Identifying Environmental Flow Requirements for the Cape Fear River

Background Literature Review and Summary

2019

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Executive Summary

The Sustainable Rivers Program (SRP) is a joint nationwide effort between the U. S. Army Corps of Engineers (Corps) and The Nature Conservancy (TNC). The mission of the program is to improve the health and life of rivers by altering dam operations to enhance and protect ecosystems, while maintaining or enhancing other dam benefits. Healthy and sustainable ecosystems provide a wide array of services to human communities, including improved water

quality and protection from floods and storms. While modification to the natural flows of river basins have benefitted humans in many ways, significant consequences and challenges can result for humans, as well as species that depend on the interconnectivity of the systems. The SRP attempts to analyze the effects from dams and use reservoir operations to enhance and manage downstream (and sometimes in lake) ecosystems.

Once a river is in the program, it goes through a formal process to consider e-flows for a basin. This includes gathering technical stakeholders to discuss the issues and potential solutions in the basin, compiling a literature review to gather information about pre- and post-dam conditions, hosting an e-flow (environmental flow) workshop to draft e-flow prescriptions, modeling the e-flow prescriptions, testing an e-flow, studying the outcomes, and eventually finding a way to make the e-flow part of regular operating procedures. The Cape Fear River was added to the SRP in 2016. It was chosen because of the numerous users in the basin, the complex human-ecology relationships, the fact that the Corps has important infrastructure in the basin, and because there are diverse species and ecosystems.

This document serves as the literature review and includes significant analysis of hydrological conditions pre- and post-dam. Within the Cape Fear River Basin, the Corps operates B. Everett Jordan Dam (Jordan Dam) and three locks and dams downstream. Jordan Dam has five Congressionally authorized purposes: (1) flood control, (2) water supply, (3) recreation, (4) water quality control, and (5) fish and wildlife conservation; while the locks and dams are authorized for navigation only.

The effects of Jordan Dam were analyzed using USGS water gages at Lillington, Lock and Dam 3 (LD3), and Lock and Dam 1 (LD1). As authorized, the 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, small floods were less frequent, but of longer duration. The dam increased baseflow and low flows. The rise and fall rate of the river were dampened. These effects were most noticeable in Lillington, but still remained at LD3. Due to LD1's distance downstream, Jordan has the potential to influence LD1 in low flow conditions. All of these changes elicit questions about associated ecological effects, including migratory cues, floodplain inundation, river-creating geomorphology, plant recruitment on streambanks, associated levels of dissolved oxygen and more.

This literature review is to help guide experts during an e-flows workshop. Experts will be divided into three areas– floodplains, water quality, and fish– with the idea that they will draft target hydrographs for stretches of the river that range from Jordan Lake to LD1. The floodplains group is tasked with thinking about flow-ecology relationships that lend themselves towards healthy, connected, functioning floodplains. The Cape Fear spans the Piedmont and Coastal plain, leading to a diverse array of floodplain forests. The water quality group is tasked with thinking about flow-ecology relationships that will reduce algal blooms and improve other water constituents. The fish group is tasked with thinking about flow needs for diadromous and rare fish.

After experts have crafted their recommendations, the group will come together to create one general flow prescription that encompasses needs for floodplains, water quality and fish, combined. At the end of the e-flows workshop, participants will brainstorm computer modeling needs, potential limitations, and ways that Jordan dam can contribute to the target recommendations. The goal of SRP is to be additive to other efforts throughout the basin and enhance healthy flows in the Cape Fear.

Summary of Terms

LD1	Lock and Dam 1
LD2	Lock and Dam 2
LD3	Lock and Dam 3, also known as William O. Huske Lock and Dam
E-flows	Environmental flows
TNC	The Nature Conservancy
Corps	United States Army Corps of Engineers
SRP	Sustainable Rivers Program
USGS	United States Geological Service
IHA	Indicators of Hydrologic Alteration
cfs	Cubic Feet per Second
mgd	Million of Gallons a Day
IBT	Interbasin Transfer
m.s.l.	Mean Sea Level
NC DEQ	North Carolina Department of Environmental Quality
WCM	Water Control Manual

Introduction and Background

The Sustainable Rivers Program (SRP) is a joint nationwide effort between the Army Corps of Engineers (Corps) and The Nature Conservancy (TNC). The mission of the program is to improve the health and life 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 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 (Figure 1).

ADVANCE: **3,325 miles of river**
Define flow prescription(s) with stakeholders and US Army Corps of Engineers

IMPLEMENT: **531 miles of river**
Test flow prescription(s) to determine optimum dam operations

INCORPORATE: **1,255 miles of river**
Revise water control plan or other legal means to include environmental flows in dam operations

TOTAL: 5,111 MILES OF RIVER

Figure 1. Sustainable Rivers Program rivers across the country as of 2018.

SRP places rivers into the categories of Advance, Implement, and Incorporate. The Advance category is the first step– in this stage, stakeholders work with the Corps to form e-flow prescriptions for a river basin. The Cape Fear River is in this category. The Implement category is when the Corps tests a flow prescription to determine the optimum dam operations. The Incorporate category is when the e-flow prescription has been tested and becomes a regular operating procedure for the Corps.

Healthy and sustainable ecosystems provide a wide array of services to human communities, including improved water quality and protection from floods and storms. While modification to the natural flows of river basins have benefitted humans in many ways, significant consequences and challenges can result for humans, as well as species that depend on the interconnectivity of the systems. Human modifications have resulted in a range of impacts to commercial fisheries, floodplain size and shape, habitat connectivity, sediment and nutrient flows, water temperature and dissolved oxygen levels. SRP attempts to analyze the effects from dams and use reservoir operations to restore and manage downstream (and sometimes in lake) ecosystems.

The natural hydrograph of a river nurtures different parts of organisms' life cycles. For instance, fish migration cues might occur in times of flood pulse events. Large floods might enhance channel morphology or create new in-stream habitat. Plant seedlings might recruit the streambanks during low flows. Within SRP, a main goal is to assess the river (as much as possible) before a dam was built, compare it to post-dam conditions, and find ways that the dam can be used to recreate better river conditions.

SRP has a well-established process to think about e-flows for an entire river basin that allows for adaptive implementation (Figure 2). In the first step, basin experts are gathered to discuss the problems in the basin and determine if there are opportunities. Next, TNC and the Corps re-engage experts as they draft a review of the basin. This review gathers information about e-flow requirements for multiple organisms (fish, mussels, birds, etc.), habitat conditions (floodplain needs, etc.), and basin characteristics. Within this review, initial analysis is done to assess hydrologic alterations using pre and post-dam water flow data. In the third step, expert stakeholders review the information and identify incompatibilities between hydrologic alterations and species/habitat flow needs. These experts brainstorm specific recommendations for flows. This process, originally developed by Brian Richter and team while working on the Savanah River in Georgia (Richter, 2006), is commonly known as the Savanah River process. The Corps models these recommendations and assesses how they can maintain their project authorized purposes while making improvements downstream. If a new flow prescription is implemented, research and data continue to refine the knowledge, so the Corps is using adaptive management to maximize the downstream benefits.

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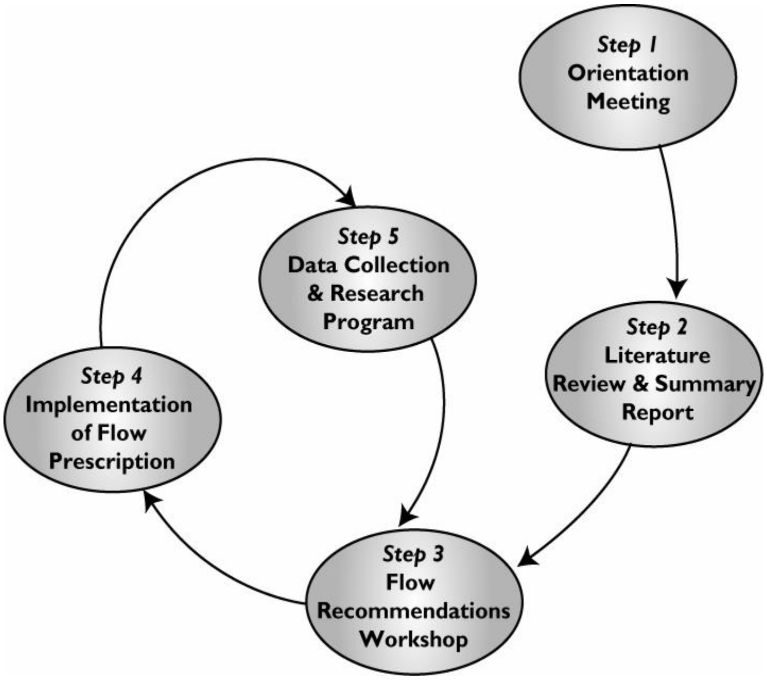


Figure 2. SRP process to consider and adopt e-flow prescriptions for a river *(Richter, 2006)***.**

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 Jordan

Dam has such potential implications for fish and wildlife habitat, water quality, and other natural resources. The Cape Fear River Basin supports 95 species of recreational fish, 42 rare aquatic species, as well as streamside habitat that has the oldest trees east of the Rocky Mountains, some being dated at over 2000 years old (Stahle, 2012). Both people and species rely on the Cape Fear River, making its water quality and water quantity of the utmost importance. Specifically, the dam reduced peak flows, increased baseflows, and reduced floodplain inundation as part of its flood control and low-flow augmentation (water quality) purposes. Additionally, three Corps-owned lock and dams downstream are significant blocks to aquatic species and have experienced algal blooms in the pools created by the lock and dams. The aim of the Cape Fear SRP is to identify preferred flow regimes for fish and wildlife populations, ecosystem function, river and floodplain habitat, and water quality, and explore whether it is possible to modify Corps' dam operations to accommodate these flow regimes. Restoring at least some aspects of the natural flow regime would be expected to benefit numerous fish species and perhaps floodplain plant communities and terrestrial wildlife. Ultimately, the goal is to identify and better integrate understanding of flow needs into real-time decisions about how and when water is released from the reservoirs to achieve more natural flow regimes, and to adjust operations as needed in response to monitoring and modeled responses.

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 (i.e. Figure 2, Step 1) occurred with basin experts in October of 2017. This literature review and summary (i.e. Figure 2, Step 2) was designed to support and inform development of flow hypotheses for an e-flows workshop involving expert stakeholders. The review summarizes 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 includes ecology and biology flow needs, as well as hydrologic conditions before and after Jordan Dam construction.

Goals and Objectives

1) Compile and compare known stakeholder issues with existing information on the river system's natural flow regimes as well as flow requirements of native species and communities.
2) Compare pre-dam construction environmental flow conditions to current environmental flow conditions in the basin and identify significant differences in pulse, magnitude, duration, frequency and timing.
3) Highlight flow needs in relation to ecological considerations for healthy aquatic species, healthy floodplains, improved water quality and improved ecological integrity of the basin through healthy environmental flows.
4) Explore potential operational changes at Corps reservoirs that could result in benefits to fish, wildlife and the general ecosystem while minimizing conflicts with current human uses and authorized project purposes.

Basin Characteristics

History

Throughout the 18th century, European settlers pursued agriculture along the Cape Fear River, establishing towns such as Wilmington and Campbellton (modern day Fayetteville) (NCPEDIA, 2006). The 19th century saw increased efforts to develop shipping on the Cape Fear River and for several decades the river was cleared of debris and dredged. Between 1915 and 1935, three locks and dams were built by the Corps to allow commercial traffic to pass up and down the river. The locks and dams have not been used for commercial navigation since 1995 and have contributed to the decline of anadromous fish species in the Cape Fear River by reducing access by spawning fish to upstream portions of the river (ACOE, 2018).

In response to a disastrous flood in the Cape Fear River basin in 1946, the construction of B. Everett Jordan Dam and Reservoir on the Haw River was authorized in 1963 through public law 88-253. Following a water quality lawsuit that delayed completion of construction, impoundment began in the fall of 1981 and the lake reached its target pool elevation by the spring of 1982. The authorized purposes of the project are flood control, water supply, water quality control, recreation, and fish and wildlife conservation.

Physiography

The Cape Fear River Basin lies entirely within North Carolina, covering 9,140 square miles and stretches across central North Carolina in a southeasterly direction toward the Atlantic Coast. The watershed is larger than the state of New Jersey. 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. Rolling, rounded hills and ridges comprise the majority of the Piedmont Province’s topographical features and elevations range from near 1,000 feet at its border with the Blue Ridge Province to 600 feet at its border with the Coastal Plain Province. The boundary between the Piedmont and Coastal Plain is known as the Fall Zone. This zone represents the elevational break between the resistant rocks of the Piedmont and the more easily eroded sediments of the Coastal Plain. Moving east, 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)

For the purposes of this document, the upper, middle and lower parts of the Cape Fear River Basin were delineated as depicted in Figure 3. Upper is everything upstream from the Deep/Haw river confluence, Middle is the Deep/Haw river confluence to LD1 and Lower is everything downstream of LD1.The lower basin also includes the Northeast Cape Fear River and the Black River. Beyond these sub–basin divisions, there are several other ways the basin has been subdivided by different stakeholders for a variety of reasons, such as population density, flora/fauna range, and existing infrastructure.

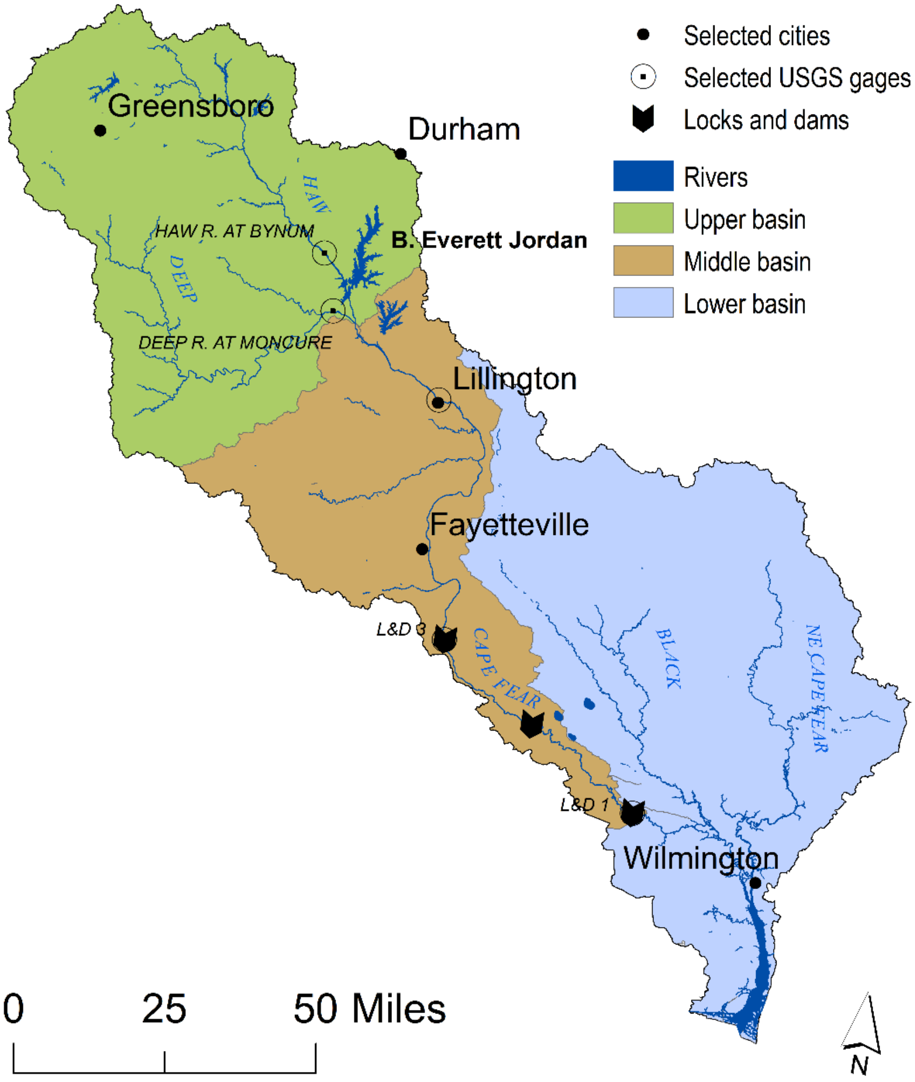
For the purposes of the E-Flow workshop, the basin was further divided into three focal reaches of the mainstem Cape Fear River that have the most potential to be influenced by dam operations. These three focus reaches have associated United States Geological Service (USGS) gages that allow in-depth analysis of hydrology, sometimes going as far back as 1924 (Table 1). The reaches are Jordan Lake to Lillington (Reach 1), Lillington to LD3 (Reach 2), and LD3 to LD1 (Reach 3). In the E-Flows workshop, we will ask participants to craft e-flow prescriptions for these sections of the river.

Table 1. Gages used in analysis and the years of data

Gage	Location	Dates of Daily Discharge Data	Flood stage (ft)	Flood stage (CFS)*
02102500	Lillington, NC	1924-2018	14	30,393
02105500	LD3, Wilm O Huske, Tarheel, NC	1937-2018	9.91+	25,798
02105769	LD1, Kelly, NC	1969-2018	24	42,160
02096960	Haw River, Bynum, NC	1974-2018	11	17,037
02102000	Deep River at Moncure, NC	1930-2018	9	22,059
	Jordan Lake Inflows and Outflows- data from the Corps	1983-2018		

*Flood stage in CFS calculated with USGS rating curves and National Weather Service predicted flood stage.

+ The National Weather Service has flood stage at 42 feet, but tells users to subtract 32.09 ft to align with USGS flood data.



Location	Drainage Area (sq. mi.)	River Miles Below Dam
Jordan Dam	1,690	--
Lillington	3,464	24
Fayetteville	4,395	59
L&D 3	4,852	79
L&D 2	5,017	104
L&D 1	5,255	135
Wilmington	8,760	174
Mouth	9,140	202

Figure 3. The Upper, Middle, and Lower parts of the Cape Fear River Basin with Corps infrastructure and USGS gages.

Hydrology

The Cape Fear River Basin starts with headwaters near Greensboro on the Haw River and near High Point on the Deep River. There are numerous tributaries that contribute flow to these rivers. The Haw River and New Hope Creek join to form Jordan Lake. Below Jordan Lake, the Haw River continues for about 4.2 miles where it combines with the Deep River to form the mainstem of the Cape Fear River. There are several large tributaries that contribute water to the Cape Fear River, including the Little River which runs through the Sandhills and enters the mainstem north of Fayetteville. The South River, Black River, and Northeast Cape Fear River all enter the mainstem of the Cape Fear River below Lock and Dam 1. The Cape Fear becomes tidally influenced below Lock and Dam 1. The Cape Fear River becomes the Cape Fear Estuary for 35 miles between Wilmington and the Atlantic Ocean. The river enters the ocean at Cape Fear, near Bald Head Island.

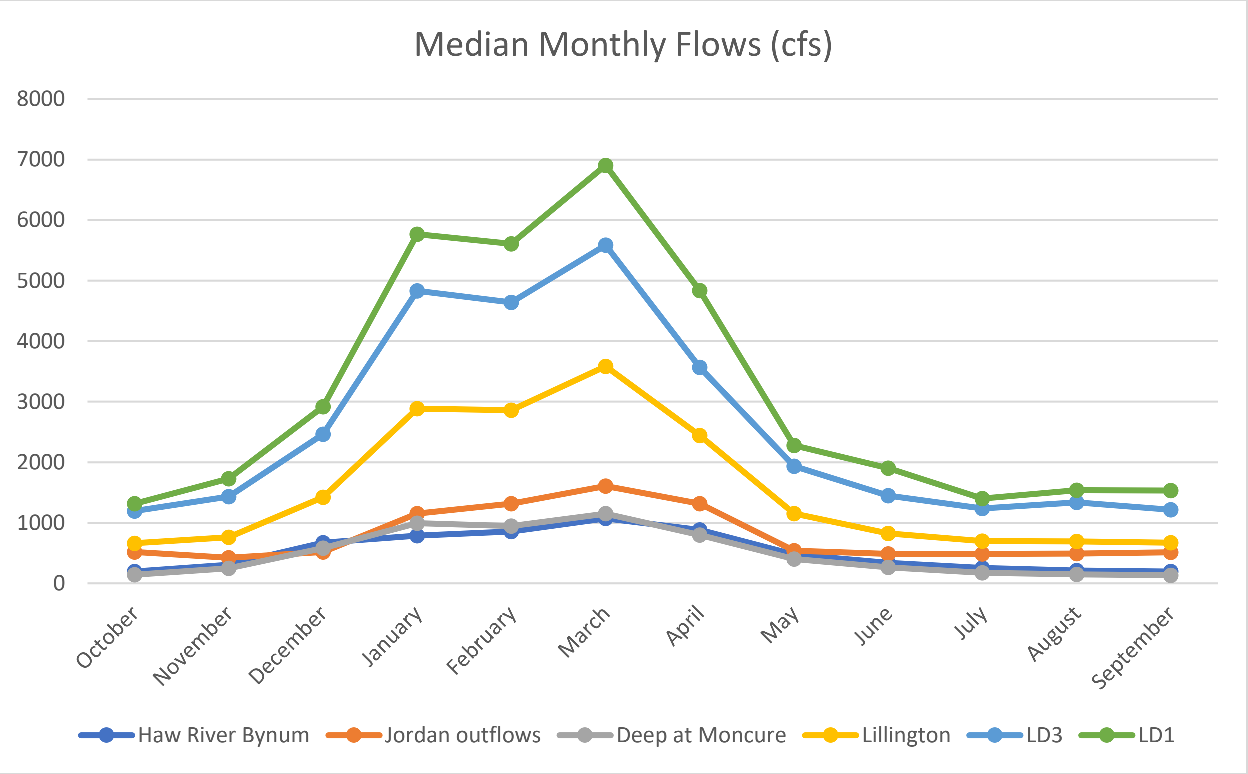


Figure 4. Median monthly flows in the Cape Fear. Data from 1983-2018.

In general, the highest river flows are during the dormant season from December to March (Figure 4). The lowest flows often occur in September and October. Using USGS gage information and software called Indicators of Hydrologic Alteration (IHA), flows of the river at various points were computed (Table 2):

Table 2. Flows at various gages in the Cape Fear River Basin.

Gage name	Description	Mean annual flow (cfs)	Oct median flow (cfs)	Jan median flow (cfs)	April median flow (cfs)	July median flow (cfs)
Haw River at Bynum	Upstream of Jordan lake	963	198	790	882	255
Jordan Lake Inflows	Corps compiled inflows at Jordan Lake	1586	244	1120	1055	362
Jordan Lake Outflows	Corps compiled outflows at Jordan Lake	1524	518	1150	1318	487
Deep River at Moncure	Just before the Deep joins the Haw	1280	146	992	796	174
Lillington	At Lillington	3041 (50%)	663 (78%)	2885 (40%)	2440 (54%)	698 (70%)
Lock and Dam 3	At LD3	4466 (34%)	1195 (43%)	4830 (24%)	3568 (37%)	1235 (39%)
Lock and Dam 1	At LD1	5056 (30%)	1315 (39%)	5765 (20%)	4835 (27%)	1400 (35%)

*Data analyzed since Jordan Lake was complete, 1983-2018. Numbers in parenthesis are Jordan outflow percentage of flow at each gage. Differences in median inflows and outflows are due to a combination of factors including (1) controlled release rates within a narrower range than unregulated inflows and (2) the effects of reservoir storage, such as releasing more than inflows to supplement downstream flows during drier months or releasing water accumulated during a portion of the previous month during a portion of the following month.

