiltration and Return Flows flow prescription, the flow prescription could likely serve both purposes. If conditions permitted and operating the dam as run of river would accomplish these outcomes, then that would be an acceptable strategy as well. The group drafted 25,000 CFS as a starting point of when overbank flow occurs according to examples from the HEC RAS modeling, but this needs further refinement. The group encourages the Corps to be opportunistic with these pulses and promote overbank flow when feasible. More overbank flow events are preferred to fewer but bigger pulses.

Break Up In-stream Stratification (Water Quality, Reach 1, Dry): The goal was to break up instream stratification.

Season: 1May to 31Oct
Events per season: Minimum flows all season, or possibly weekly pulses
Magnitude: 800-5,000 CFS
Duration: 150 days
Duration of peak: 150 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	150	1,200	150

Purpose. Prevent algal blooms and low dissolved oxygen.

Description: A sustained flow of 800 CFS, but ideally 1,200 CFS from 1May to 31Oct was determined to be the minimum flow requirement to achieve the desired goals, and this flow prescription would be useful in wet, dry and average water years. Periodic pulses may work the same as minimum flows if pulses were more advantageous to other group (Fish/Flood plains) purposes, thus the operation window is drawn to 5,000 CFS to allow for pulsing (although no pulses were drawn in RPT). Continued monitoring for algal blooms and dissolved oxygen as different minimum flow or pulse combinations were experimented with would help refine this prescription. If conditions permitted and operating the dam as run of river would accomplish these outcomes, then that would be an appropriate strategy as well.

Low flows: All year long, the water quality group requests a low flow minimum of 800 CFS to avoid algal blooms. If this cannot be achieved, pulses to break-up stratification are recommended.

Water Quality, Reach 1, Wet and Average

The water quality team used Reach 1 Dry above to demonstrate the general trends that would work for all water years. The prescription for Reach 1 Wet and Average follow the same operational boxes as the dry recommendation above. The water quality team encourages the Corps to be opportunistic to achieve the ecological purposes of the operational boxes. In a wet water year, send more pulses (and even higher pulses) to promote Infiltration and Return Flows. Also, if there is more water, keep a minimum flow of 1,200 CFS in Break Up In-Stream Stratification to reduce the chances of algal blooms. If 1,200 CFS is not feasible, keep a minimum of 800 CFS and try pulses during this time.

Reach 3

Many of the prescriptions developed for Reach 1 could be applied in Reach 3 by raising the CFS slightly. The needs were mostly the same and the group agreed that the following flow prescriptions would be the most effective at improving water quality in Reach 3: break up stratification and infiltration and return flows.

Water Quality, Reach 3, Dry

Environmental flow recommendations for this reach are shown in Figure 17. Characteristics of each flow component are detailed below.

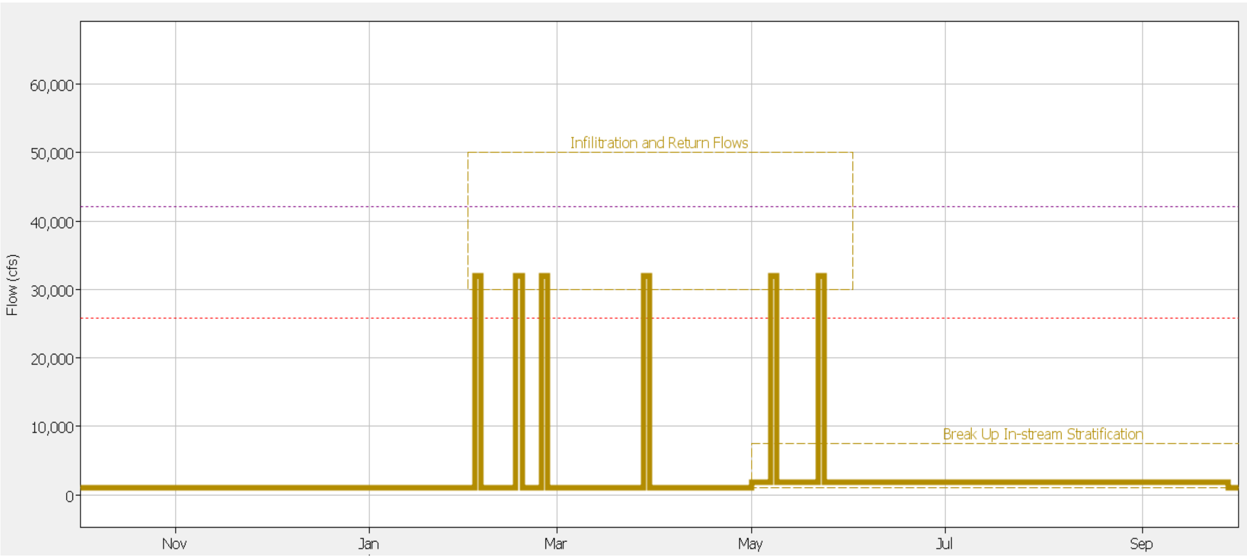


Figure 17. Flow prescription for Water Quality, Reach 3 Dry. Purple dotted line is NWS flood stage at LD1. Red dotted line is NWS flood stage at LD3.