As will be described in the Water Resource Management for Jordan Reservoir section below, both the Deep River and Jordan Lake releases have a strong influence on the flows at Lillington, which is about 24 miles downstream of Jordan Dam. During wet times of the year (like January), Jordan Lake releases and the Deep River are contributing nearly equal flow to Lillington (Table 2). Yet, during dry times of the year (like October), the releases from Jordan are much more influential at Lillington than the contribution of the Deep River (Table 2).

There is a significant amount of rainfall runoff and additional tributaries between Jordan Lake and LD3. Jordan releases represent approximately 34% of the mean annual flow at LD3. Yet, seasonality is once again important. During wet times (i.e. January), Jordan releases represent about a quarter of flows at LD3. During dry times, Jordan releases represent more than 40% of flows at LD3. This trend is similar for LD1, which is even farther downstream and influenced by more overland flow. Jordan Lake represents 30% of mean annual flow, 20% during wet times (January), and just under 40% during dry times at LD1 (Table 2).

From manager observations, in-river, travel times under low flow conditions (<500 cfs) from Jordan Dam to points downstream are approximately as follows: 12 hours to Lillington, 36 hours to Fayetteville, 2 days to LD3 and 3.5 days to LD1. From Jordan to Lillington, outflows of 500-1500 cfs take approximately 6-8 hours of travel time and high outflows (greater than 5,000 cfs) can take 4-6 hours. Total square mileage of drainage area from Jordan Dam to points downstream are as follows: 1,690 at Jordan Dam (Haw River), 1,434 at Ramseur (Deep River), 3,464 at Lillington, 4,395 at Fayetteville, 5,255 at LD1, 8,760 at Wilmington, and 9,140 at the ocean.

An important hydrology- ecology relationship is the occurrence of river overbank flow. The National Weather Service flood stage estimates overbank flow at USGS gages (Table 1). 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 (Appendix 1, for an example see Figure 5). Overbank flow has important ecological implications for water quality, floodplain health, and fish habitat access.

Figure 5. HEC-RAS Imagery example from REACH 1 – INUNDATION AT 20,000 CFS. Representative location is approximately 15 river miles downstream of Jordan Dam.

Climate

The climate of Cape Fear River basin is humid and subtropical, with generally hot summers, mild winters, and wet springs. Temperatures vary widely during the year, ranging from average July highs of 90 °F and January lows of 31 °F, with an annual average temperature of 61°F per year in Fayetteville, near the basin mid-river point. Rainfall averages range from 42 inches per year in Greensboro, near the headwaters, to 57 inches in Wilmington at the coast.

Climate Change

Under ongoing climate change, upward trends in both temperature and extreme precipitation have already been observed in the Southeastern US, and are predicted to continue (Carter, et al., 2018). With respect to temperature, minimum temperatures are increasing at a faster rate than maximum temperatures. Precipitation measurements indicate that summer is becoming drier, and fall is becoming wetter. Extreme rainfall events, which have already increased in frequency and intensity, are expected to be more prevalent in the future (Carter, et al., 2018). Warming of both air and ocean temperatures promotes more slow-moving tropical storms that produce extreme precipitation, such as observed during Hurricanes Harvey and Florence (Wang, Zhao, Yoon, Klotzbach, & Gillies, 2018). Moreover, sea level rise will make these flooding events even worse, especially for coastal areas subject to storm surge (Strauss, Tebaldi, & Kulp, 2014). Sea level rise in some parts of the southeast is substantially higher than global averages (Carter, et al., 2018). For North Carolina, measured average sea level rise in the 20th century ranged from 0.68 (+/– 0.16) ft at Wilmington to 1.15 (+/- 0.09) ft (Kopp, 2015). Among states in the continental US, North Carolina is considered one of the most vulnerable to sea level rise, given the large extent of land that is less than 1m above the average high tide line (Strauss B. H., 2012). In addition to more extreme wet conditions, increasingly extreme droughts are also projected for the Southeastern US. For North Carolina, there is a higher likelihood of longer dry spells during the winter months (Keellings & Engström, 2019).

Hurricanes

While North Carolina has a centuries long history of experiencing the effects of hurricanes, recent severe storms have brought increased attention to the threats they pose to the natural and manmade environment, stoking public interest in increasing preparedness and resiliency. The state's coastal communities have always adapted to hurricanes, and storms have often driven necessary innovations in land use, planning, building codes and other resiliency measures that reduce damage should future storms occur. The National Hurricane center ranks North Carolina as the number four in its rankings of states most commonly struck by hurricanes behind only Florida, Louisiana and Texas.

A combination of factors makes North Carolina especially vulnerable to hurricanes. The subtropical geographic location of the state, adjacent to the warm waters of the Gulf Stream in the Atlantic Ocean, plays a large role in the susceptibility to a hurricane landfall. With more than 300 miles of shoreline, the state has proportionally greater ratio of shoreline as compared to other states of a similar size. Despite being the 28th largest state in square miles, North Carolina ranks 7th in miles of shoreline. Population centers located in coastal areas increase loss of life and costs associated with hurricanes.

Hurricane Hazel, which made landfall as a category 4 storm in 1954, was one of the most disastrous hurricanes in United States history, causing significant flood damage in North Carolina. Other hurricanes after Hazel caused relatively less damage until the larger disasters resulting from Hurricane Diana in 1984 and Hurricane Hugo in 1989. Hurricane Fran in 1996 and Hurricane Floyd in 1999 caused significant flooding, had high death tolls, and caused billions of dollars in damage. Following some less severe hurricanes affecting North Carolina in the early 2000s, Hurricane Matthew made landfall in 2016, causing more than 4 billion dollars in damage. In 2018, Hurricane Florence struck, with Hurricane Michael coming four weeks later, inundating areas flooded just two years earlier. The total costs of damages resulting from Florence and Michael are 24 and 25 billion dollars, respectively, according to NOAA (Adam Smith, 2019). The ability of Jordan to lessen the impact of hurricanes is influenced by the hurricane track, rainfall below the dam, and storm surge.

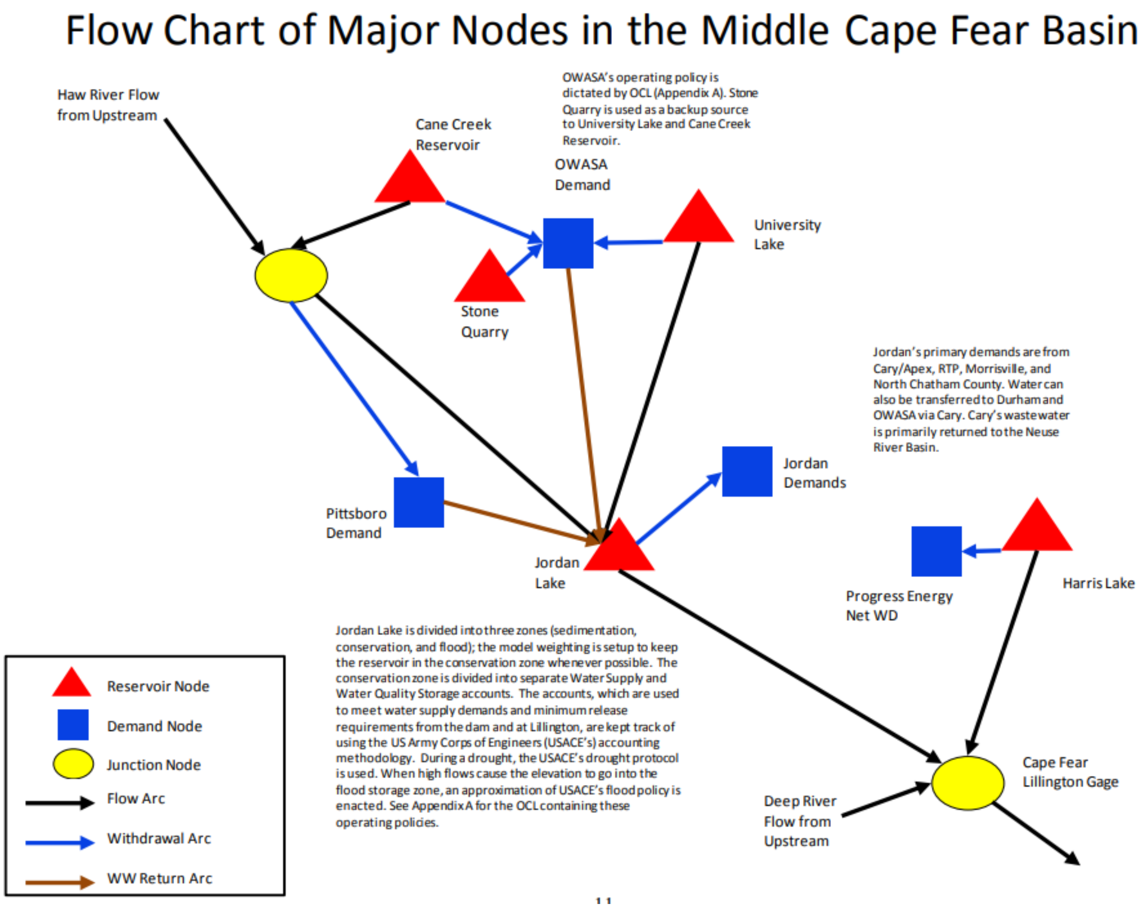
Critically, from a water management perspective, hurricanes hit the basin during what is normally the driest time of year. The official hurricane season for the Atlantic is from 1 June to 30 November and the peak of the season is from mid-August to late October. Tropical storms can affect North Carolina any time between May and December, but the majority of storms have hit between August and October, coinciding with the peak of hurricane season. In average year conditions, August to October are the driest months (Figure 4). This poses water managers with a situation where they are having to balance dry times with potentially large water inflows from hurricanes.

Demographics, Interbasin Transfers, and Existing Water Quantity Models

The Cape Fear River Basin includes all or a portion of 26 counties in North Carolina, including 114 municipalities and some of the fastest growing regions around the Triad, Triangle, and Wilmington. The 2010 population within the Cape Fear basin was 2,072,304, one-fifth of the state's population (2010 census).

There are numerous water supply users in the Cape Fear basin, including at least 300,000 people who rely on water from Jordan Lake. Other major municipalities in the upper and lower basin use surface water for their drinking water supplies, including Wilmington, Fayetteville, Greensboro and more. There are several approved interbasin transfers (IBTs) in the Cape Fear. Piedmont Triad Regional Water Authority is approved to transfer 30.5 million gallons a day (mgd) from the Deep River basin to the Haw River and Yadkin River basins. Wake County (Cary, Apex and Morrisville) have an approved IBT to take 33 mgd from Jordan Lake and return it to the Neuse River (with some return flow to the Cape Fear). Pender County has approval to take 14.5 mgd from behind LD1 on the mainstem of the Cape Fear and return it to the South River and Northeast Cape Fear Rivers.

In addition to drinking water users, there are many industrial and agricultural users in the basin. To record the many water withdrawals and returns, the NC Department of Environmental Quality (NC DEQ) contracted with Hydrologics to create an OASIS model of the Cape Fear and Neuse River Basins. OASIS is a patented mass balance, water resources simulation model. It includes reservoirs, demand nodes, and flow information (Figure 6) (Hydrologics, 2013). As Oasis is a go-to model for NC DEQ, Oasis might be used in a future SRP step to further understand any recommended e-flow prescriptions. The Corps also maintains its own suite of river basin models for the Cape Fear including a rainfall-runoff model, a reservoir simulation model, and a river hydraulics model.



Flow Chart of Major Nodes in the Middle Cape Fear Basin

OWASA's operating policy is dictated by OCL (Appendix A). Stone Quarry is used as a backup source to University Lake and Cane Creek Reservoir.

Jordan's primary demands are from Cary/Apex, RTP, Morrisville, and North Chatham County. Water can also be transferred to Durham and OWASA via Cary. Cary's wastewater is primarily returned to the Neuse River Basin.

Jordan Lake is divided into three zones (sedimentation, conservation, and flood); the model weighting is setup to keep the reservoir in the conservation zone whenever possible. The conservation zone is divided into separate Water Supply and Water Quality Storage accounts. The accounts, which are used to meet water supply demands and minimum release requirements from the dam and at Lillington, are kept track of using the US Army Corps of Engineers (USACE's) accounting methodology. During a drought, the USACE's drought protocol is used. When high flows cause the elevation to go into the flood storage zone, an approximation of USACE's flood policy is enacted. See Appendix A for the OCL containing these operating policies.

Figure 6. Example from the OASIS model. Figure taken directly Hydrologics 2013.

Water Resource Management in the Project Area

Jordan Reservoir

The B. Everett Jordan Dam and Lake project was authorized by Congress as a part of the General Comprehensive Plan for Flood Control and Allied Purposes, as outlined in the 1938 and 1944 Flood Control Act, as amended. Twenty-five years later, Public Law 88-253 authorized its construction. Project design and coordination with state and federal agencies began immediately. In 1973, Public Law 93-141 changed the name of the project from "New Hope Reservoir" to "B. Everett Jordan Dam and Lake" (BEJ Master Plan).

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 1,915 feet. The drainage area upstream of the project is approximately 770 square miles. The dam impounds the Haw River and its largest tributary, New Hope Creek, which joins the Haw 0.3-miles above the dam site. Due to the difference in stream gradients between the Haw and New Hope, most of the project is in the New Hope Basin. The combined Haw and New Hope drainage basin covers 1,690 square miles above the Jordan Dam or 18 percent of the Cape Fear River Basin. The top of the dam "as-constructed" is at elevation 291.5 feet above mean sea level (m.s.l.). The total Jordan project area encompasses 46,768 acres of which 13,900 acres are permanently flooded to form a reservoir (Jordan Lake) at 216 feet above mean sea level. Approximately 150 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 17 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. The project 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 project is operated for flood risk management. Flood storage has never been exceeded, and conservation storage has never been fully depleted. Jordan Dam has private hydropower on it, but this does not influence operations.

Water Storage Pools and Lake Shoreline

At the conservation pool elevation of 216 feet m.s.l., the fetch of Jordan Lake at the dam is about 1,000 feet across, increasing to approximately 9,000 feet across at its widest point, about 4.5 miles upstream on the New Hope arm. The main body of impounded water extends 18 miles up the New Hope River and 5 miles up the Haw River, and includes approximately 200 miles of shoreline. At normal pool, the lake has a mean depth of 15.4 feet and a maximum depth of about 66 feet.

Waters held in Jordan Dam and Lake are divided into basic storage pools. The sediment pool extends from the bottom of the lake to elevation 202 feet m.s.l. At 202 feet m.s.l., the surface area of the lake is 6,658 acres, and the impoundment capacity is 74,700 acre-feet of water. The conservation pool extends from elevations 202-216 feet m.s.l. The top of the conservation pool is 216 feet m.s.l., and this is the normal operating level of the lake. At the top of the conservation pool, the surface area of the lake is 13,940 acres, and the total impoundment capacity is 215,130 acre-feet. The conservation pool is further subdivided into separate storage pools for water supply and water quality (45,810 acre-feet for water supply and 94,620 acre-feet for water quality); releases and withdrawals from each respective pool are tracked separately and do not affect the other pool's storage.

The flood control pool is between 216 and 240 feet m.s.l. (the elevation of the spillway crest). At the top of this pool, the surface area of the lake expands to 31,800 acres, and the water storage capacity increases to 753,560 acre-feet.

Jordan Operations and Typical Water Releases

The Corps' mission is to operate its dams and reservoirs within approved operational guidelines to maximize Congressionally authorized purposes, and B. Everett Jordan Dam and Lake is no exception. The process used by the Corps to achieve this mission includes monitoring factors in antecedent, real-time, and forecasted weather conditions. The Corps makes real-time operational decisions at its dams based on existing conditions, as well as upstream/downstream effects and works in close coordination with the Southeast River Forecast Center (SERFC), the officially designated river forecaster. While the Corps factors current and reasonably expected future conditions, decisions are normally made based on actual events and “water on the ground”, not based on rainfall forecasts. Throughout the operational decision-making process, the Corps coordinates with partners/stakeholders and keeps affected interests informed through weekly calls, individual updates, and press releases. There are many competing interests in the basin and the Corps must constantly balance the needs of these stakeholders and the authorized purposes of Jordan Dam and Lake. Because Jordan Dam and Lake is the only Corps project actively managed for flood control on the Cape Fear River, and due to the large volumes of water in play and extensive water needs throughout the basin, the Corps management decisions have significant implications downstream.

Typical Lake Operations:

The year-round targeted operation level of the lake is 216 feet m.s.l., which is the top of the conservation pool (also referred to as the guide curve). Unless other demands or circumstances dictate (such as below-normal inflows to the lake), the lake is maintained at this level for water supply and recreational use. Generally, during periods of normal flow when the lake is near guide curve, releases from the dam will be comparable to inflows coming into the lake (after allowances for water withdrawals and evaporation). As stated earlier, the top of the flood control pool is at elevation 240 feet m.s.l. (the elevation of the spillway crest). Flood storage in the reservoir is used to provide downstream protection during flood events. If floodwaters fill the reservoir above the spillway crest, water flows through the uncontrolled chute spillway.

Flood operations:

Flood control along the Cape Fear River is the primary objective of Jordan Dam and Lake, especially for the vicinity of Fayetteville. This is accomplished by temporarily storing floodwaters coming into Jordan Lake until they can be released without creating damaging stages downstream of Jordan Dam.

At the beginning of a significant rainfall event, the project outflow will often be reduced to the minimum (about 200 cfs) to prevent Jordan Dam releases from contributing to downstream flooding. Data exchanges and coordination take place with the National Weather Service (NWS) and Southeast River Forecast Center (SERFC). Lake level forecasts are made throughout the flood event using Corps models; however, operational decisions are typically made based on “water on the ground”, not on rainfall forecasts that may not materialize as expected.

Jordan Lake staff are notified of the lake level forecast and they in turn notify NC State parks, Jordan Lake Marina, and the NC Department of Transportation (roads and possibly flooding). If the lake elevation is forecasted to approach or exceed 221 ft m.s.l., Hydro Matrix Partnership Ltd (private entity that produces hydropower through an agreement with the Federal Energy Regulatory Commission) is notified to fully raise their hydropower units since unit damage occurs above lake level 222 ft m.s.l. If the downstream lock and dams (LD3 and LD1) lock walls are expected to be overtopped, staff at the locks and dams are notified to remove the lock gate motors to prevent damage, which generally occurs if Lillington is forecasted to be 12,000 cfs or higher.

Fayetteville is usually the critical flood damage center on the Cape Fear River for which Jordan Dam is operated. According to the water control plan for Jordan Dam, the designated non-damage stage at Fayetteville is 31 feet at the USGS gage or approximately 20,000 cfs. [Note: The present-day NWS flood stage at Fayetteville is somewhat higher than 31 ft (32 ft for Action Stage and 35 ft for Flood Stage), but this lower stage in the water control plan is still typically used as a conservative operating threshold. In addition, backwater effects from LD3 influence the stage-discharge relationship at Fayetteville.] Ahead of a significant rain event, releases from Jordan Dam may be reduced to minimum (about 200 cfs) or near minimum to minimize any contribution to flooding at Fayetteville. Under the water control plan, Jordan outflows are generally not increased until Fayetteville stage has peaked and is below 31 ft or below 20,000 cfs. Once Fayetteville peaks and is below 20,000 cfs, the Corps may begin increasing Jordan outflows, but normally not to exceed 20,000 cfs at Fayetteville. An exception to this would be if Jordan Lake level has exceeded the spillway crest elevation of 240 ft and flows at Fayetteville may be maintained above 20,000 cfs, but would not exceed the uncontrolled flood peak that had occurred. The Deep River greatly influences downstream flow in the Cape Fear River during floods and is therefore a significant factor regarding the timing and magnitude of releases from Jordan Dam as well.

Low Flow (Water Quality) Operations

Water quality storage in the conservation pool is used to meet minimum flow requirements immediately downstream of Jordan Dam (40 cfs) and also downstream at Lillington (600 cfs +/- 50 cfs). While the minimum release at the dam is only 40 cfs (which was based on historical 7Q10 flows), typical minimum releases are closer to 200 cfs due to concerns over wear and tear on gate seals. During low flow conditions, when the combined flow of the Haw and Deep Rivers falls below 600 cfs at Lillington, releases are made as necessary to maintain a 600 c.f.s. (+/- 50 cfs) minimum flow at the Lillington gauge.

During extended low flows or droughts, when water quality storage in Jordan Lake drops below 80%, the Drought Contingency Plan for Jordan Dam and Lake goes into effect, which allows for tiered reductions in the 600 cfs minimum flow target at Lillington to conserve remaining water quality storage. Table 3 summarizes that drought release schedule:

Table 3. Drought Release Schedule

Drought Level	Water Quality Storage Remaining (%)	Jordan Dam Minimum Release* (cfs)	Jordan Dam Maximum Release (cfs)	Lillington Daily Average Flow Target (cfs)
0	>= 80	40+	600	600 +/- 50
1	60 – 80	40+	Lillington target	450 - 600 +/- 50
2	40 – 60	40+	Lillington target	300 - 450 +/- 50
3	20 – 40	40+	200+*	None**
4	0 – 20	40+	100-200+*	None**

* Water quality release plus any required downstream water supply releases.
** Lillington flow will be total of Jordan Dam release plus local inflow.

During droughts, accounting of the water supply and water quality storage remaining is performed daily to identify potential problems with the remaining storages and allow conservation efforts to be established to minimize the impacts of drought operation. The State of North Carolina will be notified as the water quality and water supply accounts are being depleted as per the “Drought Contingency Plan” for Jordan Lake. (USACE, WCPlan, 1992)

The intake tower of Jordan Dam has the design capacity to selectively release water from higher multi-level water quality gates. This is usually done during the spring through fall, when the lake may be stratified, to release water with higher dissolved oxygen levels, to reduce surface water residence times in the lake and to reduce potential for in-lake algal blooms. However, during the winter months, when the lake is not stratified, and also during the warmer months, when releases exceed the capacity of the water quality gates, water is released through the emergency gates near the bottom of the lake. Construction of the privately owned, add-on hydropower project (discussed below) has impacted operation of some of the tower’s water quality gates; however, the turbines’ intake flume does pull from the upper water column as well.

Water Supply

Drinking water supply is one of Jordan Dam and Lake’s authorized purposes. In 1988, the USACE and the State of North Carolina finalized a water supply agreement allowing the State to use 32.62 percent of the total conservation storage space between elevations 202 and 216 feet m.s.l.. The water supply storage has an estimated safe yield of 100 million gallons per day (mgd). The State then allocated portions of the total water supply storage to prospective units of local government. Since the initial allocations agreed upon in 1988, three additional rounds of allocation revisions have taken place, with some original allocation holders releasing their allocations and other applicants receiving allocations. As of March 9, 2017, Round 4 Jordan Lake Water Supply Allocations were approved (Commission, 2017), totaling almost 96% of the available water supply storage. Table 4 shows the percentage change between the Round 3 allocations of 2002 to the Round 4 allocations of 2017.

Table 4. Allocation of Jordan Lake Water Supply Pool.

Applicant	Round 3 (2002) Allocation Percent	Round 4 (2017) Allocation Percent
Cary Apex Morrisville RTP	39	46.2
Chatham County- North	6	13
Durham	10	16.5
Hillsborough	0	1
Holly Springs	2	2
Orange County	1	1.5
Orange Water & Sewer Authority	5	5
Pittsboro	0	6
Raleigh	0	4.7
Total Percent	**63**	**95.9**

Hydropower

Hydropower is not a federally authorized purpose of Jordan Dam and Lake; however, under an agreement with the Federal Energy Regulatory Commission, private entities are allowed to add hydropower to Corps projects if those projects do not interfere with other project purposes or impact the safety of the dam. Construction of the hydropower plant by Hydro Matrix Partnership Ltd. on Jordan Dam began in 2008, and it became operational in January of 2012. Since then, the hydropower plant at Jordan Dam has produced over 7 GWh. The plant has two hydroelectric generators; combined, the generating modules produce about 16,900 MW annually, which is enough electricity to power 4,000 homes. (USACE, 2019)

Locks and Dams

The Cape Fear River Locks and Dams were authorized under the River and Harbor Act of 1910, 1934, 1935, and 1965, and Section 4 of the Flood Control Act of 1944. The Cape Fear River Locks and Dams, located in Bladen County in southeastern North Carolina, consist of three federally built and maintained locks and dams. LD1 and LD2 were constructed between 1915 and 1917, respectively, and LD3 (also known as William O. Huske Lock and Dam) was completed in 1935. The locks and dams were originally constructed to ensure a navigable channel for commercial barges from Wilmington to Fayetteville; however, they have not been used for commercial navigation since 1995. Simply by their presence in the river, the locks and dams provide incidental water supply pools for multiple municipalities; however, water supply is not an authorized purpose of the Cape Fear River Locks and Dams and no water supply agreements exist. The locks and dams are run-of-river structures, meaning that river flows simply pass over the dams with no capability to regulate flows.

Use of the lock chambers at all three locks and dams to facilitate diadromous fish passage during spawning season (approximately January-May) is at the request of the North Carolina Wildlife Resources Commission, and is accommodated as Corps resources allow. Fish locking at LD1 has not occurred since completion of the rock arch rapids fish passage structure in 2012, which was constructed as a mitigation feature associated with deepening of Wilmington Harbor; however, weekly maintenance lockages at LD1 occur year-round (as do weekly maintenance lockages at all three locks and dams). Debris accumulation at lock gates and in lock chambers, particularly following large rainfall events, may preclude any use of lock chambers until which time debris is removed.

The Effects of Jordan Dam

With flood control as its primary authorized purpose, Jordan Dam was designed to dampen big floods (Figure 7). And, due to water quality requirements below the dam, it also has minimum target flows at Lillington. The Corps is balancing downstream flooding conditions as described in the previous section. To analyze the effects of Jordan Dam on the downstream hydrology, USGS gage data was analyzed at Lillington, LD1, and LD3. Ideally, there are at least 20 years of pre-Jordan Dam data at each gage to feel confident in pre-dam conditions. This was true at Lillington and LD3, yet not at LD1 (see Table 1).

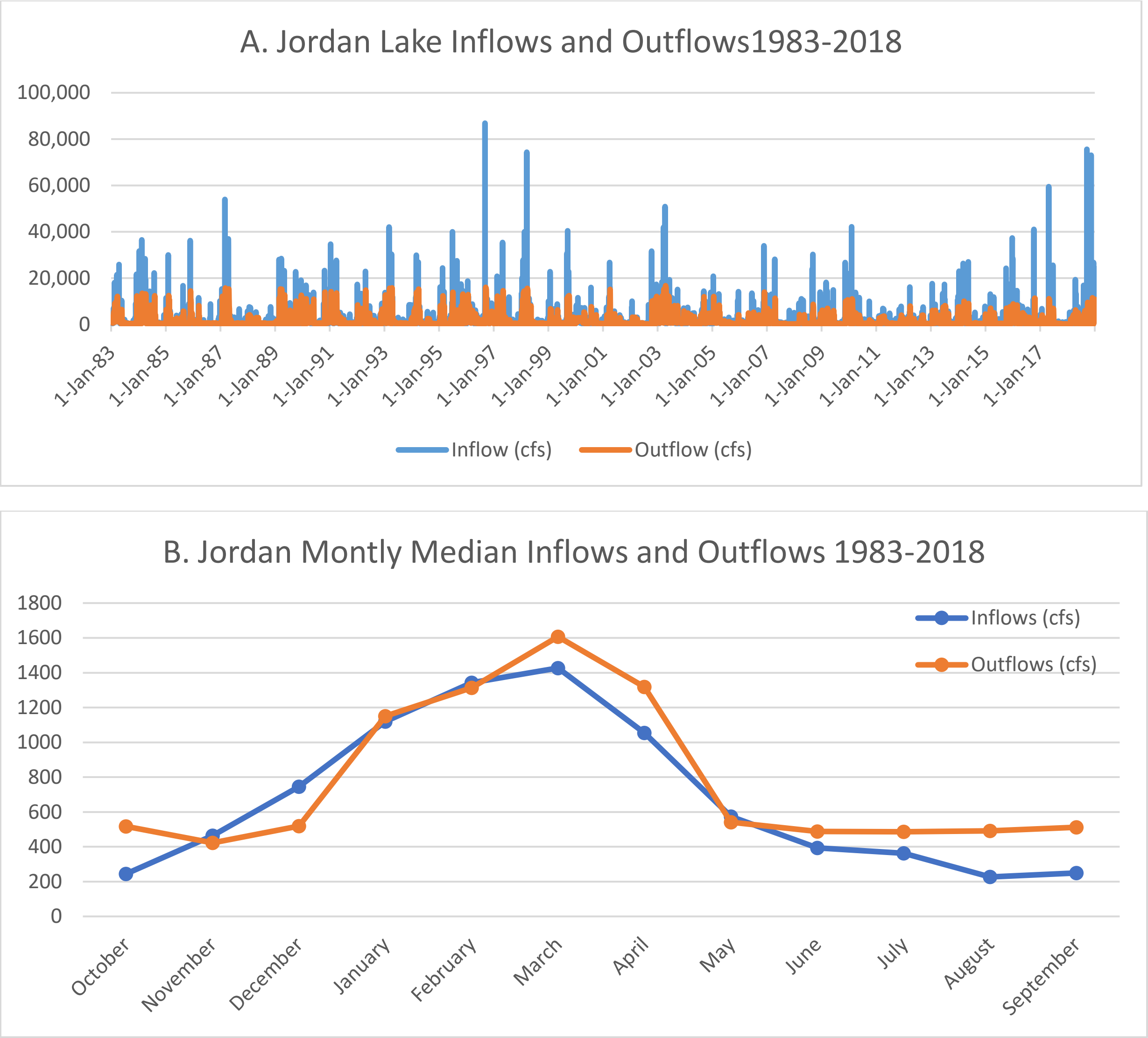


Figure 7. A. Inflows and Outflows at Jordan Dam from 1983-2018. B. Monthly Median Inflows and Outflows at Jordan Dam from 1983-2018. Data from the Army Corps of Engineers.

For all analysis, the years 1980-1983 were removed to minimize the effects of the Jordan Dam being built and filled. USGS gage flow data are daily mean values. We used non-parametric tests (i.e. medians) to compute statistics. To define flow components, anything above 75% exceedance of the daily flows for the period were classified as high flows. Below this value was classified as low flows and 10% or less was considered extreme low flows. Small floods were defined as a 2-10 year return period, large floods were greater than a 10 year return interval. We computed a "range of variability approach (RVA)" that binned pre-dam data into 0-33%, 33-67%, 67-100% categories. We computed the expected frequency with which the post-impact values should fall within each category, based on the pre-impact frequencies. That allows an alteration factor to be determined.

Effects of Jordan at the Lillington gage

The Lillington gage is 23.8 miles below Jordan Dam. As described in the Hydrology Section, during wet times of the year (like January), Jordan Lake releases and the Deep River are contributing comparable flow to Lillington. Yet, during dry times of the year (like October), the releases from Jordan are much more influential at Lillington than the contribution of the Deep River (Table 2 in hydrology section).

When looking at the effects of Jordan Dam at Lillington, as expected, there were much bigger floods (including large floods, small floods, and high flow pulses) before the dam was built (Figure 8). Yet, looking at the median monthly flows, the pre and post-dam water flows follow a similar yearly trend (Figure 9). Depending on the time of year, the monthly median flows ranged from 550 to 4,140 cfs pre-dam and 663 to 3,585 cfs post-dam.

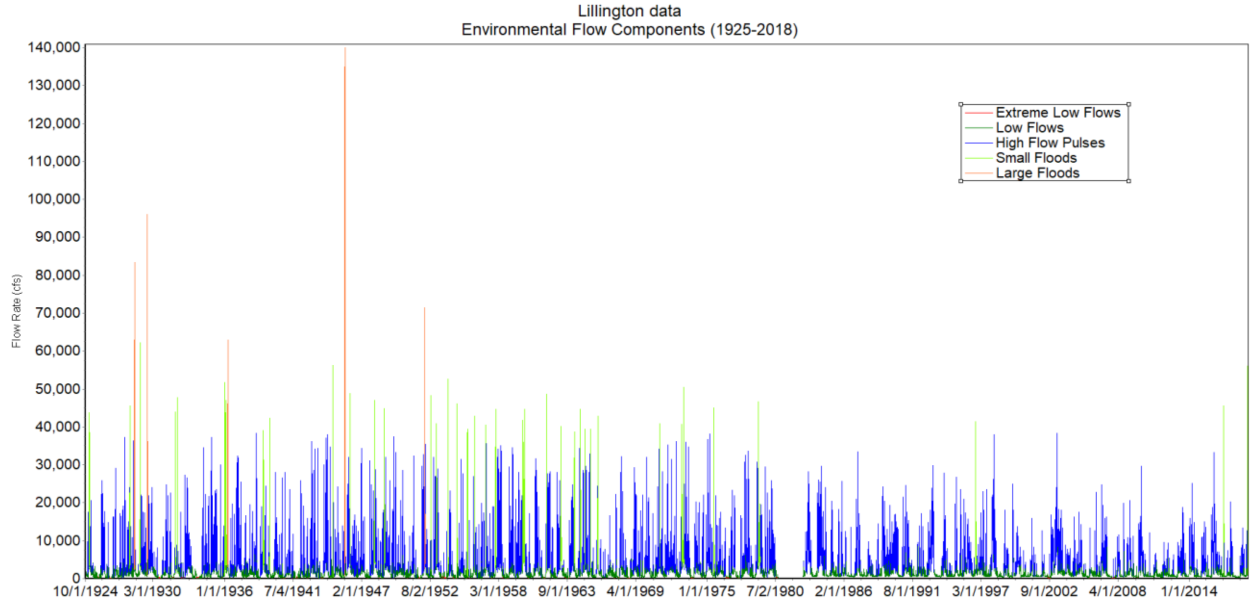


Figure 8. Hydrograph data from 1925-2018 with environmental flow components

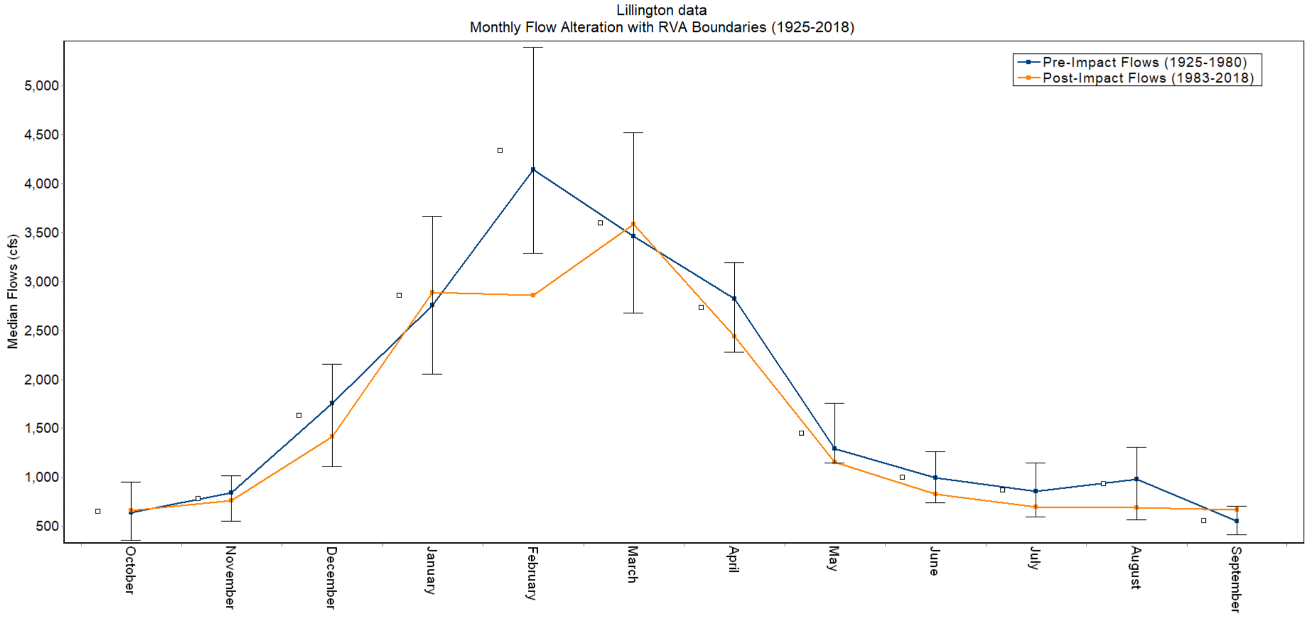


Figure 9. Median monthly flows at Lillington.

One of the main effects of the dam is the dampening of large flow pulse events. The mean annual flow at Lillington was 3,387 cfs before the dam was constructed and not too different at 3,041 cfs after the dam was constructed. Yet, the basin frequently had storm events that would drive pulses in the river. The highest documented flow on the river pre-dam was 140,000 cfs and post-dam was 56,000 cfs. These events both happened as a result of hurricanes.

To investigate pulse flows (i.e. higher flow events that are often with storms), we computed the 3-day maximum for every year. The median 3-day maximum pre-dam was 30,470 cfs and post-dam was 20,770 cfs (Figure 10). The National Weather Service flood stage estimates that Lillington floods at 30,393 cfs (Table 1) so post-dam there are significantly fewer overbank flow events. The median number of high pulse events was 15 before the dam and 11 after the dam (Figure 11). Because the dam holds back water, the duration of high pulse events is longer post-dam (median 5.25 days) than pre-dam (median 4 days) (Figure 12). Floods are less frequent and of smaller magnitude, but of longer duration.

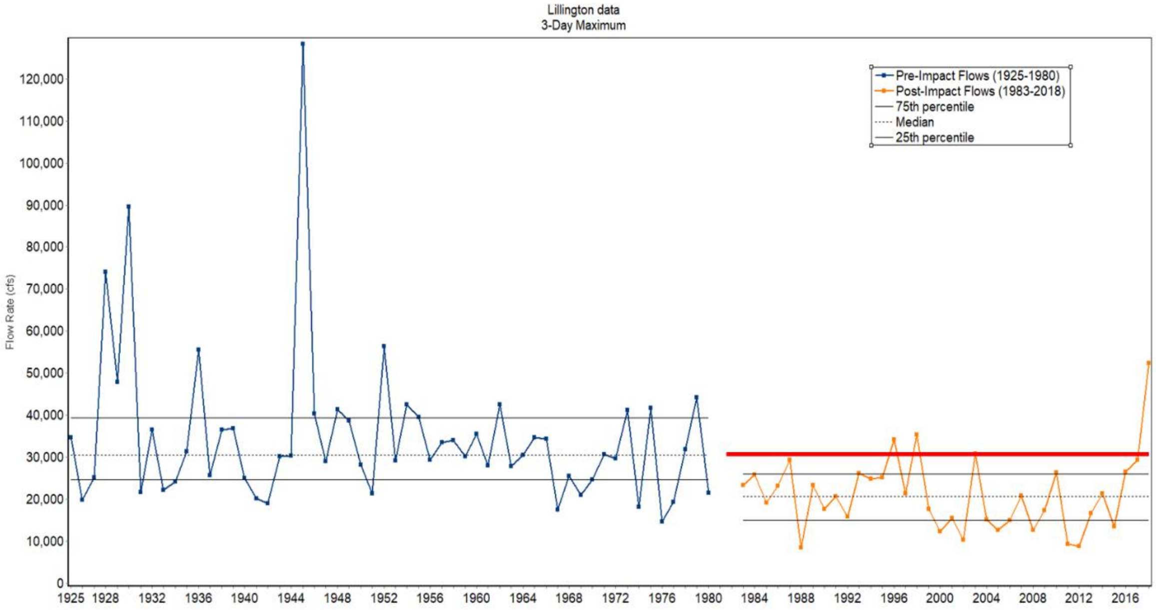


Figure 10. Three -day yearly maximum flows at Lillington. Red line indicates National Weather Service Flood Stage.

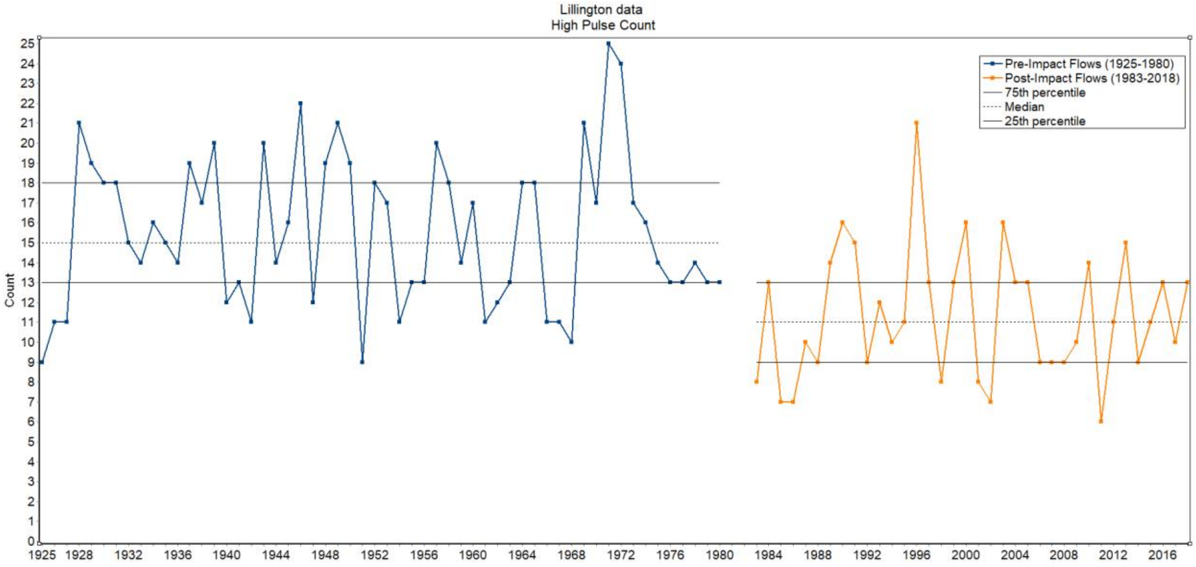


Figure 11. The number of high pulse events at Lillington.

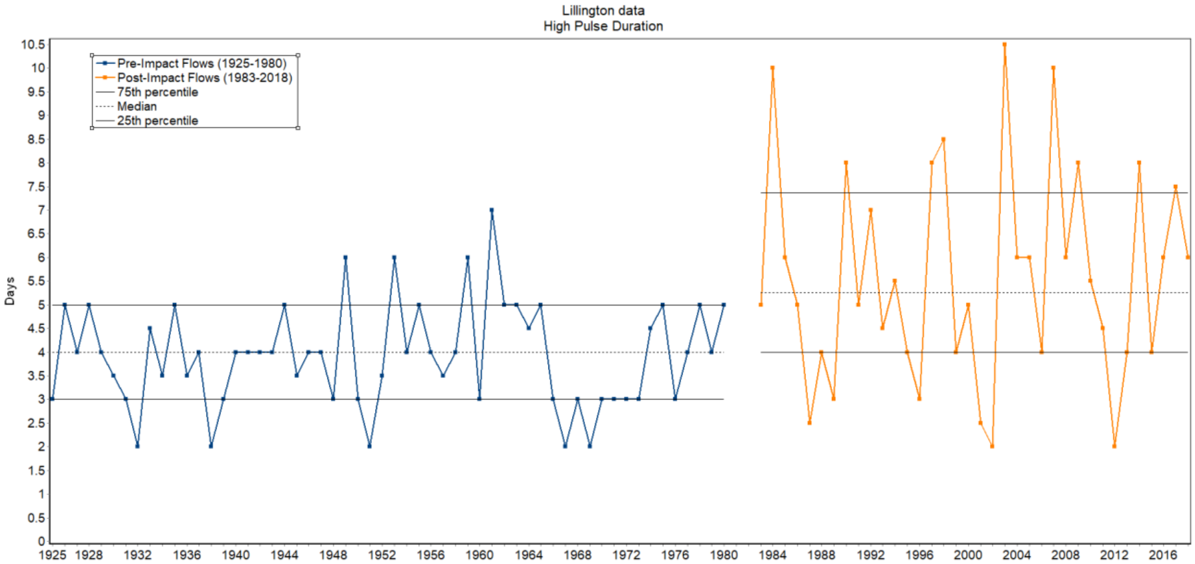


Figure 12. The length (in days) of high pulse events in Lillington.

In addition to reducing floods and pulse flows, Jordan increases low flows at Lillington, including baseflow (Figure 13). The lowest recorded pre-dam flow was 11 cfs in October of 1954 and 155 cfs recorded in August of 2002 post-dam. Again, the Corps considers water quality below the dam and maintains minimum flow targets. To investigate low flow conditions, the 3-day annual minimum flows were analyzed. The median 3-day minimum before the dam was 156 cfs and after the dam was 488 cfs, a difference of over 300 cfs flow (Figure 14). There was not a significant difference in the timing of low flow events, the number of low flow events, or the duration of low flow events pre- and post-dam.