Infiltration and Return Flows (Water Quality, Reach 3, Dry): The goal was to team Jordan Dam releases with Deep River flows in the spring each year to cause overbank flooding where possible.

Season: 1Feb to 1Jun
Events per season: 6
Magnitude: 30,000-50,000 CFS
Duration: 2 days
Duration of peak: 2 days

Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
03Feb	2	32,000	2
16Feb	2	32,000	2
24Feb	2	32,000	2
28Mar	2	32,000	2
07May	2	32,000	2
22May	2	32,000	2

Purpose. Facilitate infiltration and return flows later in the year.

Description: The appropriate time for these flows would be 1Feb to 1Jun and this flow prescription would be useful in wet, dry and average water years. The group agreed that if a natural flow events occurred that accomplished the same goals, there was not a need to adhere strictly to the schedule of prescribed flows. The group arrived at six pulses per spring but was flexible on timing, duration and even number as long as the end benefit of reducing nutrients and supporting infiltration was accomplished. If conditions permitted and operating the dam as run of river would accomplish these outcomes, then that would be an acceptable strategy as well. The group drafted 30,000 CFS as a good point of when overbank flow occurs according to examples from the HEC RAS modeling, but this needs further refinement as the NWS flood stages show different flow rates flood the banks at various stretches of river. The group encourages the Corps to be opportunistic with these pulses and promote overbank flow when feasible. More overbank flow events are preferred to fewer but bigger pulses.

Break Up In-stream Stratification (Water Quality, Reach 3, Dry): The goal was to break up instream stratification.

Season: 1May to 31Oct
Events per season: Minimum flows all season, or possibly weekly pulses
Magnitude: 1,000-7,500 CFS, target goal of 1,800 CFS
Duration: 150 days
Duration of peak: 150 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
01May	150	1,800	150

Purpose. Prevent algal blooms and low dissolved oxygen.

Description: A sustained flow of 1,000 CFS, but ideally 1,800 CFS from 1May to 31Oct was determined to be the most beneficial and this flow prescription would be useful in wet, dry and average water years. Periodic pulses may work the same as minimum flows if pulses were more advantageous to other group (Fish/Flood plains) purposes, thus the operation window is drawn to

7,500 CFS (although no pulses were drawn in RPT). Continued monitoring for algal blooms and dissolved oxygen as different minimum flow or pulse combinations were experimented with would help refine this prescription. If conditions permitted and operating the dam as run of river would accomplish these outcomes, then that would be an appropriate strategy as well.

Low flows: All year long, the water quality group requests a low flow minimum of 1,000 CFS to avoid algal blooms. If this cannot be achieved, pulses to break-up stratification are recommended.

Water Quality, Reach 3, Wet and Average
The water quality team used Reach 3 Dry above to demonstrate the general trends that would work for all water years. The prescription for Reach 3 Wet and Average follow the same operational boxes as the dry recommendation above. The water quality team encourages the Corps to be opportunistic to achieve the ecological purposes of the operational boxes. In a wet water year, send more pulses (and even higher pulses) to promote Infiltration and Return Flows. Also, if there is more water, keep a minimum flow of 1,800 CFS in Break Up In-Stream Stratification to reduce the chances of algal blooms. If 1,200 CFS is not feasible, keep a minimum of 1,000 CFS and try pulses during this time.

Reach 0

In addition to the other reaches, the water quality group was also tasked with exploring solutions to water quality issues in Jordan Lake which was named Reach 0. The overabundance of nutrients results in algal blooms, and is thought to contribute to nutrient loading and water quality problems downstream. For Reach 0, a new flow prescription known as Reduce Nutrients was developed, which was determined to be appropriate for wet, average or dry years. Because the Nutrient Removal flow prescription was of similar CFS, timing and frequency as those needed for the Infiltration and Return Flows flow prescription, the flow prescription could likely serve both purposes.

Water Quality, Reach 0, Wet
Environmental flow recommendations for this reach are shown in Figure 18. Characteristics of each flow component are detailed below.