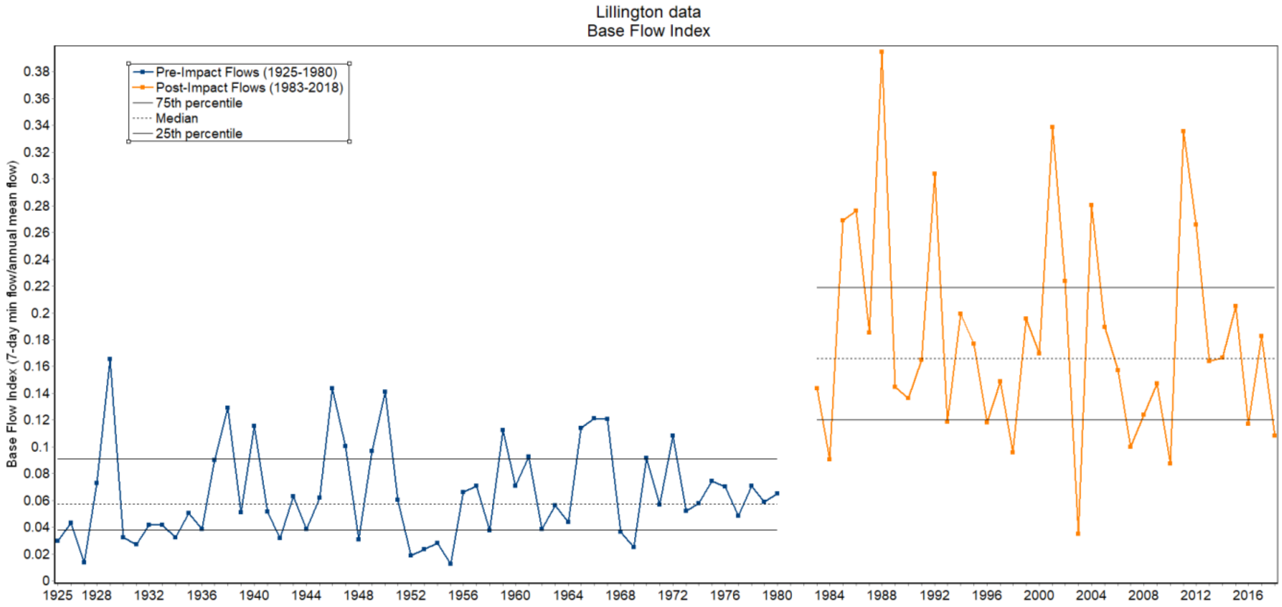


Figure 13. The baseflow index, which is the 7-day minimum divided by the mean flow at Lillington.

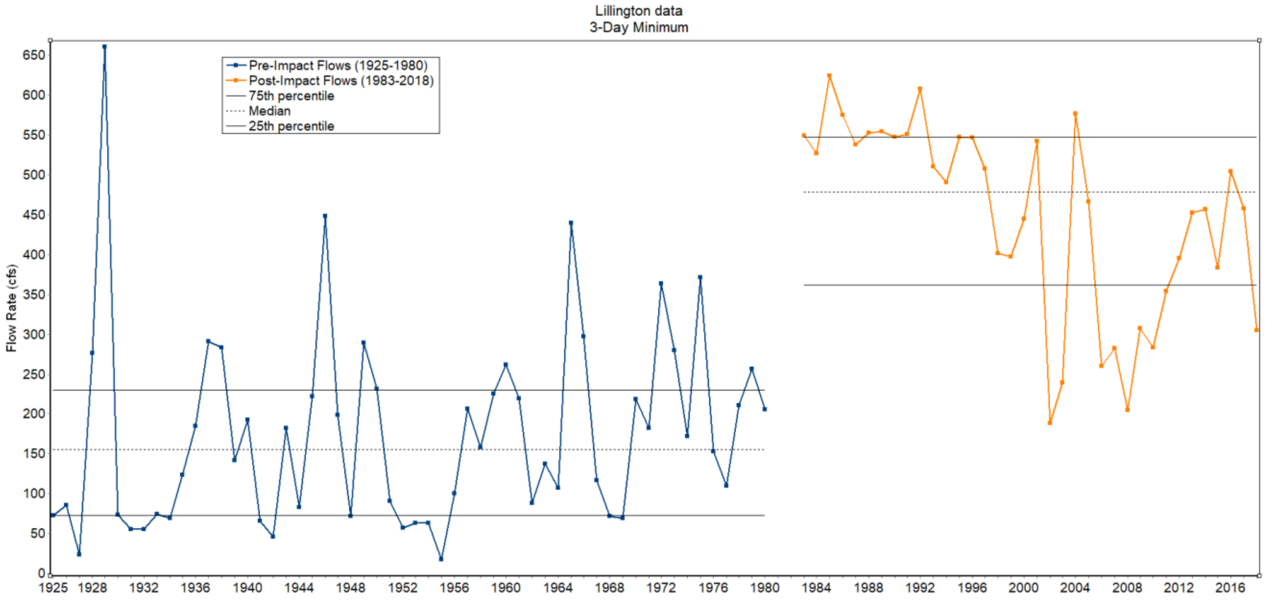


Figure 14. The yearly 3-day minimum at Lillington.

Another finding is that the river rose and fell faster before the dam was built (Figures 15 and 16). The daily rise rate (median) was 275 cfs pre-dam and 112 cfs post-dam (Figure 15). The daily fall rate was -288 cfs pre-dam and -130 cfs post dam (Figure 16).

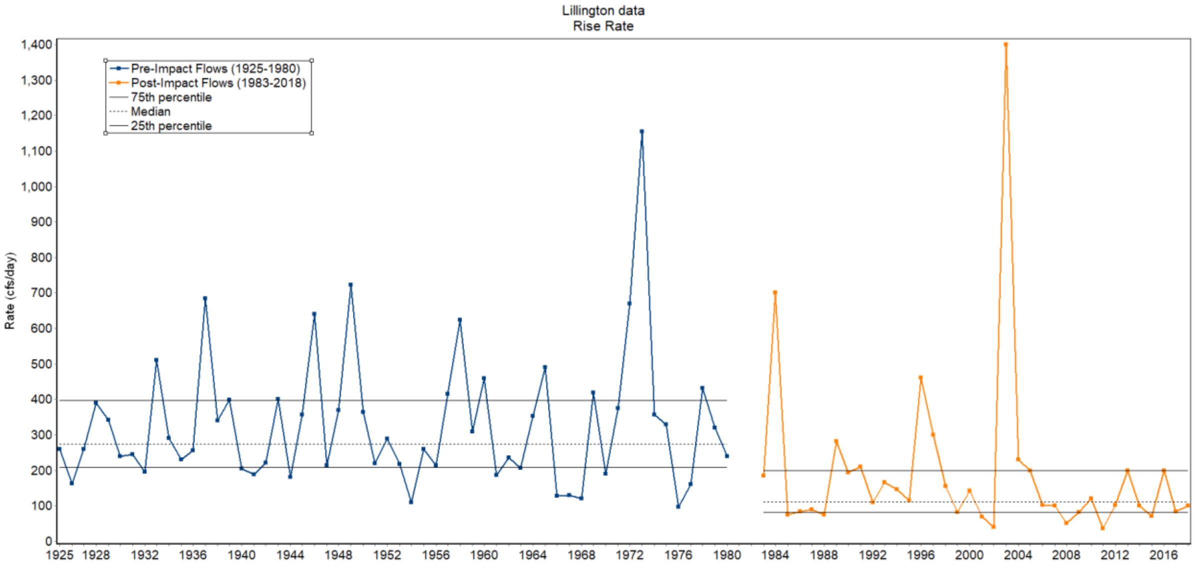


Figure 15. The river rise rate at Lillington.

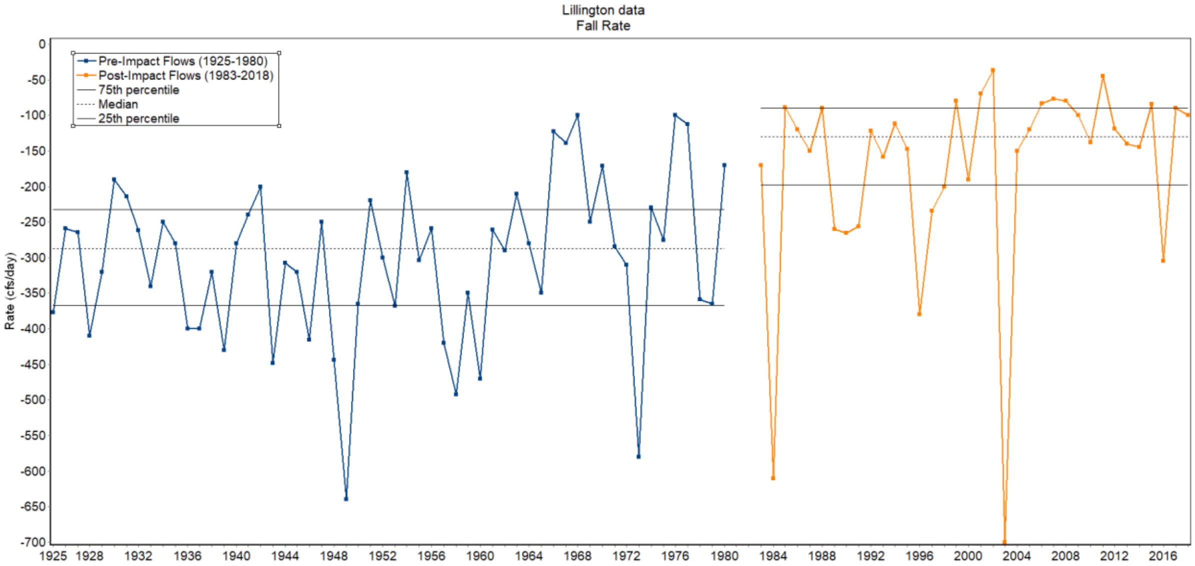


Figure 16. The daily fall rate at Lillington.

To summarize the effects of Jordan at Lillington, large floods were wholly removed. Small floods and pulse events were reduced in magnitude so that overbank flow at the Lillington gage rarely happened. Post-dam, small floods were less frequent, but of longer duration. Low flows were increased by approximately 300 cfs in 3-day dry conditions. The rise and fall rate of the river were dampened. All of these changes are generally expected outcomes based on the authorized flood and low flow operations of Jordan Dam and Lake. Part of the SRP process is to consider the associated ecological effects of these changes, including migratory cues, floodplain inundation, river-creating geomorphology, plant recruitment on streambanks, associated levels of dissolved oxygen and more. For additional data at the Lillington gage, see Appendix 2.

Effects of Jordan at the LD3 gage:

Although LD3 is even farther downstream and there is more influence of downstream runoff, there are still effects of Jordan Dam. The influence of the dam is similar to those at Lillington. For the most part, the shape of the yearly hydrograph is not too different before and after the dam was built (Figure 17). The mean annual flow at LD3 pre-dam was 5,043 cfs and post-dam was 4,466 cfs. Yet, the river saw significant pulses from hurricanes– the highest recorded one-day flow pre-dam was 112,000 cfs and post-dam was 83,200 cfs. To understand a more regular flood event, the median 3-day maximum was significantly higher pre-dam at 33,580 cfs compared to post-dam at 25,020 cfs (Figure 18). The National Weather Service estimates flooding at 25,798 cfs, which implies that there was more overbank flow pre-dam than post-dam. There was a significantly higher number of big pulse events pre-dam (median 12) compared to post-dam (median 9.5). Similar to the Lillington gage, baseflow was increased after the dam was built (Figure 19) and the median 3-day minimum was lower pre-dam (568 cfs) and higher post-dam (795 cfs) (Figure 20).

Ecologically, many of the same questions remain. If the dam is reducing the size and number of big pulses, how does this influence the downstream ecology? And, if baseflow and minimum flows are increasing, how does that influence the ecology? For additional data at LD3, see Appendix 3.

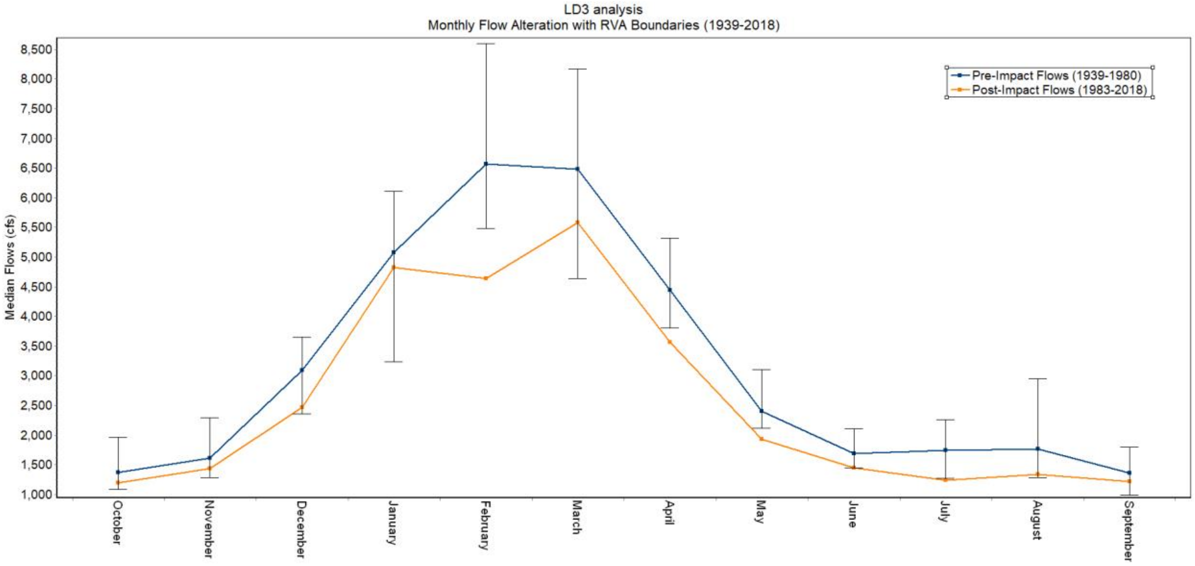


Figure 17. Median monthly flow at LD3.

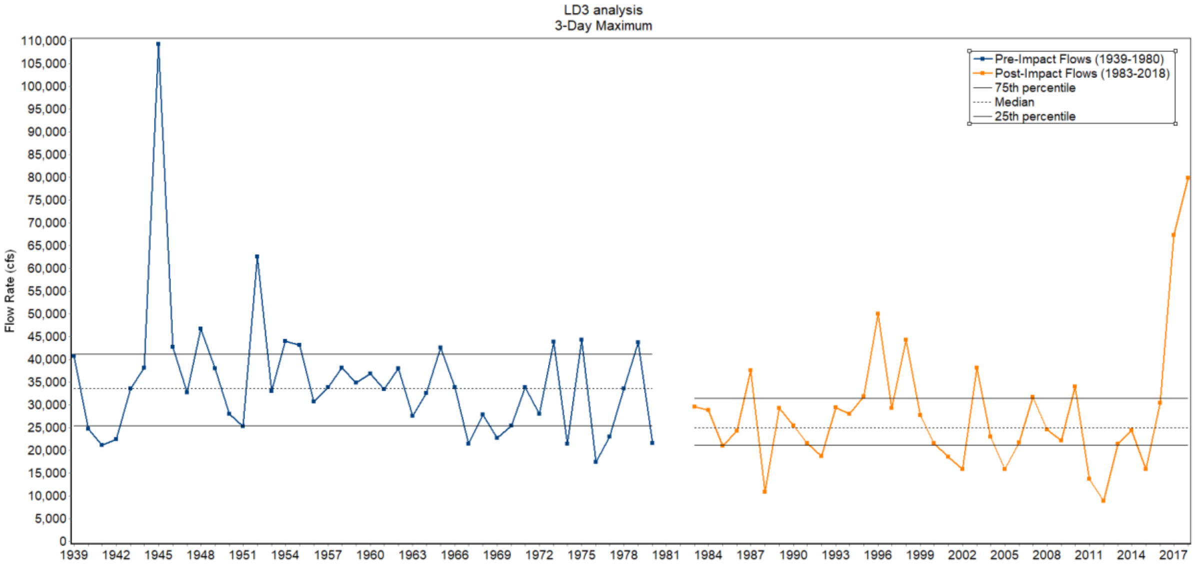


Figure 18. Three-day yearly maximums at LD3. The National Weather Service Flood Stage is 25,798 cfs, showing the river had overbank flooding more pre-dam than post-dam.

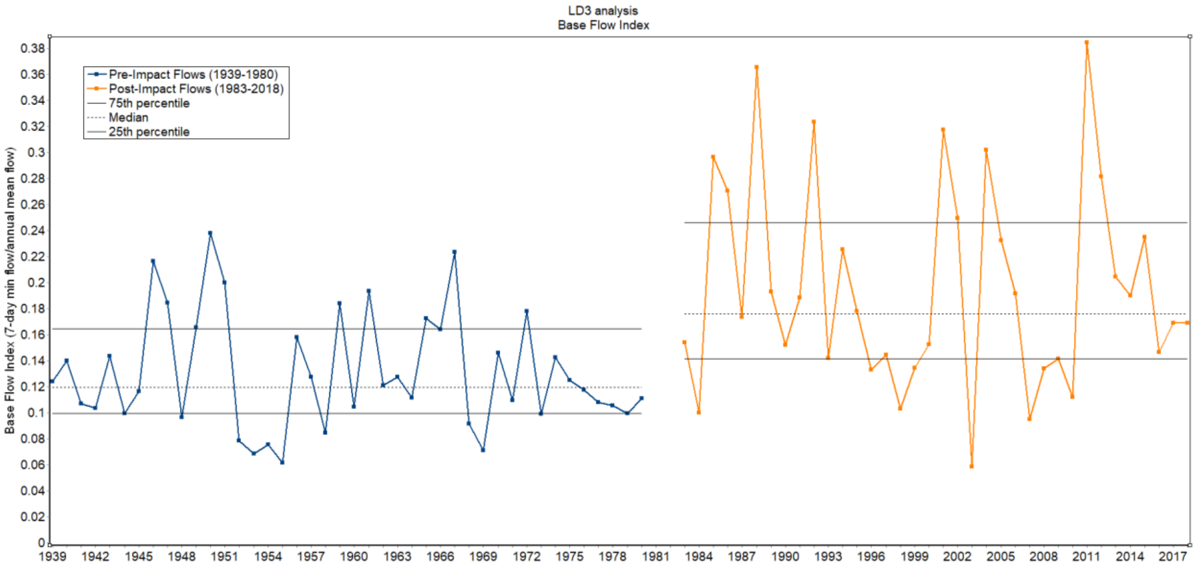


Figure 19. Baseflow index, 7-day minimum flow divided by annual flow at LD3.

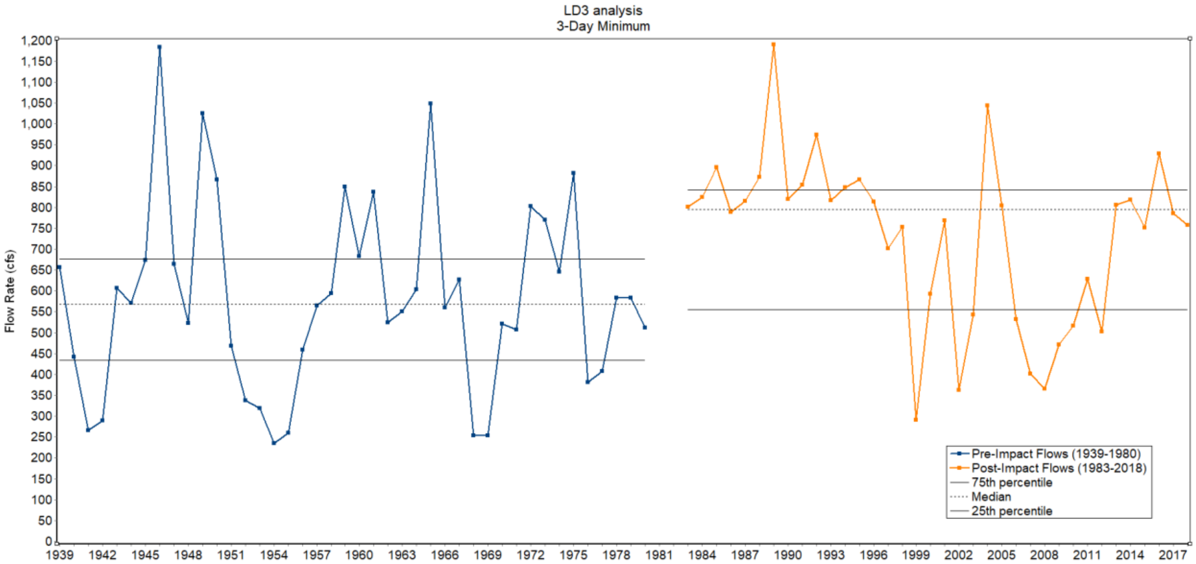


Figure 20. Three-day yearly minimums at LD3.

Effects of Jordan at LD1

LD1 did not have enough data to give confidence that a comparison pre-and post- dam would be reliable. Yet, there are some data that can guide ecological considerations. There is a lot of downstream runoff between Jordan Lake and LD1, yet Jordan Dam can still influence LD1 in certain conditions. Jordan Dam releases represent 30% of mean annual flow, 20% during times (January), and just under 40% during dry times (October) at LD1 (Table 2 in hydrology section). Since Jordan Dam was built, the median 3-day maximum at LD1 was 22,270 cfs. It is unlikely that Jordan Dam releases would have a significant impact during these high-water events. Yet, the median 3-day minimum post-dam was 820 cfs. In this instance, releases from Jordan Dam could influence flows at LD1. For LD1 data, see Appendix 4.

Floodplain condition in the basin

The Cape Fear River Basin spans the piedmont and coastal plain, creating floodplain forests that vary in species composition and human environments that range from urban to rural. In an effort to capture the condition of the floodplains throughout the basin, a mapping product called the Active River Area (ARA) was used (Nature Conservancy, 2008). This product is a GIS layer that represents land areas that contribute water to a stream or river, and the ARA provides a good representation of the floodplain. This, combined with the National Land Cover Dataset, allows investigation of the general patterns in the floodplain. A basinwide assessment of the developed areas within the ARA, which represents impervious cover within the floodplain, revealed an estimated 67,472 acres in this category (Figure 21). Within the ARA, there were 419,179 acres

(27%) of forest land, 700,753 acres (46%) of wetlands, and 258,452 acres (17%) of land that represents neither forest or wetland (mostly agriculture and grasslands) (Figure 20).

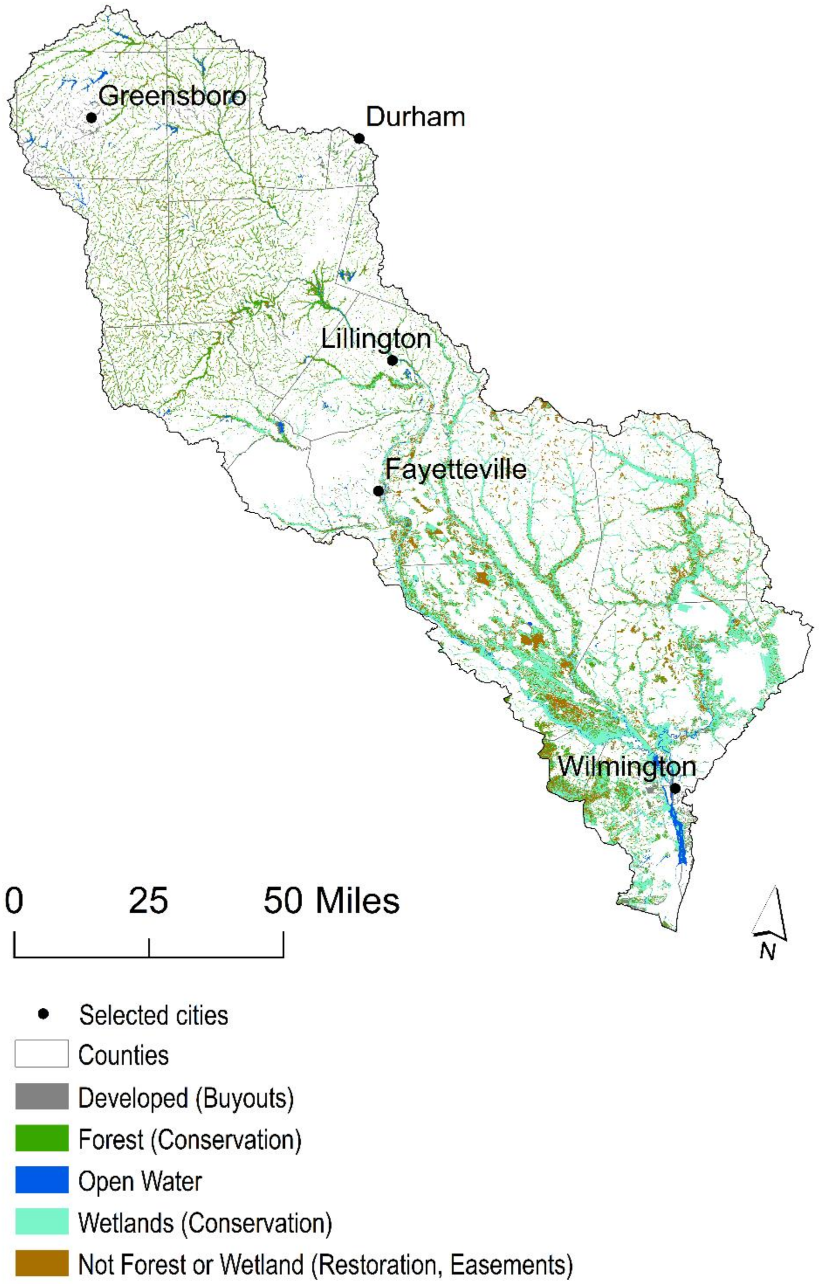


Figure 21. Land categories within the Active River Area.

Since the e-flows workshop will focus on areas downstream of Jordan Lake, it is important to have more detail for these sections and to focus on the mainstem of the river that can be influenced by Jordan Dam releases. As a reminder, the focus reaches in the e-flows workshop will be Jordan Lake to Lillington (Reach 1), Lillington to LD3 (Reach 2) and LD3 to LD1 (Reach 3). To determine the vegetation communities within these floodplains, TNC used the ARA and combined it with a 300m buffer from the center of the river to further refine our floodplain boundaries. Next, TNC added the GAP dataset. The GAP data is a USGS product that lists vegetation and land cover patterns (USGS, 2019). In North Carolina, TNC added in additional references where the Natural Heritage Program had ground-truthed the vegetation. The GAP data has many categories of vegetation, so TNC highlighted the top 5 vegetation types for each reach (Table 5). Each of these categories corresponds to typical tree species within them (Table 6). Maps were created for each reach of the river (for example map, see Figure 22). For a view of all of the reaches of the river, see Appendix 5.

Table 5. Vegetation types within the floodplains between Jordan Lake and LD1

	Dominant Ecosystems	Acres	Percent (of ARA within 300m)
Reach 1	Large Floodplain Forest - Forest Modifier	1,138	24%
	Open Water (Fresh)	1,096	24%
	Dry-Oak (Pine) Forest - Hardwood Modifier	953	20%
	Harvested Forest- Grass/Forb Regeneration	258	6%
	Evergreen Plantation or Managed Pine	257	6%
	Dry Oak-(Pine) Forest - Mixed Modifier	200	4%
	Total	***4,662***	***84%***
Reach 2	Small Brownwater River Floodplain Forest	2,884	28%
	Open Water (Fresh)	1,805	18%
	Wet Longleaf Pine Savanna and Flatwoods	1,274	12%
	Dry and Dry-Mesic Oak Forest	752	7%
	Upland Longleaf Pine Woodland	663	6%
	Cultivated Cropland	569	6%
	Total	***10,306***	***77%***
Reach 3	Small Brownwater River Floodplain Forest	6,178	51%
	Open Water (Fresh)	1,723	14%
	Wet Longleaf Pine Savanna and Flatwoods	927	8%
	Small Blackwater River Floodplain Forest	692	6%
	Black Water Stream Floodplain Forest - Forest Modifier	453	4%
	Peatland Pocosin	381	3%
	Total	***12,074***	***86%***

Table 6. Description of typical species found within the GAP data vegetation communities.

Ecosystem	**Dominant Vegetation**
Large Floodplain Forest	Box Elder (*Acer negundo*), River Birch (*Betula nigra),* Green Ash (*Fraxinus pennsylvanica*), Sweetgum (*Liquidambar styraciflua*), Tulip Poplar (*Liriodendron tulipifera*), American Sycamore (*Platanus occidentalis*), Swamp Chestnut Oak (*Quercus michauxii*), Cherrybark Oak (*Quercus pagoda*), Loblolly Pine (*Pinus taeda*), Virginia Pine (*Pinus virginiana*), Black Willow (*Salix nigra*), Sugarberry (*Celtis laevigata*), Spicebush (*Lindera benzoin*), American Water-Willow (*Justicia americana*)
Dry-Oak (Pine) Forest	Mockernut Hickory (*Carya alba*), Pignut Hickory (*Carya glabra*), White Oak (*Quercus alba*), Scarlet Oak (*Quercus coccinia*), Southern Red Oak (*Quercus falcata*), Chestnut Oak (*Quercus prinus*), Northern Red Oak (*Quercus rubra*), Post Oak (*Quercus stellata*), Black Oak (*Quercus velutina*), Flowering Dogwood (*Cornus florida*)
Small Brownwater River Floodplain Forest	Box Elder (Acer negundo), Sugarberry (*Celtis laevigata*), Green Ash (*Fraxinus pennsylvanica*), Sweetgum (*Liquidambar styraciflua*), Water Tupelo (*Nyssa aquatica*), American Sycamore (*Platanus occidentalis*), Swamp Chestnut Oak (*Quercus michauxii*), Cherrybark Oak (*Quercus pagoda*), Swamp Laurel Oak (*Quercus laurifolia*), Bald Cypress (*Taxodium distichum*)
Wet Longleaf Pine Savanna and Flatwoods	Slash Pine (*Pinus elliottii*), Longleaf Pine (*Pinus palustris*), Pond Pine (*Pinus serotina*), Large gallberry (*Ilex coriacea*), Fetterbush (*Lyonia lucida*), Pineland threeawn (*Aristida stricta*), Toothache Grass (*Ctenium aromaticum*), Carolina dropseed (*Sporobolus pinetorum*), Wireleaf Dropseed (*Sporobolus teretifolius*)
Dry and Dry-Mesic Oak Forest	Sweetgum (*Liquidambar styraciflua*), White Oak (*Quercus alba*), Southern Red Oak (*Quercus falcata*), Water Oak (*Quercus nigra*), Post Oak (*Quercus stellata*)

Upland Longleaf Pine Woodland	Bluejack Oak (*Quercus incana*), Turkey Oak (*Quercus laevis*), Sand Post Oak (*Quercus margarettiae*), Sand Laurel Oak (*Quercus hemisphaerica*), Longleaf Pine (*Pinus palustris*)
Peatland Pocosin	Sweetbay Magnolia (*Magnolia virginiana*), Pond Pine (*Pinus serotina*), Staggerbush (*Lyonia mariana*), Swamp Titi (*Cyrilla racemiflora*), Loblolly Bay (*Gordonia lasianthus*), Large Gallberry (*Ilex coriacea*), Inkberry (*Ilex glabra*), Fetterbush (*Lyonia lucida*), Swamp Bay (*Persea palustris*), Honeycup (*Zenobia pulverulenta*), Laurel Greenbrier (*Smilax laurifolia*)
Blackwater Stream Floodplain Forest	Swamp Tupelo (*Nyssa biflora*), Sweetbay Magnolia (*Magnolia virginiana*), Swamp Laurel Oak (*Quercus laurifolia*), Bald Cypress (*Taxodium distichum*)
Small Blackwater River Floodplain Forest	River Birch (*Betula nigra*), Sweetgum (*Liquidambar styraciflua*), Swamp Tupelo (*Nyssa biflora*), Planertree (*Planera aquatica*), Water Oak (*Quercus nigra*), Pond Cypress (*Taxodium ascendens*), Bald Cypress (*Taxodium distichum*), Coastal Plain Willow (*Salix caroliniana*), Black Willow (*Salix nigra*)

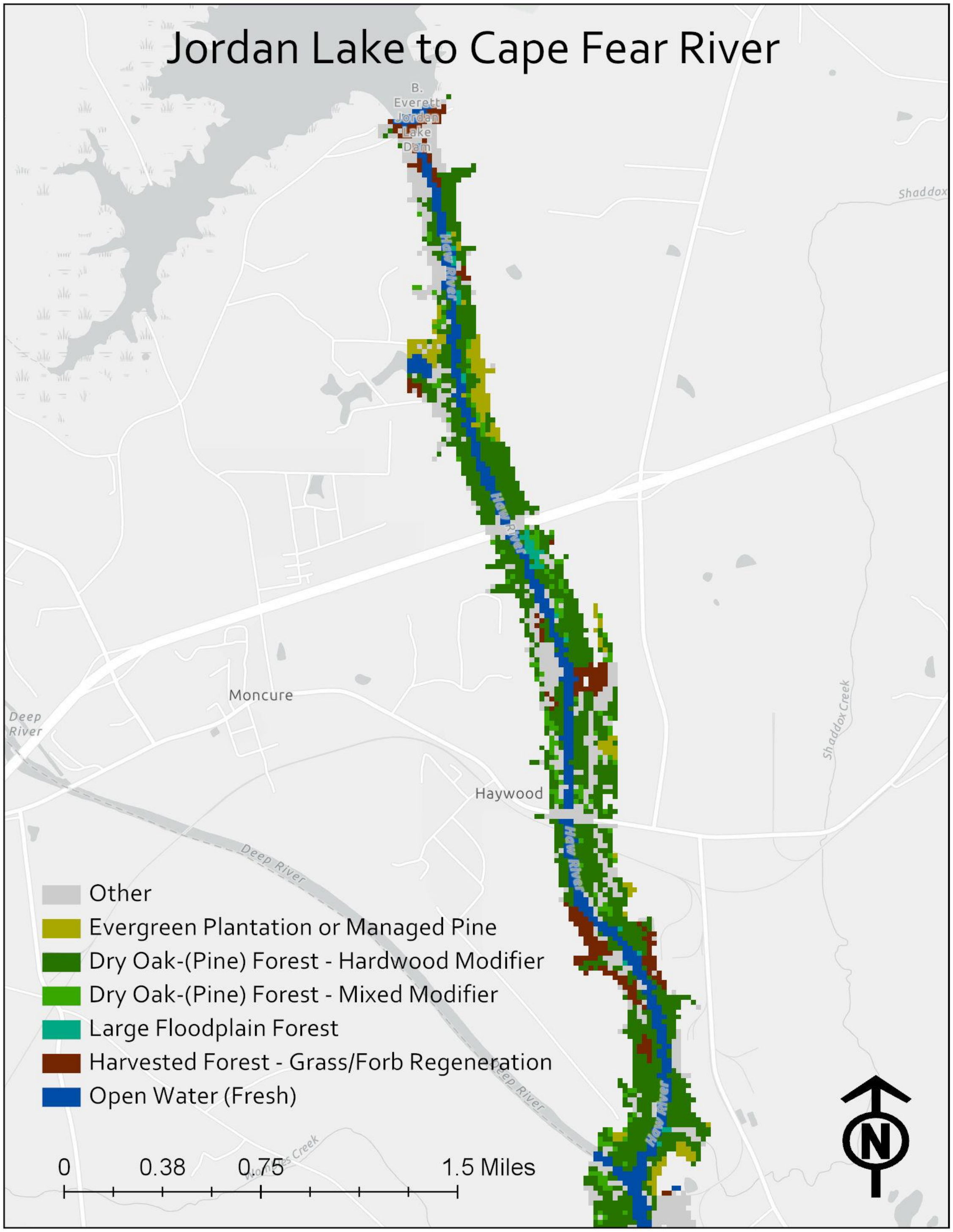


Figure 22. Floodplain vegetation data for Jordan Lake to the confluence of the Deep and the Haw.

Workshop participants will be asked to think about the hydrology requirements that are linked to healthy floodplains within the study area. Healthy floodplains were defined as ones that have active water exchange with the river (hyporheic, surface, or groundwater flow), healthy vegetation, they support the aquatic life food chain, and provide additional aquatic life habitat if flooded.

General Water Quality Issues Throughout the Basin

Water quality has implications for both aquatic life and human use. Since upstream activities effect the downstream community, water quality considerations were reviewed within the upper, middle, and lower basin as depicted in Figure 3.

Waters within the Cape Fear River are of varying quality and characteristics, from relatively pristine blackwater streams to heavily managed reservoirs and impoundments that suffer from chronic nutrient pollution and algal blooms (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). As of 2005, over 475 freshwater miles of river, representing 90 distinct named waters within the basin, are formally listed as impaired. The most common reason for impairment in reservoirs was a violation of the chlorophyll a standard (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005)(Appendix 6). Emerging industrial contaminants, including perfluaroalkyl substances (e.g., GenX) have recently posed additional water quality challenges in the river (North Carolina Department of Environmental Quality, 2018), although addressing these challenges is outside the scope of the SRP.

An array of studies have been carried-out by state and local governments, academic researchers and a variety of other stakeholders to determine the sources of water quality problems and to evaluate possible solutions. The NC Department of Environmental Quality maintains numerous monitoring stations across the Cape Fear River Basin that are used for water quality assessments approximately every two years. The most recent assessment (2016) included data collected from 2010-2014 at 290 distinct ambient monitoring stations (NC Department of Environmental Quality, 2018). The State also uses biotic sampling in assessments of water quality, including 480 stations where invertebrates were sampled from 1983-2014 (NC Department of Environmental Quality, 2018), and 136 stations where fish samples were collected between 1992-2010 (NC Department of Environmental Quality, 2018). The NC Division of Water Resources also tested 481 samples for algal blooms between 2012 and 2018, including both routine samples and investigations in response to complaints (Table 7, Figure 23). An additional 153 water quality stations are monitored by coalitions on a volunteer basis (NC Department of Environmental Quality, 2018). Recently, the North Carolina General Assembly funded the North Carolina Policy Collaboratory to study nutrient management strategies for Jordan Lake (Collaboratory, 2018). Despite substantial research, stressors affecting many waterways in the basin are still not well-understood (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005).

Table 7. Summary of algal bloom detection results in DWR sampling conducted within Cape Fear River Basin 2012 – 2018.

Year	Non-detect	Algal Bloom	Potentially Harmful Algal Bloom	Total Samples
2012	0.13	0.23	0.65	79
2013	0.08	0.34	0.58	53
2014	0.17	0.24	0.60	72
2015	0.25	0.20	0.55	162
2016	0.26	0.18	0.56	108
2017	0.40		0.60	5
2018	0.50		0.50	2

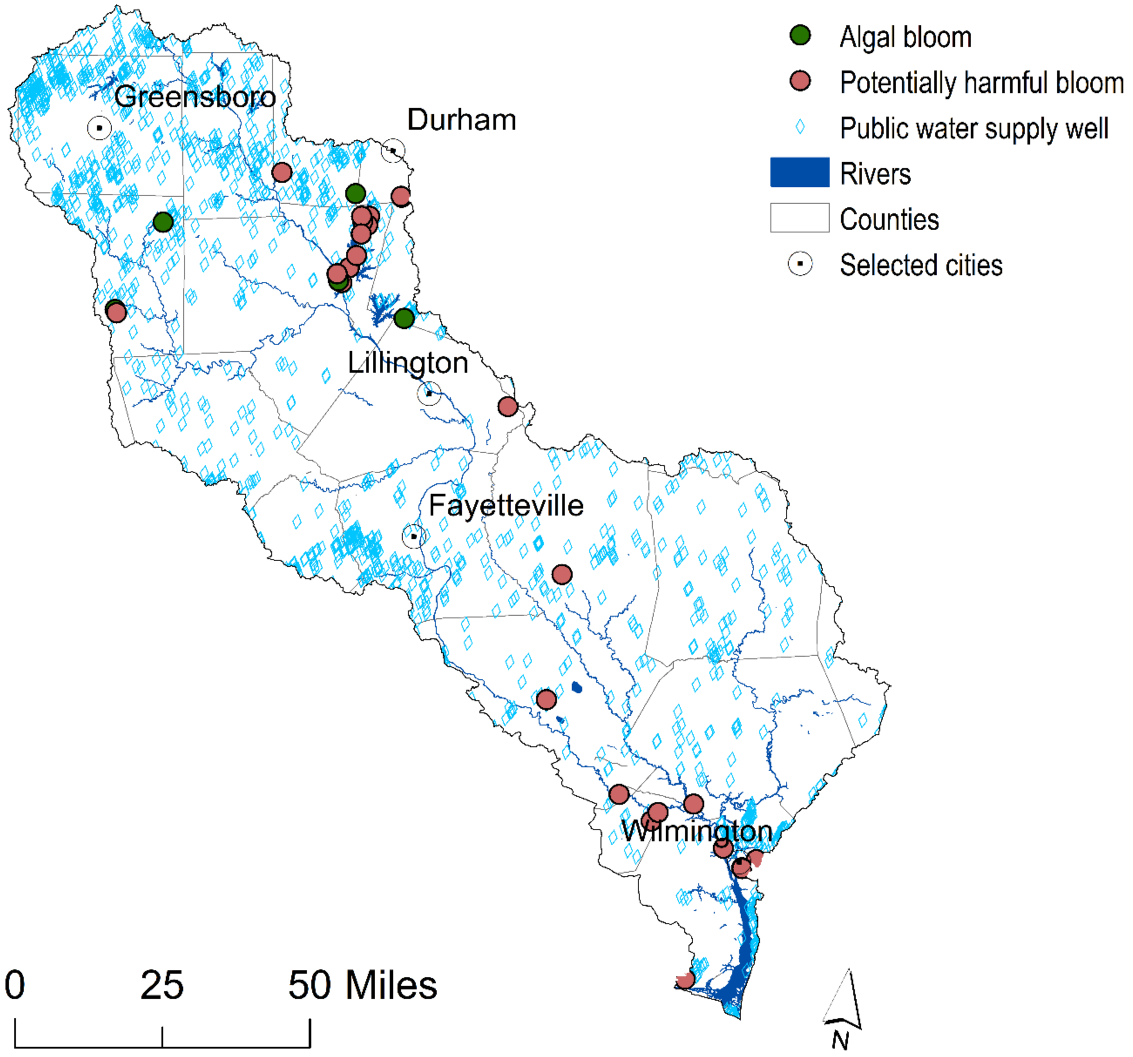


Figure 23. Map of algal blooms from 2012-2018. Data from NC DEQ.

Land use history in the Cape Fear River Basin provides important context for understanding water quality issues. The role of 'legacy sediment' as a source of nutrient loading has become a prominent area of research (James, 2013). Extensive post-Colonial forest clearing and agricultural practices in Eastern North Carolina led to rapid erosion of upland soils, at up to 500 times the long-term background rate of soil production and erosion (Wegmann, Osburn, Lewis, Peszlen, & Mitasova, 2013). The large volume of accumulated sediment behind millpond structures continues to contribute significantly to non-point source total suspended solids and nutrient loads in piedmont streams (Wegmann, Osburn, Lewis, Peszlen, & Mitasova, 2013). Notable recent changes include an increasing density of concentrated animal feeding operations (CAFOs) and population growth rates, placing North Carolina as the 5th fastest growing state in the nation since 2010 in terms of urban growth (U.S. Census Bureau, 2018).

Seasonal and interannual variation in climate interacts with land use to pose unique challenges for maintaining a reliable high-quality water supply to support the growing human population in the region. Under high flow conditions, more nutrients and contaminants are released into waterways, particularly from non-point sources. Seasonal flooding and hurricane-induced flooding can distribute pollutants over broad areas. Yet, drought and low-flow conditions result in increased concentrations of substances in streams and more acute impacts from point sources, even when these sites are operating within the limits of NPDES permits. Low flows are also associated with lower dissolved oxygen (DO) and higher water temperatures that can be harmful to aquatic life, and longer retention times that promote algal blooms (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005).

Given the diverse landforms and land uses within the Cape Fear River Basin, the state of knowledge for water quality in the upper, middle, and lower basins is separately considered in further detail below.

Water Quality in the Upper Basin

The upper Cape Fear River Basin has been subject to high rates of urban and suburban growth in recent years in the cities of Greensboro, Burlington, Pittsboro, Apex, Cary, Durham, and Morrisville (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005; Eanes, 2018; U.S. Census Bureau, 2018). Many of the waterways in the upper basin exhibit symptoms of the 'urban stream syndrome'– streams that are heavily incised, have flashy hydrology, lack diverse fauna, and frequently have nutrient and pesticide issues (Walsh, et al., 2005). Expanded development has resulted in increased impervious surface area, reduced infiltration (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005) and flashier hydrographs (Somers, et al., 2013). Streams draining urban areas have modified hydrology with a high proportion either becoming channelized or incised, with degraded habitat in the form of eroded streambanks, increased sedimentation, and few riffles observed within streams. Streams in the upper basin are characterized by high turbidity, chlorophyll a exceedances, low dissolved oxygen (DO), and relatively high pesticide loads. Fish consumption warnings are in place for much of the surface waters in the upper basin due to the presence of mercury and other heavy metals (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005).

The thermal regime of rivers and streams is an often-overlooked aspect of water quality (Olden & Naiman, 2010). The thermal regime of the Cape Fear River has been altered due to reduced forest cover and urban heat island effects. The condition of vegetated buffers is generally poor across portions of the upper basin; for example, even 14 years ago, nearly 60% of the buffers within the Little Troublesome Creek Watershed are considered disturbed (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). Urban streams lacking forest cover have more variable baseflow temperatures than their forested counterparts and temperature spikes due to stormwater runoff extend downstream even into seemingly more natural forested waterways (Somers, et al., 2013).

Within Jordan Lake, specifically, water quality issues have existed since its impoundment. The impairments affecting Jordan Lake are chlorophyll a (a green pigment in algae), turbidity, and pH (NCDEQ, 2019). Because of the continuous poor water quality in Jordan Lake, Section 3(c) of the Jordan Rules (S.L. 2009-216) requires yearly monitoring by the state to evaluate progress in reducing nutrients and pollution in the lake.