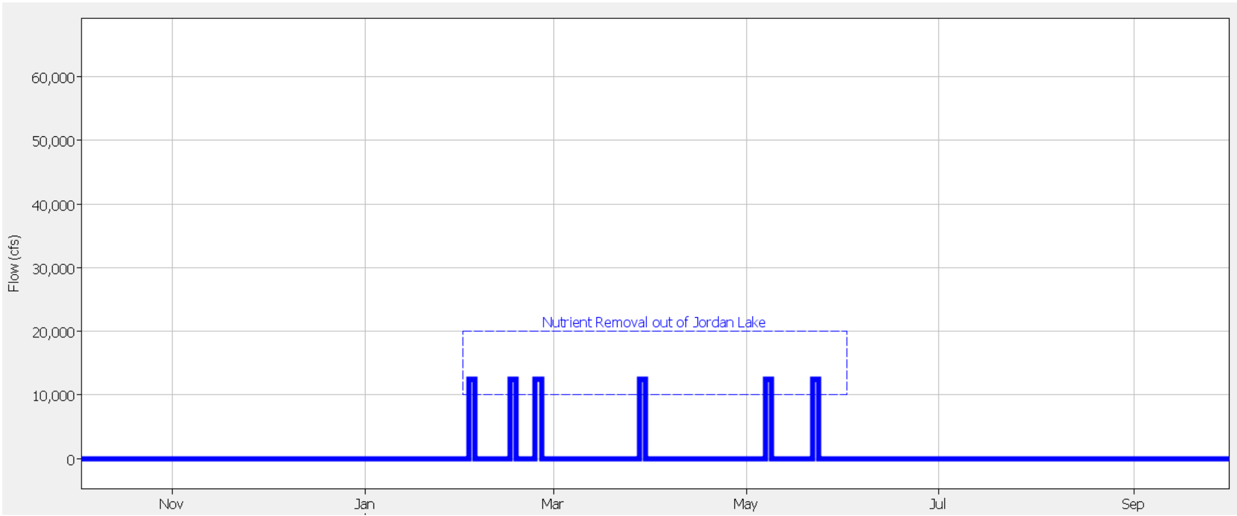


Figure 18. RPT plot of flow recommendations for the Cape Fear River, Reach 0, Wet, Water Quality. This prescription is for direct releases out of Jordan Lake.

Nutrients Removal (Water Quality, Reach 0, Wet): The goal was to remove nutrients from Jordan Lake by sending it downstream and into the floodplain in the spring each year to reduce the amount of nutrients in the system.

Season: 1Feb to 1Jun
Events per season: 6
Magnitude: 10,000-20,000 CFS
Duration: 2 days
Duration of peak: 2 days
Hypothetical Sample Schedule (CFS targets listed below are only estimates):

Date	Duration (days)	Peak (CFS)	D.O.P. (days)
03Feb	2	12,500	2
16Feb	2	12,500	2
24Feb	2	12,500	2
28Mar	2	12,500	2
07May	2	12,500	2
22May	2	12,500	2

Purpose. Reduce nutrients in Jordan Lake overall and specifically in the New Hope Arm of Jordan Lake.

Description: The appropriate time for these flows would be February 1 to June 1 and this flow prescription would be useful in wet, dry and average water years. In wet years, the group agreed that if a natural flow events occurred that accomplished the same goals, there was not a need to adhere strictly to the schedule of prescribed flows. The group arrived at six pulses per spring but was flexible on timing, duration and even number as long as the end benefit of reducing nutrients in Jordan was accomplished. Because the Nutrient Removal flow prescription was of similar CFS, timing and frequency as those needed for the Infiltration and Return Flows flow prescription, the flow prescription could likely serve both purposes. A caveat for this flow prescription was to not send water with low dissolved oxygen downstream.

Water Quality, Reach 0, Average and Dry

The water quality team used Reach 0 Wet above to demonstrate the general trends that would work for all water years. The water quality team encourages the Corps to be opportunistic to achieve the ecological purposes of the releases. In an average or dry year, the Corps could send fewer pulses downstream.

Research and modeling needs from the water quality team

- Travel times: What are the actual travel times from Jordan dam to LD1 in different flow conditions?
- Can pulses or sustained higher base flows break up in-stream stratification and reduce the potential for harmful algal blooms? If using pulses, what is the frequency required?
- Are there salinity issues above LD1?
- How will ongoing and future development affect future water quantity in the Basin?
- Would winter/spring pulses return flows provide benefits in Reach 2 even if it is not possible to overtop the banks and achieve interaction with the floodplain for this portion of the Cape Fear River?
- Are Buckhorn Lake water quality issues due to high chlorophyll a from Jordan Lake, or is this a local issue?
- Under dry conditions, in-stream mixing in reach 1 could be prescribed by better understanding how chlorophyll a responds to flow.
- What is the origin of the 600 CFS target for flow? Is this sufficient? The group suspects that higher flows are needed to prevent water quality problems at low flows. More information is in House Document 508, which is a letter from the Chief of Engineers, Dept of Army from 1962.
- A better understanding of infiltration, hyporheic flow, soil moisture conditions, etc. would be helpful in determining whether winter and spring pulses that push water up onto the floodplain will result in higher baseflows and cooler temperatures in the warm season.
- We do not have a good estimate of how much sediment deposition could occur on the floodplain and implications for water quality if flood pulses were implemented.
- We do not have a good understanding of in-lake sediment.
- We do not have a good understanding of how flow prescriptions discussed would affect bank stability and erosion. Under wet conditions are high flows a problem for erosion and sedimentation? Does this have nutrient implications?
- Under dry conditions, the group suspects that pulses would be more effective than a sustained low flow alone for water quality. Without better data, the group recommended a minimum flow of 1200 CFS at the LD to avoid harmful algal bloom conditions.
- Would winter and spring pulses result in measurable nutrient processing and growing season return flows to raise base flow, improve water quality, and reduce in-stream temperature?
- How much nutrient removal would be possible with pulses of water taken from deeper in the water column?
- We do not have a sufficient understanding of sediment oxygen demand?
- We do not fully understand the effects of discharging water pulled from depth in Jordan Lake; there may be tradeoffs for nutrients and temperature.