Nuisance algal blooms have also been recorded throughout the upper Cape Fear River Basin including at Graham-Mebane Lake, Jordan Lake, Lake Burlington, Cane Creek Reservoir, and University Lake (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). Chlorophyll a levels are used as a proxy for algal growth. *Microcystis aeruginosa*, an algae species which produces harmful chemicals as a byproduct of its lifecycle, has been positively identified at Jordan Lake and in downstream areas of the Cape Fear River (Polera, 2016). Cyanotoxins have been detected year-round at Jordan Lake, with four distinct toxins identified simultaneously (Wiltsie, Schnetzer, Green, Vander Borgh, & Fensin, 2018).

The upper Cape Fear River Basin has a profound impact on receiving waters in the middle and lower portions of the basin. Stormwater from growing urban centers in the upper basin is a significant source of nutrient pollution downstream; a recent study found that ~50% of the nutrient load in the lower basin can be attributed to outflows from Jordan Reservoir and the Deep River (Tech, 2015).

Water Quality in the Middle Basin

Although the middle portion of the watershed has historically had high forest cover, recent high rates of population growth have been concentrated in the vicinity of headwater streams in this part of the Cape Fear River Basin. Waterways in the middle basin are at risk of further degradation from future development (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005; Buck Engineering, 2004). In the 2005 assessment, the Cape Fear River was considered to be impaired for aquatic life at the confluence of the Haw and Deep Rivers (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). The 2018 303d list shows Highway 42 to the Buckhorn dam as impaired for chlorophyll a (NCDEQ, 2019). Similar to the upper watershed, the middle basin suffers from exceedances of chlorophyll a and fecal coliform bacteria, high turbidity, and low pH. Water quality data collected from July 1998 through April 2003 at 22 monitoring stations indicated that nitrogen and phosphorous are the nutrients of greatest concern (Buck Engineering, 2004). Reservoirs in the middle basin are hypereutrophic and algal blooms have become common during low flow conditions (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). Persistent blooms have been observed at LD1, 40 miles upstream from the City of Wilmington, where the City's drinking water intake is located (Isaacs, et al., 2014). Trash and urban debris are a concern in some portions of the watershed, notably in the Fayetteville region. Nutrient sources in the middle basin originate from several major point source dischargers, such as wastewater treatment plants, but also from non-point sources such as stormwater runoff and agricultural operations.

Water Quality in the Lower Basin

As is true of the upper and middle portions of the basin, development has expanded in the lower basin. The region is still important for agriculture, and notably contains among the highest densities of hog and poultry CAFOs in the country (e.g., Sampson and Duplin Counties) (Martin, Emanuel, & Vose, 2018), but has seen residential development increases as well. The lower basin is characterized by elevated total suspended solids (TSS), sedimentation, and reduced quality of in-stream habitat, as well as low pH (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). Animal waste spills have occurred periodically under seasonal flood conditions, as well as during Hurricanes Floyd, Matthew and Florence (Pierre-Louis, 2019) (Siegal, 2018).Although spraying of CAFO liquid waste on fields is permitted from March 1st – September 30th, concentrations of nutrients and fecal coliform pollution in the basin have a consistently observable seasonal peak during summer (Mallin & McIver, Season matters when sampling streams for swine CAFO waste pollution impacts, 2018). Point sources of nutrient and waste input, including industries and waste water treatment plants, also contribute to water quality concerns including chloride exceedances, chlorine violations, and other toxic effluents (e.g., GenX). Although low dissolved oxygen is an issue in some areas of the lower basin, naturally low DO occurs in some tributaries including water sourced from swamps in the Black River. A fish consumption hazard is in place for the lower basin and the estuary's shellfish harvest is considered to be impaired (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005).

The lower basin has been seasonally affected by toxic algal blooms in the last several years, thought to be driven mainly by excess nutrient inputs from non-point sources (North Carolina Department of Environment & Natural Resources Division of Water Quality, 2005). A study of phytoplankton production in the Cape Fear River Estuary found that alternating nitrogen and phosphorous concentrations affect algae growth (Mallin, Cahoon, McIver, Parsons, & Shank, 1999).

Potential effects of climate change and future development on water quality

Projected changes in precipitation and temperature due to ongoing climate change will have implications for water quality in the Cape Fear. More intense precipitation events are expected to contribute more nutrients into waterways compared to baseline conditions (Paerl & Paul, 2012). Increasing temperature and atmospheric CO_2 are likely to promote greater algal growth and to lend a favorable advantage to problematic cyanobacteria species, particularly under high nutrient load conditions (Paerl & Paul, 2012). Although hydrologic changes including water residence time, temperature, and ratios of other limiting nutrients may affect how aquatic systems process nitrogen and phosphorous, it should be noted that the greatest predictor of nutrient exports from surface waters remains the rate at which nutrients are applied within the contributing watershed (Baron, et al., 2013). Increases of impervious surface and development in the basin will exacerbate these issues.

Potential for operations to influence water quality

Strategic flow management using Jordan Dam could be considered to ameliorate water quality in Cape Fear River basin with respect to both nutrient load and temperature, although the exact amount of these improvements would vary spatially. The Corps has limited available resources to revise Lock and Dam operations.

Selective deep water withdrawals, which destabilize stratification of the water column, might be possible to reduce the negative effects of excessive nutrient concentrations. Nutrients are more concentrated at depth in the reservoir due to settling of suspended sediments—re-release of these nutrients through mixing into the upper water column may be a significant source of the nutrient load supporting phytoplankton growth. A nutrient management study of Jordan Lake has called for additional research into the role of legacy sediment (NC Policy Collaboratory, 2017). Experimental releases of deep water from Ford Lake, Michigan, before anoxic conditions developed, increased vertical mixing and DO at depth, altered water column nutrient concentrations, and reduced the prevalence of Microcystin compared to normal operations—a result which was subsequently replicated over three seasons (McDonald & Lehman, 2013). It is important to note that Ford Lake is only 10% the size of Jordan so these results may not be fully transferable.

Multiple strategies are available to influence water temperature. Areas downstream from dams often experience thermal depression in spring and summer, due to releases of water at temperatures that are lower than pre-dam flows, and artificially elevated temperatures in winter due to releases of water from reservoirs subject to thermal inversion (Olden & Naiman, 2010). Alternatively, a variety of strategies can be used to intentionally manage downstream temperatures to achieve ecological objectives. Multi-level intakes, such as that already installed at Jordan Dam, could possibly permit temperature management by selective releases of water from different depths. Destratification to mix the water column and modify temperatures prior to water releases can also be achieved using aeration systems, pumps, or submerged weirs or curtains. Stilling basins can slow flow releases, and draft tubes can be added to hydroelectric power generation operations to attenuate heat after water has passed through turbines (Olden & Naiman, 2010). Of note, the hydropower on Jordan Dam is a small operation and not likely to create excessive heat as water goes through the generators.

Jordan could also be used to help improve flows during conditions that promote algal blooms in the lower basin. For instance, potentially harmful algal blooms were detected five times at LD1 between June 21, 2012 and August 21, 2012. During this two-month period, the USGS gage recorded the median daily flow at 1350 cfs, the lowest flow at 498 cfs, and the highest flow at

3180 cfs. While flow is only one component of reducing algal blooms, releases from Jordan could potentially help move water in the low-flow conditions.

Biological Communities

In addition to considering healthy floodplains and water quality, here we provide general information about the aquatic biological communities. Flow levels affect access to habitat, conditions for spawning, water quality components that affect organisms, and more. There are 35 species of concern in the basin, including two aquatic snails, two crayfish, 18 freshwater or anadromous fishes, and 13 mussels (NCWRC, 2005, pp. I1-I2) (Appendix 7).

Fish

The Cape Fear River is mostly fresh water, but because the river is tidally influenced in the area below LD1, there is the potential for a diverse assemblage of fishes to occur. Fishery resources in this part of the Cape Fear River can be classified into three categories: permanent resident species, anadromous species, and estuarine dependent species. Anadromous fish species historically spawned nearly Smiley Falls, just outside of Lillington. Now, the locks and dams are barriers to fish passage. LD1 has a rock arch rapids to assist fish in passage. Corps personnel use the lock chambers at LD2 and LD3 to lock fish upstream during certain times of the year that correspond to anadromous fish spawning schedules provided by the North Carolina Wildlife Resources Commission (approximately January-May).

In addition to rare anadromous fish, there are several rare freshwater fish such as the Cape Fear Shiner, the Carolina Darter and the Sandhills Chub (Appendix 7). Of these, the Cape Fear Shiner is an endangered species. This fish has been documented in and around the mainstem Cape Fear and tributaries just below Jordan Dam (Figure 24).

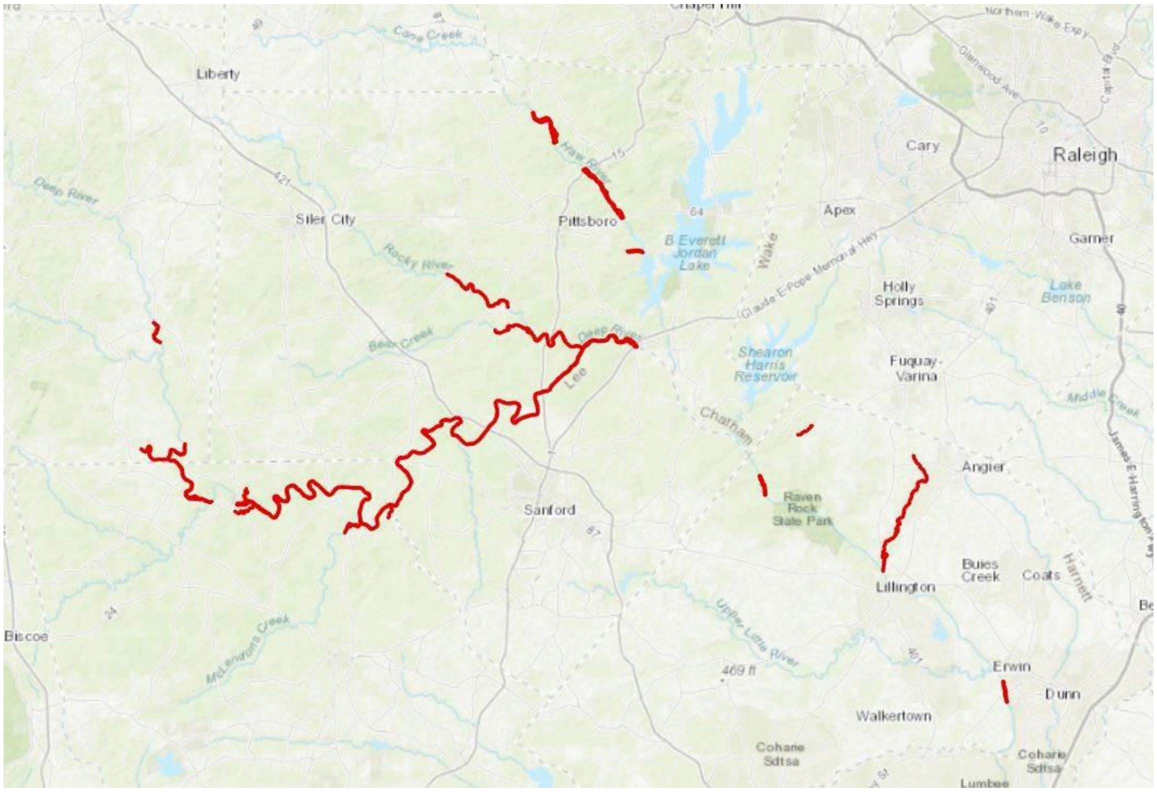


Figure 24. NC Natural Heritage data indicating potential locations of the Cape Fear Shiner.

Downstream, numerous fish have been documented near the locks and dams. At LD1, Nichols and Louder (1970) reported numerous resident species; including longnose gar (*Lepisosteus osseus*), gizzard shad (*Dorosoma cepedianum*) shorthead redhorse (*Moxostoma macrolepidotum*), bluegill (*Lepomis macrochirus*), redbreast sunfish (*L. auritus*), black crappie (*Pomoxis nigromaculatus*), bowfin (*Amia calva*), common carp (*Cyprinus carpio*; exotic), white catfish (*Ameiurus catus*), channel catfish (*Ictalurus punctatus*; exotic), brown bullhead (*Ameiurus nebulosus*), and black bullhead (*A. melas*). Although large numbers of carp, longnose gar, and white catfish were captured in the lock chamber, the remaining resident species were present in relatively small numbers at any given time during the four-year sampling period. Additional resident species that occur in the vicinity of LD1 include threadfin shad (*D. petenense*), Spotted Suckers (Minytrema melanops), whitefin shiner (*Cyprinella nivea*), spottail shiner (*Notropis hudsonius*), redear sunfish (*L. microlophus*), largemouth bass (*Micropterus salmoides*), blue catfish (*Ictalurus furcatus*), and flathead catfish (*Pylodictis olivaris*) (USACE 2010). Blue, channel, and flathead catfish, both introduced species, dominate the resident assemblage in terms of biomass. Catfish, largemouth bass, and sunfish are important recreational fisheries below LD1.

Anadromous species that undertake annual migrations from coastal waters to spawning grounds in the upper freshwater reaches of the Cape Fear River include Atlantic sturgeon (*Acipenser brevirostrum*) and shortnose sturgeon (*Acipenser oxyrinchus*), striped bass, American shad, hickory shad (*Alosa mediocris*), blueback herring (*A. aestivalis*), and alewife (A. *pseudoharengus*). Both sturgeon species are federally listed. In addition to anadromous species, elvers of the catadromous American eel (*Anguilla rostrata*) migrate upriver to freshwater juvenile nursery areas in the upper Cape Fear River each year to spend their early lives in the freshwater tributaries (USACE 2010). Historically, anadromous fish spawning runs extended ~180 miles upstream of the river mouth to Smiley Falls near Lillington (Stevenson 1899). Recent studies (Raabe 2017) indicate that of those fish that approach LD1 in an apparent attempt to pass, ~53 to 65% of American shad and ~19 to 25% of striped bass are successful at passing the dam and continuing upstream.
During the e-flows workshop, experts will be asked to think about anadromous and rare fish flow needs. Table 8 provides basic background information of spawning needs and preferences for various fish found in the Cape Fear River Basin.

Table 8. Cape Fear River Fish Spawning Schedule and Requirements.

Fish Name	Spawning Locations	Spawning Times	Other Requirements
American Eel	Sargasso Sea of the Western Atlantic	Late summer and fall	Catadromous; live in freshwater and migrate to saltwater to spawn
American Shad	Spawn in mid-river shallow water over rocky bottoms	November – July At Night (60-68 degrees)	Anadromous; live in saltwater and migrate to freshwater to spawn

Atlantic Sturgeon	Spawning occurs in hard bottom substrates with flowing water.	April-May, Fall spawn recorded in the Roanoke River and possible throughout NC.	Anadromous; live in saltwater and migrate to freshwater place of their birth to spawn
Black Crappie	Shallow, calm water near vegetation	March – May (60-68 degrees)	Clear ponds, natural lakes and reservoirs with moderate vegetation
Blue Catfish	Under logs or other submerged structures, or along undercut river banks	Late spring and early summer (70-75 degrees)	Large rivers with fast currents, but can be found in lakes in open water
Bluegill	Protected areas with clear, quiet water and a sand, gravel, or mud bottom	May – October (peak at 70 degrees)	Found in most all habitats but most abundant in ponds and reservoirs
Bowfin	Marshy, weedy bays	April and May At Night	Lakes and large slow-moving rivers with muddy bottoms and dense vegetation
Bullhead Catfish	Soft bottoms of mud and sand	Spring (75-80 degrees)	Found in many habitats and abundant in NC streams, rivers, ponds, and lakes
Cape Fear Shiner	Slower flowing pools with rocky substrate	May-July	Only found in the Upper Cape Fear River Basin and typically observed in slow pools, riffles, and slow runs
Chain Pickerel	Vegetation in water a foot or two deep	Early spring	Naturally calm areas in lakes and rivers with abundant aquatic vegetation
Common Carp	Shallow bays, tributary headwaters, marshy river sloughs and marshes, around muddy shallows and aquatic vegetation	Late April and early May	Along the shoreline of lakes and rivers
Flathead Catfish	Depressions in river bottom, hollow logs or holes along the bank	Summer (72-84 degrees)	Large rivers and lakes in deep, slow

			stretches near submerged debris
Largemouth Bass	One to four feet of water	Spring (63-68 degrees)	Lakes, ponds, and sluggish streams and rivers with a lot of submerged structure
Pumpkinseed	Circular spots over gravel near the shore in 6-12 inches of water	Late Spring or early summer	Shallow areas of lake and slow-moving rivers with submerged vegetation and brushy cover
Redbreast Sunfish	Coarse sand or gravel near the shore	Late April or early May	Found in all habitats in NC except cold mountain waters
Redear Sunfish	Saucer-shaped depression near shore in mud or sand bottom	April (70 degrees)	Found in all habitats in NC except cold mountain waters
Spotted Bass	Gravel or rock bottom-sweep away silt	Spring (63-68 degrees)	Found in the upper CFR in NC
Striped Bass	Near the surface	Spring (62-70 degrees)	Anadromous; live in saltwater and migrate to freshwater to spawn
Warmouth	Multiple nests on gravel or sandy bottoms	Mid-spring into Late-summer	Swamps, marshes, shallow lakes, and slow-moving streams and canals with soft, muddy bottoms
White Catfish	Large depression scoured out over sand or gravel	Late May into July	Tidal rivers and streams , but also in freshwater lakes, ponds, rivers, and streams
White Perch	Migrate from brackish water to freshwater to spawn	Spring	Prefer low-salinity estuaries, but inhabit coastal rivers and lakes
Yellow Perch	Tributaries	February or early March (45-50 degrees at night)	Cool, clear lakes, with a sandy or gravelly bottom and rooted underwater vegetation

Freshwater bivalves, reptiles and amphibians

At the E-flows workshop, participants will be asked to think mostly about fish when drafting e-flow prescriptions. Yet, there are many other important aquatic organisms and here information is summarized in case experts need additional information when crafting e-flow recommendations.

Bivalves

Most freshwater mussels, a type of bivalve, live in lotic systems with moving water such as the Cape Fear River. These lotic mussels require certain flows with a mix of cobble and sand bottoms to anchor themselves. Since mussels are a stationary species, they are a reliable indicator of water quality as they are sensitive to many parameters including contaminants, nutrients, dissolved oxygen levels and excess siltation (Conservancy, 2019). After fertilization, females release their larvae, which attach on to fish. After a few weeks, or in as few as seven days, the larvae transform into juveniles and will drop off and anchor themselves to the bottom, where they will spend the rest of their lives. Appendix 8 is a list of known species of bivalves found in the Cape Fear River and some of their habitat/flow requirements.

Reptiles and amphibians

Within the Cape Fear River, there is a diverse assemblage of reptiles and amphibians that span different habitat requirements (See Appendix 9). Reptiles and amphibians provide important benefits to the ecosystems in which they live. They help in the dispersion of seeds and pollination, tadpoles aid in nutrient cycling and mosquito population control, and reptiles and amphibians, in general, help control populations of organisms across all Phylums (Hocking, 2014).

Amphibians are more closely associated with water and wetlands than most reptiles, birds, or mammals. Most frogs, toads, salamanders, and newts lay their eggs in water, have aquatic larvae, and inhabit forests or other upland habitats as adults. Frogs, salamanders, and newts have permeable skin, allowing them to breathe and absorb water through their skin. This makes amphibians a great indicator species of a healthy environment. Since amphibians breathe through their lungs and skin, amphibians are particularly susceptible to poor water quality conditions. Many frogs under the genera of Rana, live their entire lives in wetlands, along with several species of salamanders that are entirely restricted to water. Other species spend the majority of their lives on land, only using water to lays eggs. Different species of amphibians require different water flow restrictions to live. Some species require either lotic or lentic systems to live in or breed, while others will simply use ephemeral ponds to breed. No matter the species, at least one life stage of an amphibian requires water to survive (EPA., 2002).

Many species of reptiles, including some species of turtles, snakes, and alligators, live semi-aquatic lives. A reptile’s skin is made of keratin scales, which makes the skin virtually waterproof and prevents the reptile’s fluids from evaporating. A reptile’s kidneys also play a large part in water absorption and retention. Their kidneys are very efficient and are able to filter waste and reabsorb liquids (Wyneken, 2013). Unlike amphibians, reptiles don’t need to live near water to survive. They live near or in water because their bodies have adapted to an aquatic environment and food sources found there. Reptiles lay eggs or give live birth on land. When the juveniles are born, they will live a semi-aquatic life. Like amphibians, some species of reptiles prefer lotic or lentic systems. However, some species are found in both.

Recreation

Recreation is important up and down the Cape Fear River, and Jordan Dam is authorized for recreation, wildlife, and water quality which all supports recreational endeavors both in the lake and in the middle/lower basin. Flows will affect recreation through supporting fish populations, providing water for kayaking/boating, improving water quality for swimmers and more.

A variety of recreational activities can be enjoyed at Jordan Lake and along the Cape Fear River. Jordan Lake is a popular recreational location and vacation site, with a multitude of recreational facilities and infrastructure along its shores: boat ramps, camp sites, restrooms, picnic shelters, swim beaches, fishing piers, recreational boating, playgrounds, trails, and a canoe launch. Along the Cape Fear River, boaters, sightseers, anglers, and picknickers are a common site. At LD1, the following recreational facilities are available: restrooms, picnic area, boat ramp, concrete walkway, and a fishing pier (CFLD Draft EA).

Defining Ecosystem Flow considerations and needs

SRP E-flows workshop

As discussed in the introduction, there are important steps to think about flows for an entire basin. One of the critical steps is to gather experts together in a workshop to draft e-flow prescriptions. The impetus of this literature review is to consolidate information for the technical experts. The goal at the workshop is to develop e-flow recommendations that could result in benefits to fish, wildlife and the general ecosystem while minimizing conflicts with current human uses by exploring operational changes at Corps’ reservoirs.

During the Cape Fear River Basin SRP e-flows workshop, experts will go through a series of tasks and questions to draft e-flow prescriptions for specific reaches of the Cape Fear River downstream of Jordan Dam, as defined in the Basin Overview section. Experts will be broken into three different groups: fish, floodplains, and water quality. The task of the experts is to draft desired hydrographs for their ecological target at a specific reach of the river. These recommendations should include desired cfs targets in wet, dry and normal years. During the breakout sessions, experts will be instructed to focus on their ecological target and consider limitations later.

For fish, experts will be asked to consider the suite of diadromous fish as well as rare fish like the Cape Fear Shiner. Flow recommendations should consider spawning cues, migration needs, access to back floodplains, flow needs for shaping appropriate spawning substrates, and flow levels that support good water quality. The floodplains group will be tasked with thinking about ways to create healthy, functioning floodplains. Flow recommendations should consider the length of time that floodplains need to be inundated, the timing of inundation, the vegetation hydrology requirements, and more. The water quality group will be tasked with primarily thinking about how to reduce algal blooms. Flow recommendations should consider pulsing events to flush the system, drought conditions, temperature improvements, and more.

After each breakout group has created their recommended flows, the whole group will come together and negotiate one all-encompassing recommendation for each stretch of the river. If more information is needed, TNC and the Corps will document additional research and modeling needs. After the group has combined their hydrographs into one recommendation, the group will have a discussion about limiting factors. These limiting factors may include limitations of the dam, unknown consequences, and more. After the meeting, TNC and the Corps expect to take the flow recommendations and use the Corps suite of modeling tools to figure out how Jordan Dam can contribute to the flow prescriptions.

Using HEC-RPT to help visualize hydrographs and craft flow recommendations

The Corps and TNC will have real-time software running 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 will display hydrographs of wet, dry, and average years in HEC-RPT. The software can then be used to draw hydrographs on top of the data (Figure 25). 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)

System: Unified

State: Dry

Pulses/Floods: Spring Pulses - Dry

Description: Pulses to help migrating fish.

Date (ddmmm): 01Mar to 30Apr

Flow (cfs): 1500 to 1800

Date (ddmmm)	Duration (Days)	Peak (cfs)	D.O.P. (Days)
15Mar	6	1600	1

Pulse/Flood Flow Data Entry Dates, durations, magnitudes, and duration of peaks.

Description:

Date (ddmmm)	Flow (cfs)	Description
01Oct	200	
01Nov		
01Jan		
01Jun		
01Aug		

Low Flow Data Entry Dates, magnitudes, and descriptions.

State Legend - Colors and line styles for states.

Main Plot - View data based on calendar date.

☑ AT DAM COMPUTED FLOW-NAT
☐ AT DAM GAGED FLOW-RES OUT

Data List - Catalog of imported time series.

Data Importer - Import flow data from DSS.

Thumbnail Plot View data based on water year.

Figure 25. HEC RPT screenshot of the software. Users can see additional hydrographs and water data in other windows.

Ongoing Efforts in the Basin

A main goal of SRP is to be additive to other efforts within the basin. TNC and the Corps recognize that e-flows and releases out of Jordan Reservoir are one part in a complicated system. While this list is not comprehensive, there are many existing efforts underway in the Cape Fear River Basin.

The UNC Collaboratory is studying nutrient issues in Jordan Lake and throughout the basin. NC DEQ has on-going basinwide planning and mitigation efforts. USGS is conducting a very large Coastal Carolinas study that fully models water quality and quantity in the Cape Fear Basin. It also includes population growth projections, climate change implications, and groundwater information. National Fish and Wildlife Foundation (NFWF) has a Coastal Resilience Evaluation and Siting Tool (CREST) tool that combines GIS layers to think about resilience. Many academics have published research and are currently studying water quality, water quantity and economic issues in the basin. The Triangle J Council of Governments (TJ COG) has several initiatives to improve the basin, including the Jordan Lake One Water group. Previously, significant analysis and modeling occurred for the Cape Fear Basin using Research Triangle Institute’s WaterFALL model. TNC has additional on-going efforts in the basin to use remote sensing to map flood events, and to work with USGS to model natural solutions.

In addition to the specific projects listed above, there are strong partnerships throughout the basin working to improve the river. These include the Upper Cape Fear River Basin Association, TJ COG, the Jordan Lake Partnership, the Middle Cape Fear Association, the Lower Cape Fear River Program, the Cape Fear Council of Governments, the Cape Fear River Assembly and the Cape Fear River Partnership.

Literature Cited

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.

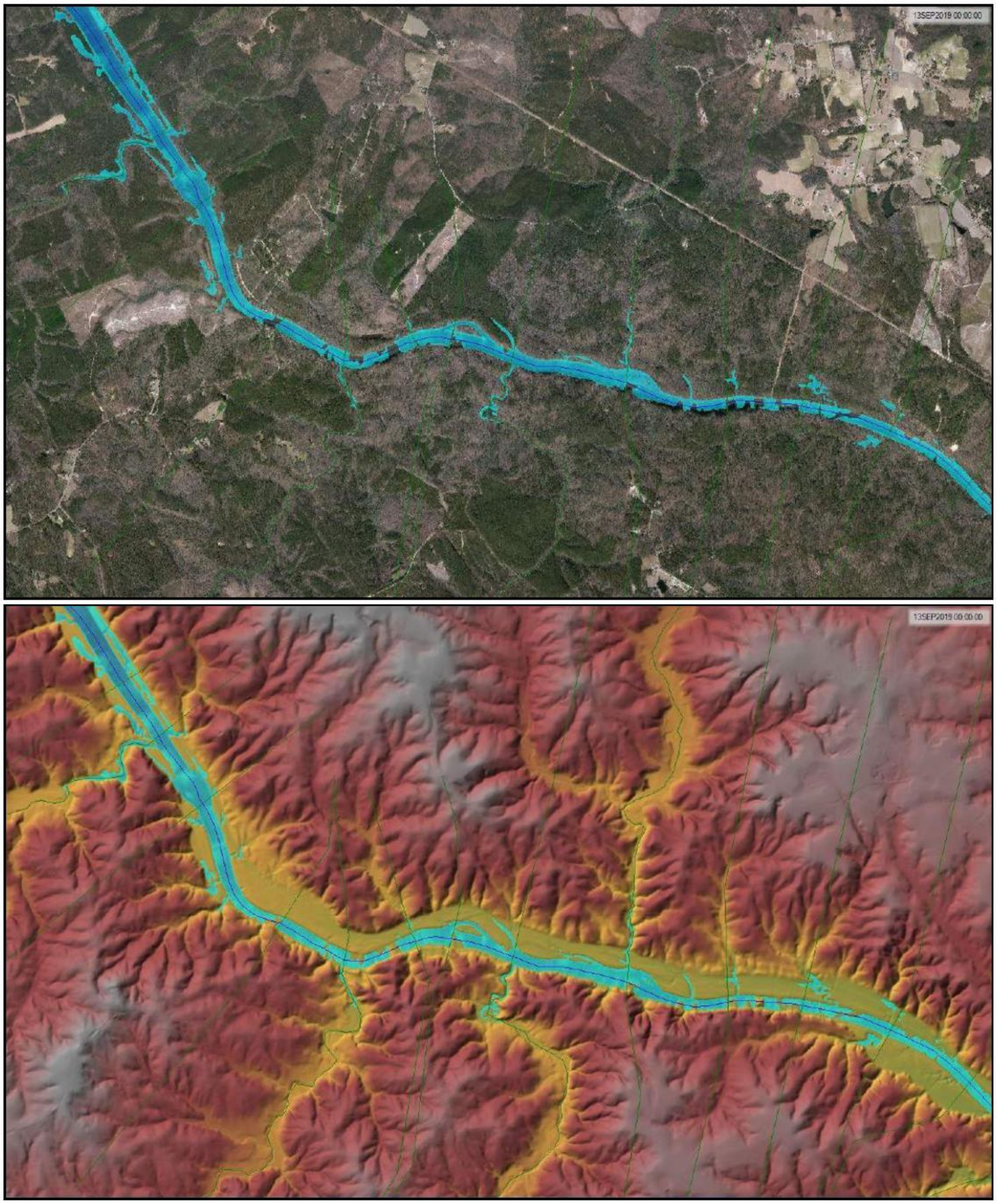
Wyneken, J. (2013). *Proceedings Association of Reptilian and Amphibian Veternarians.* Retrieved from REPTILIAN RENAL STRUCTURE AND FUNCTION: https://cdn.ymaws.com/members.arav.org/resource/resmgr/Files/Proceedings_2013/41.pdf

Appendix 1: HEC RAS Inundation Report

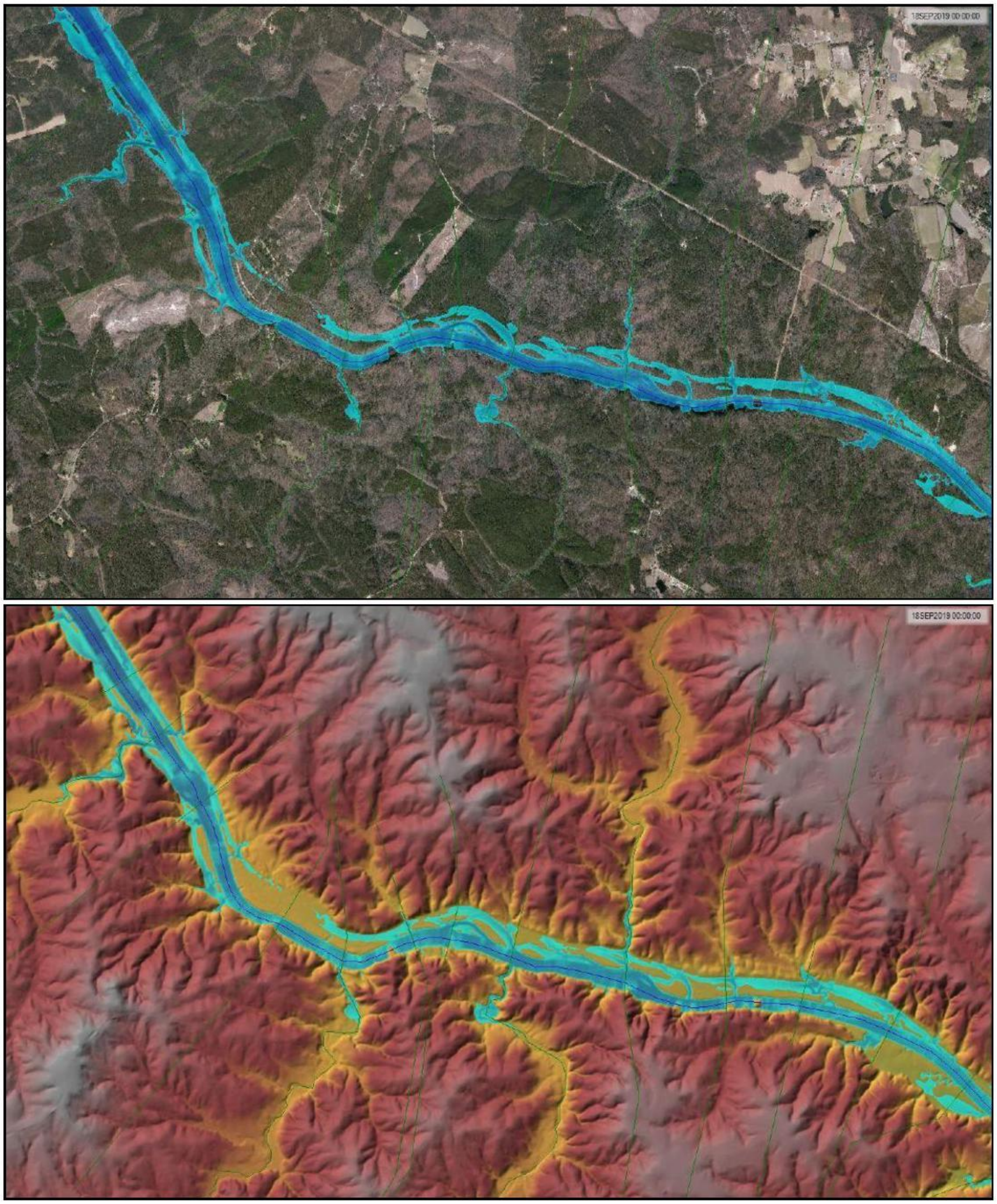
The following graphics depict the estimated inundation footprint at 3 locations on the Cape Fear River, at 5 different magnitudes of river flow. A river hydraulics model was used to route a range of flows (20k, 30k, 40k, 50k and 60k cubic feet per second (cfs)) from Jordan to Lock and Dam 1. Elevations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



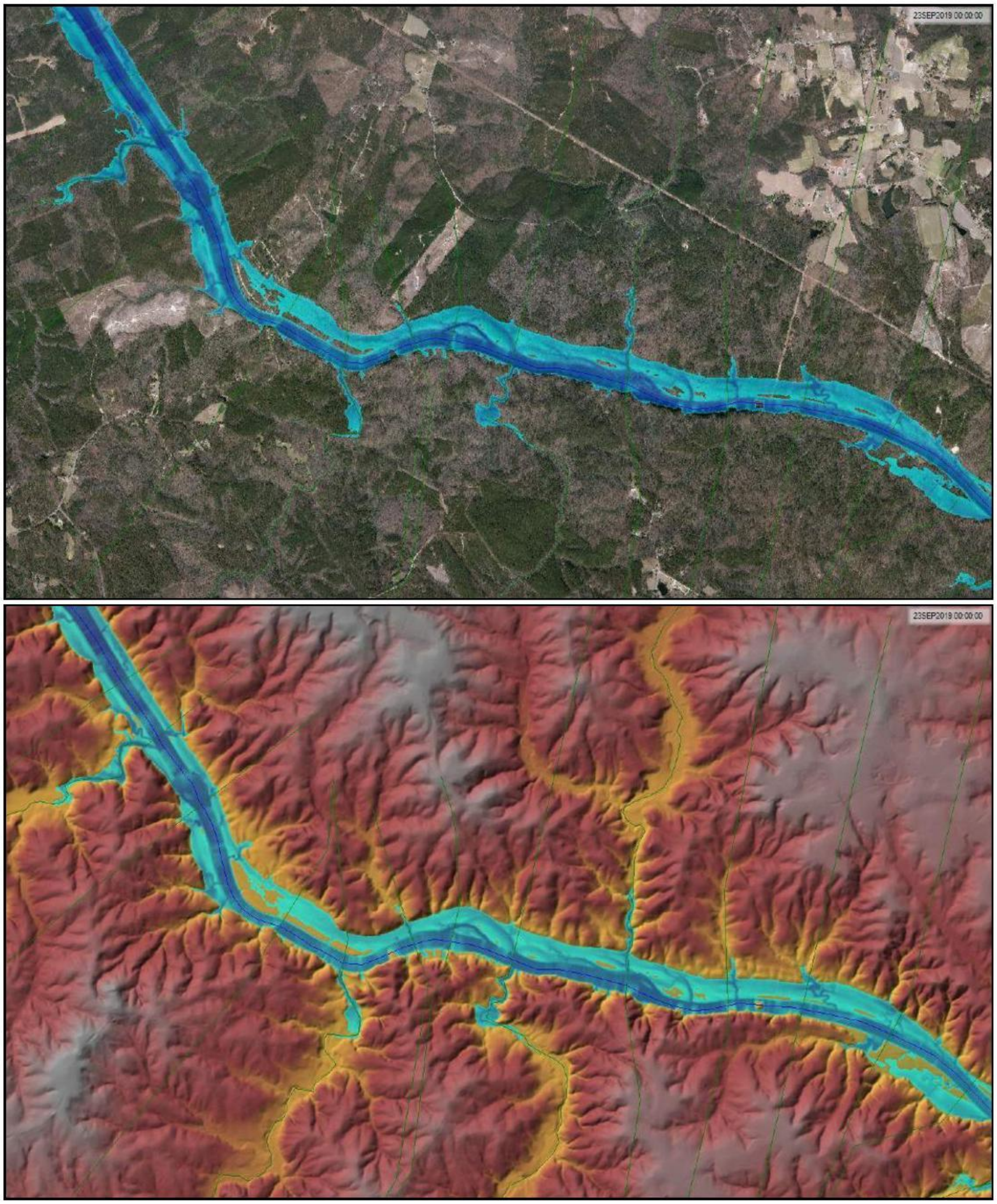
REACH 1 – INUNDATION AT 20,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



REACH 1 – INUNDATION AT 30,000 CFS

REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON

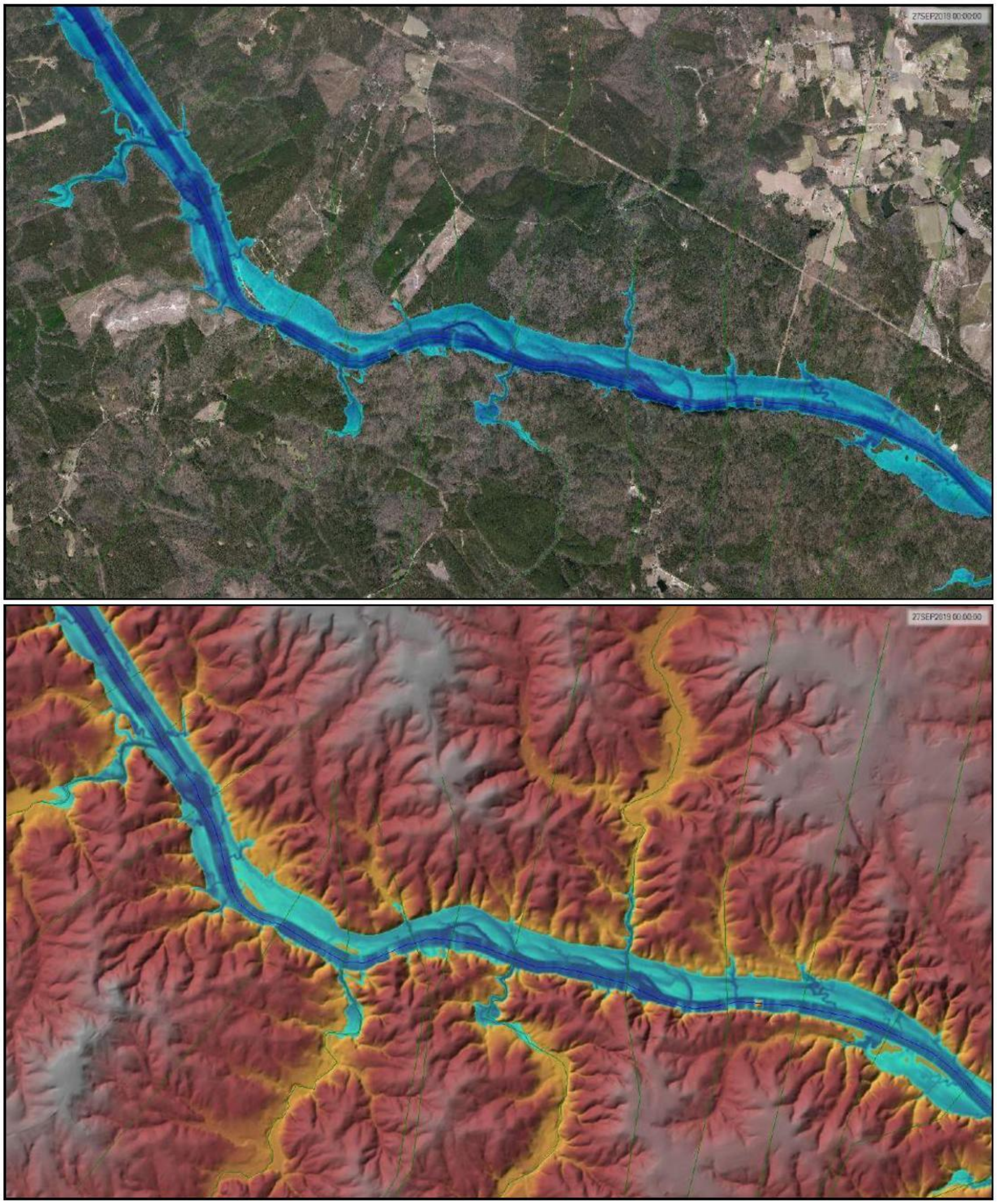
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



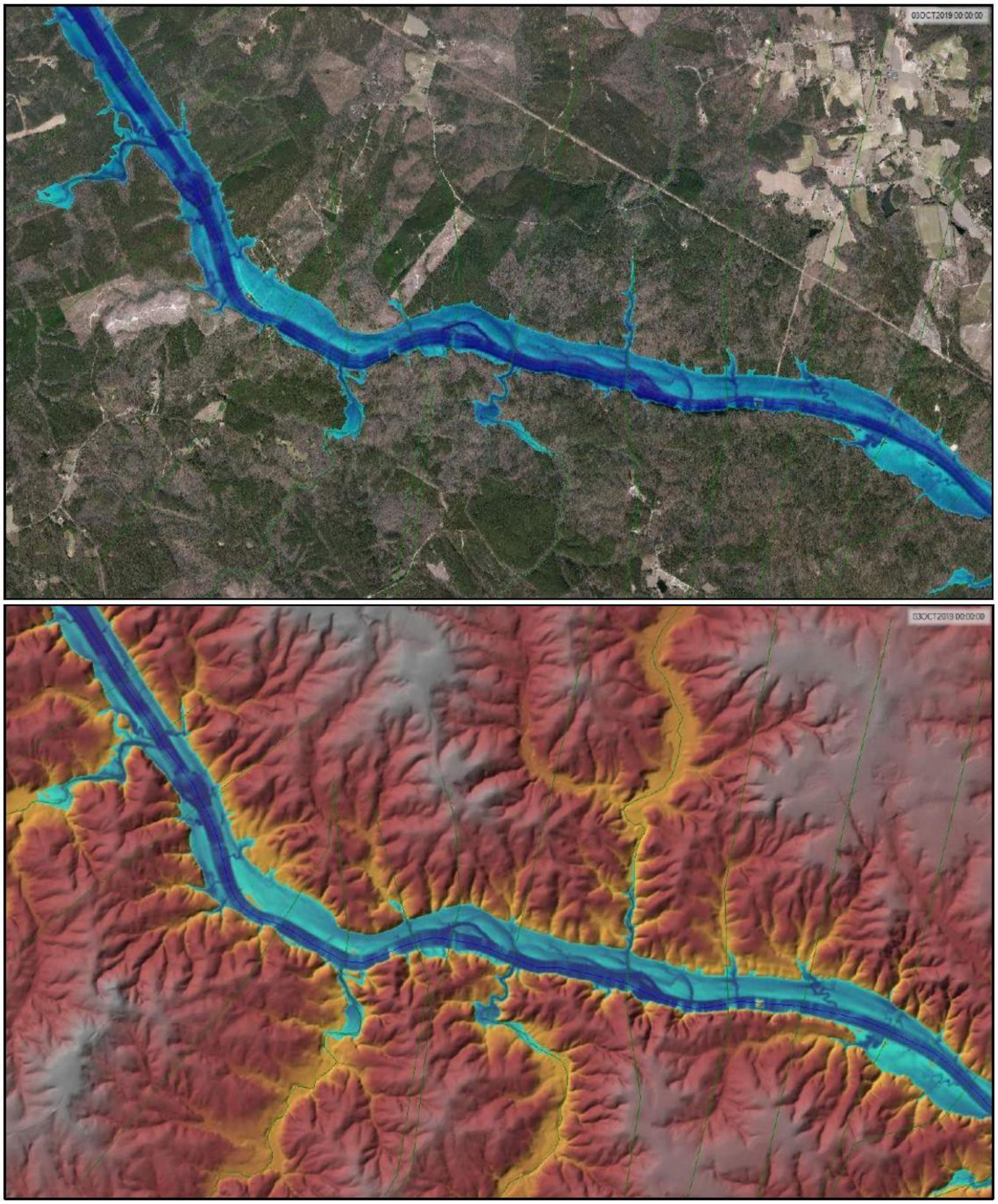
REACH 1 – INUNDATION AT 40,000 CFS

REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON

REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



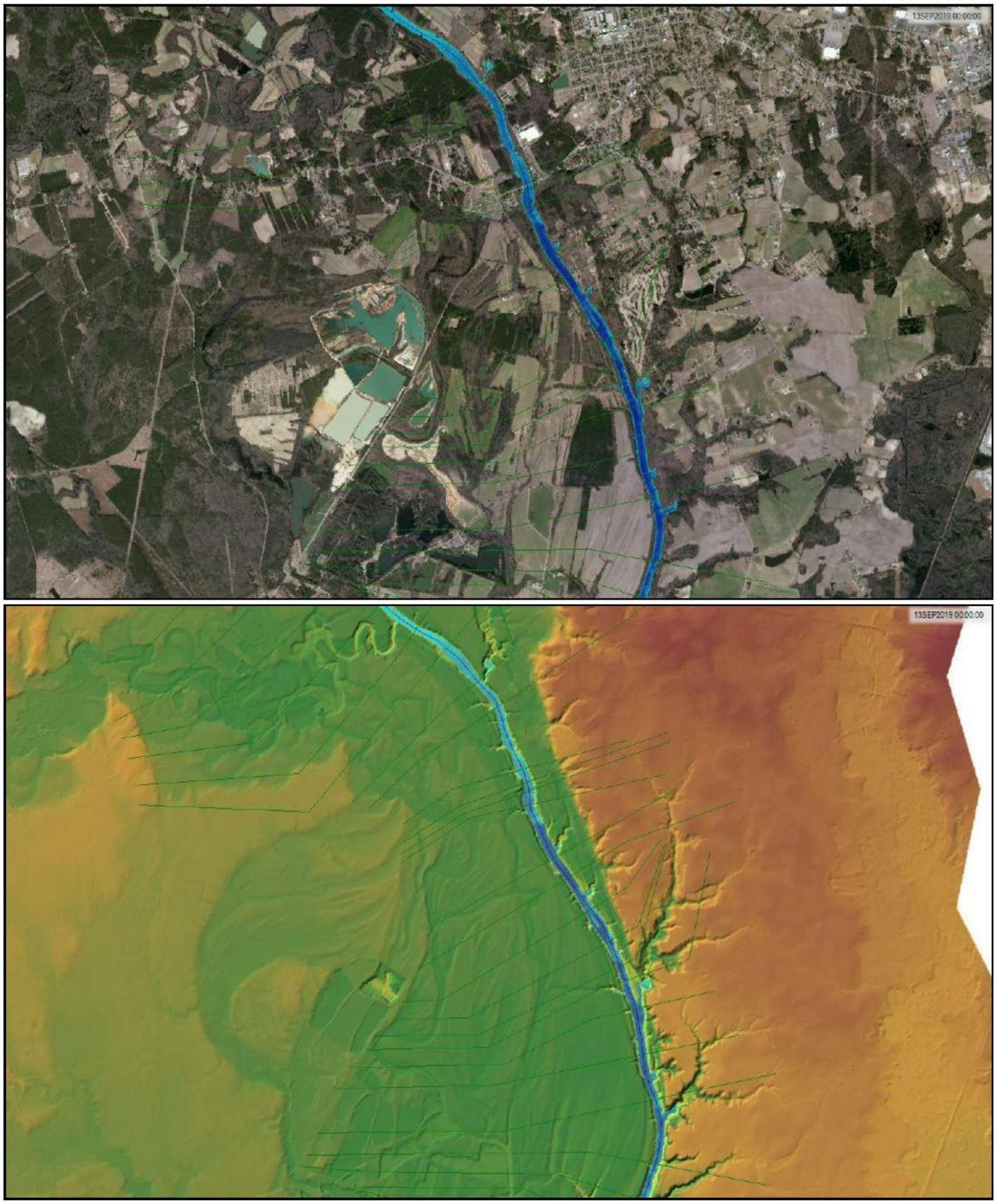
REACH 1 – INUNDATION AT 50,000 CFS
REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



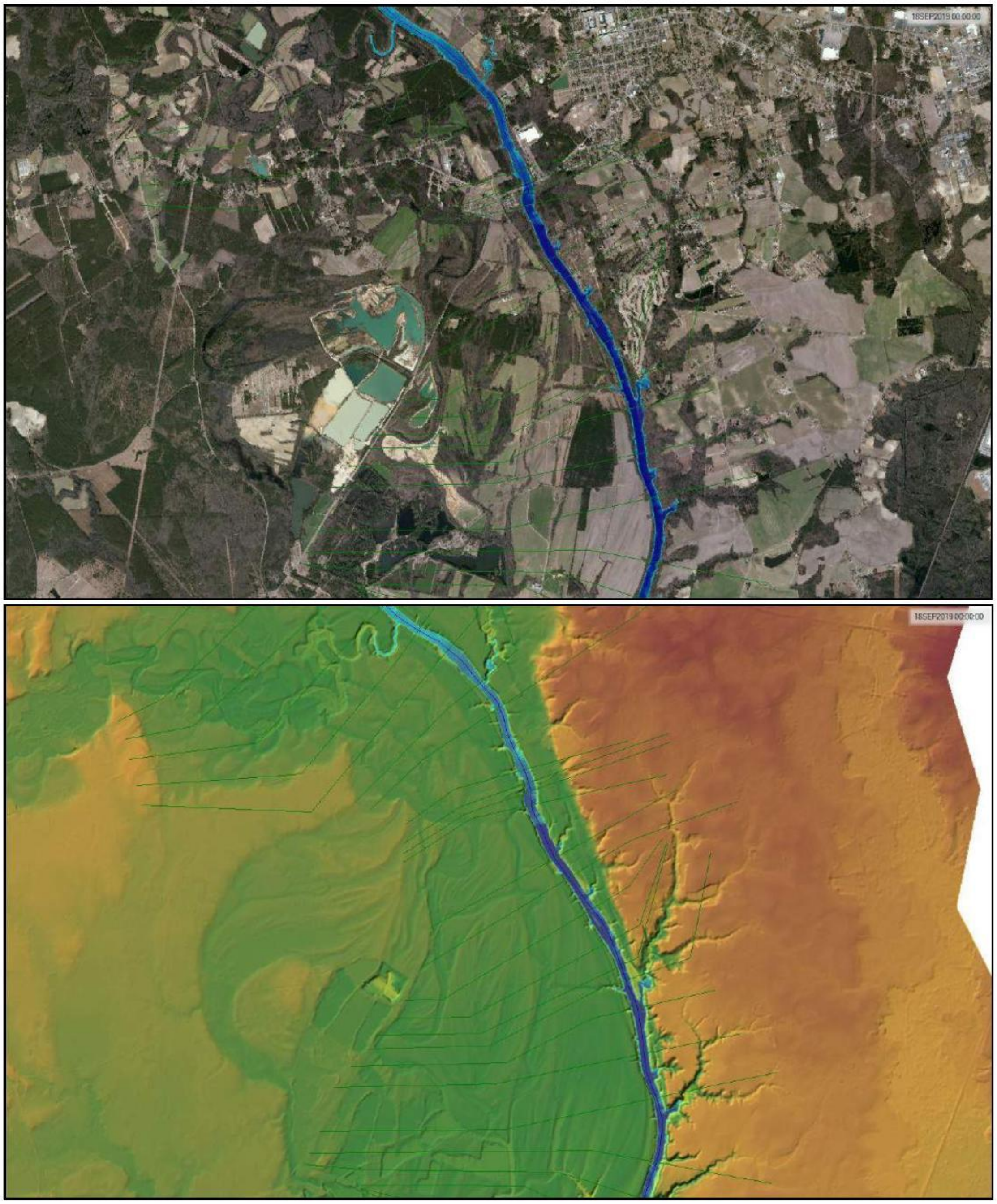
REACH 1 – INUNDATION AT 60,000 CFS

REACH 1 IS LOCATED BETWEEN JORDAN DAM AND LILLINGTON

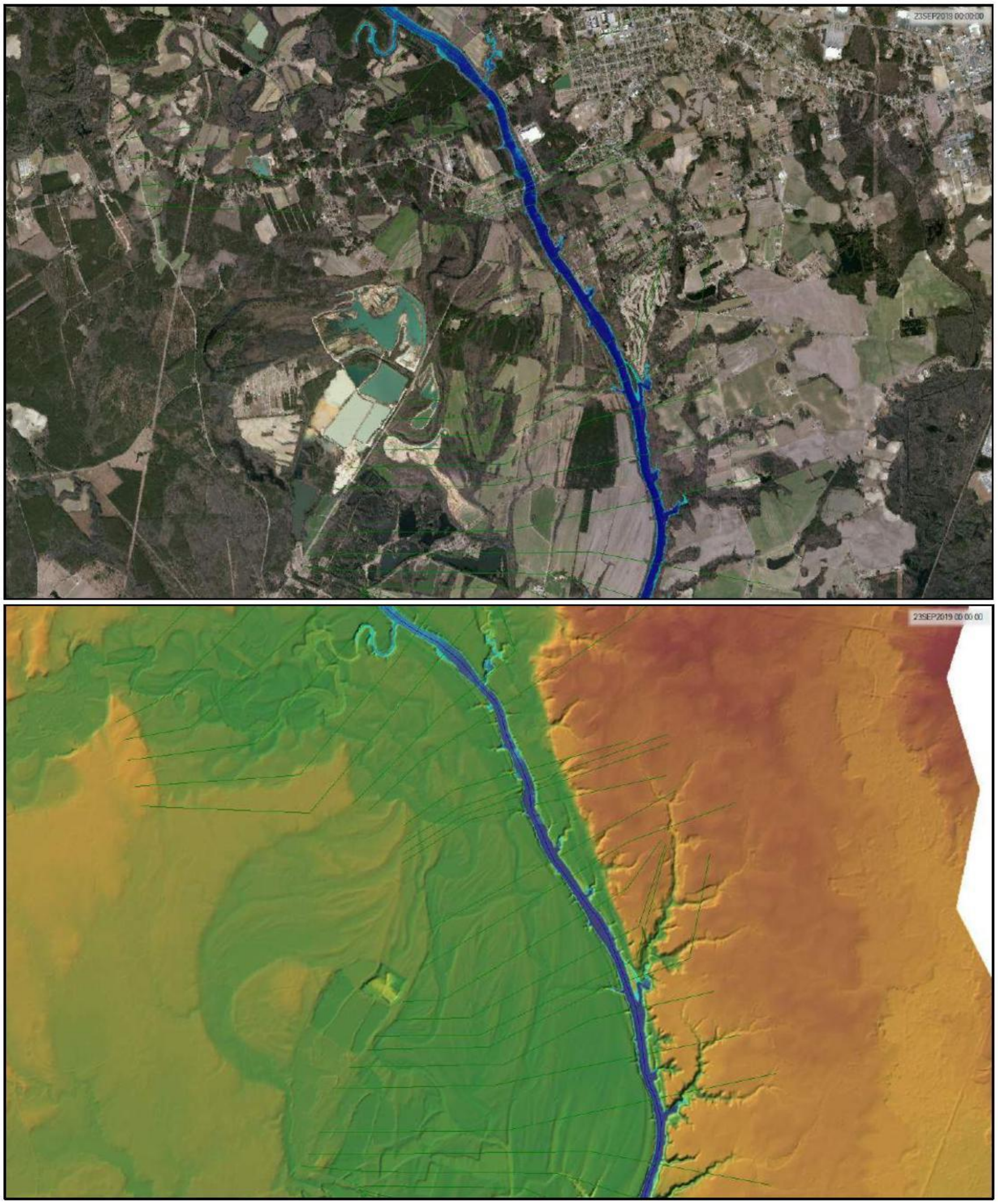
REPRESENTATIVE LOCATION IS APPROX 15 RIVER MILES DOWNSTREAM OF JORDAN DAM



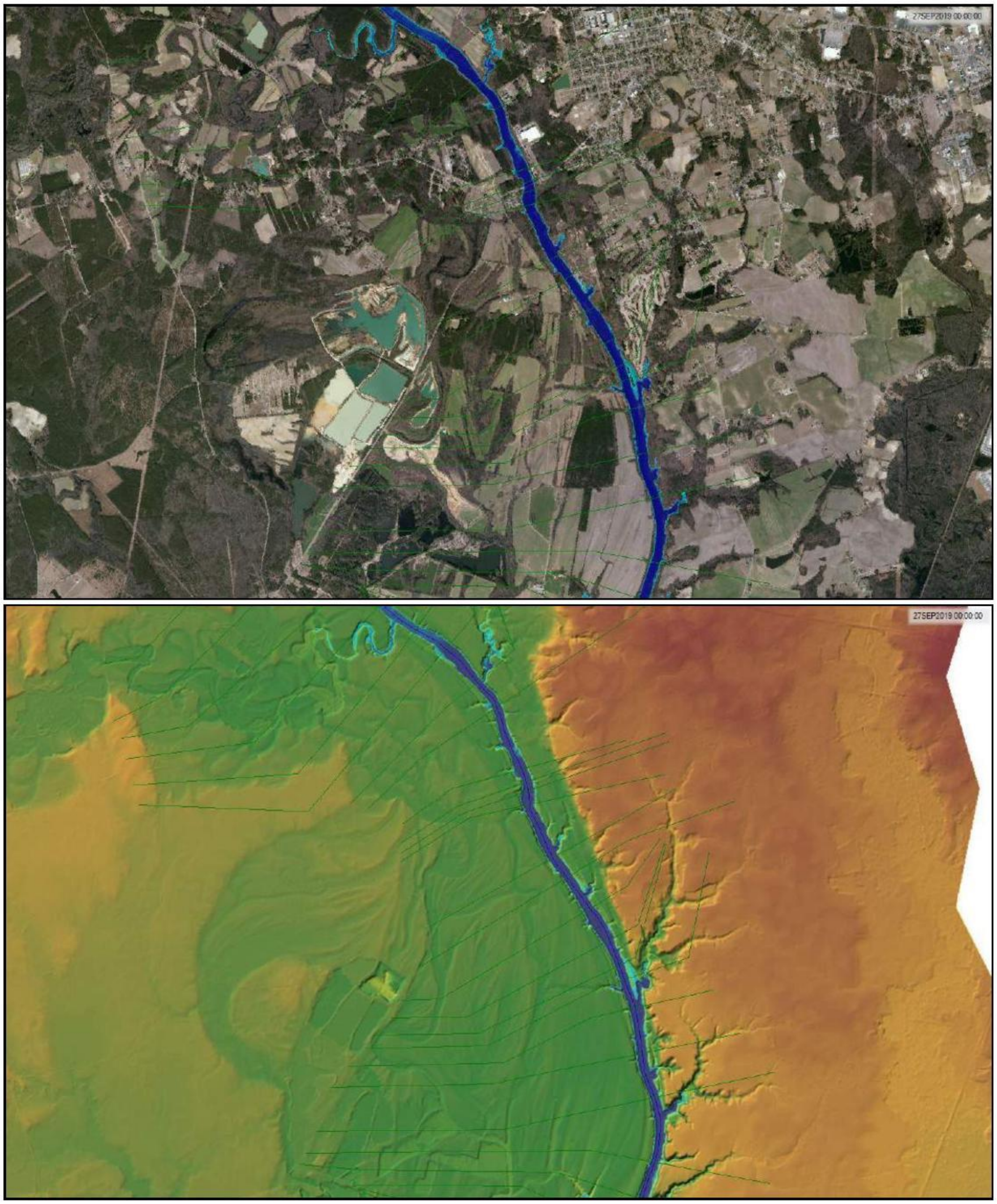
REACH 2 – INUNDATION AT 20,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



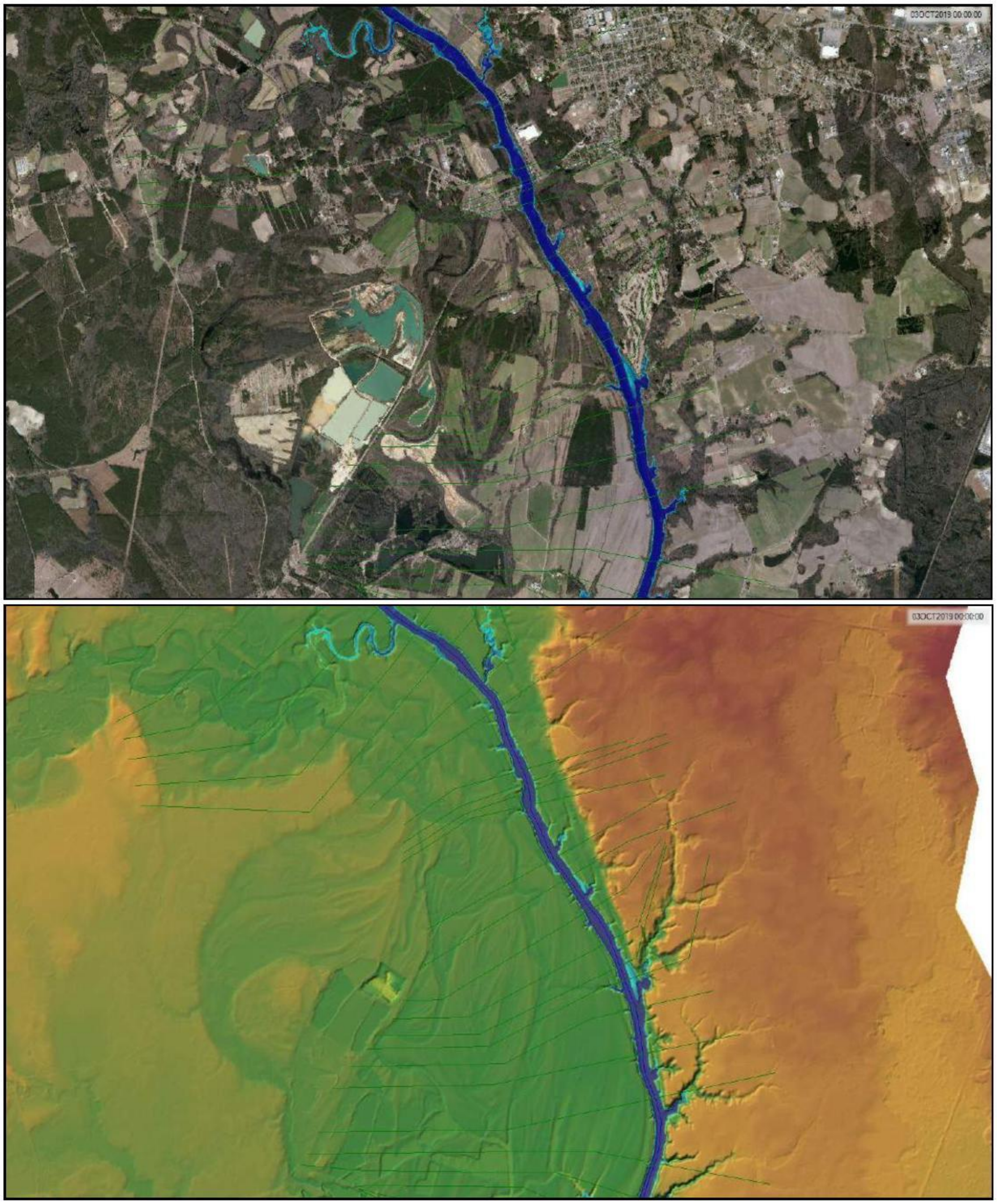
REACH 2 – INUNDATION AT 30,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



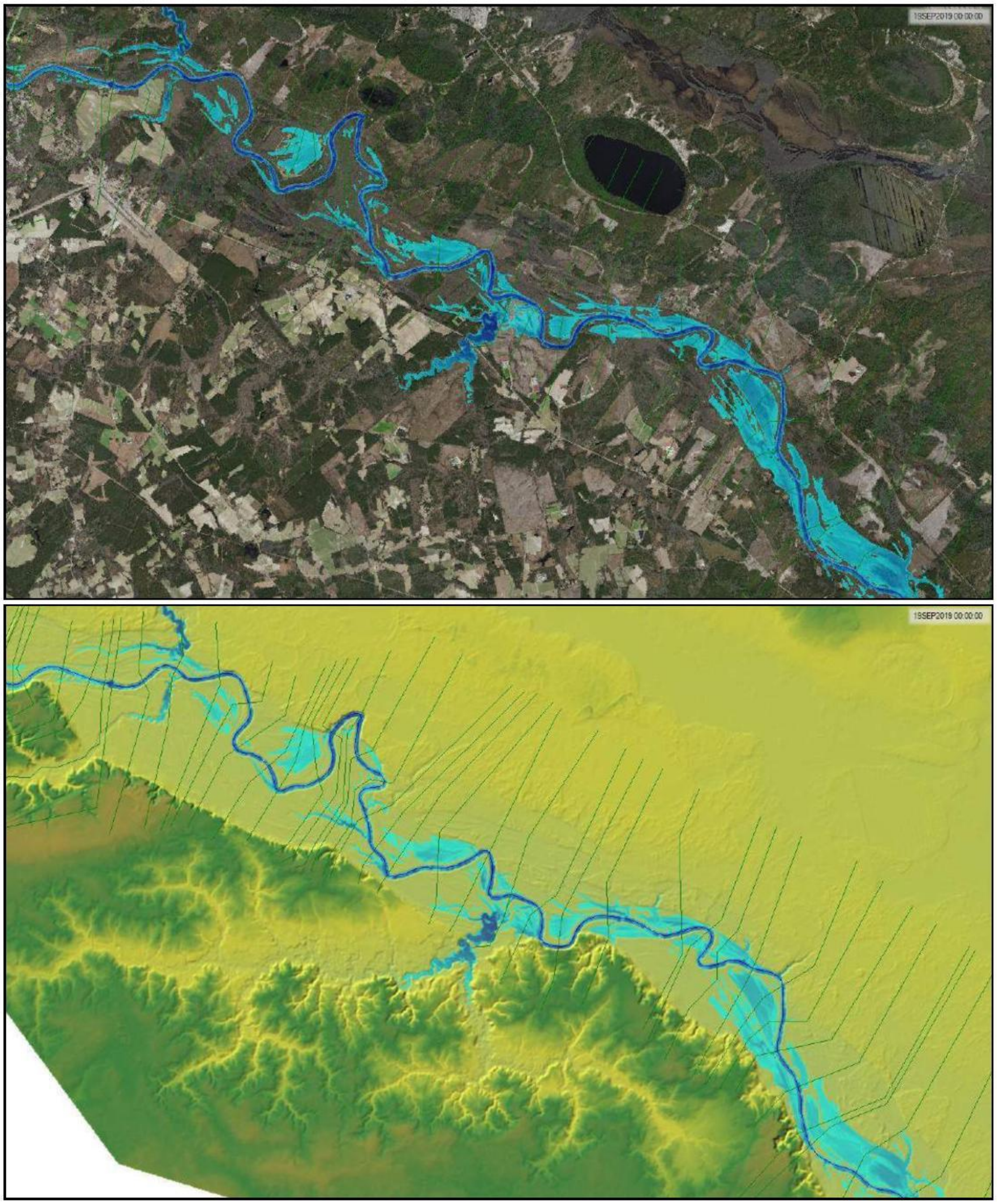
REACH 2 – INUNDATION AT 40,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



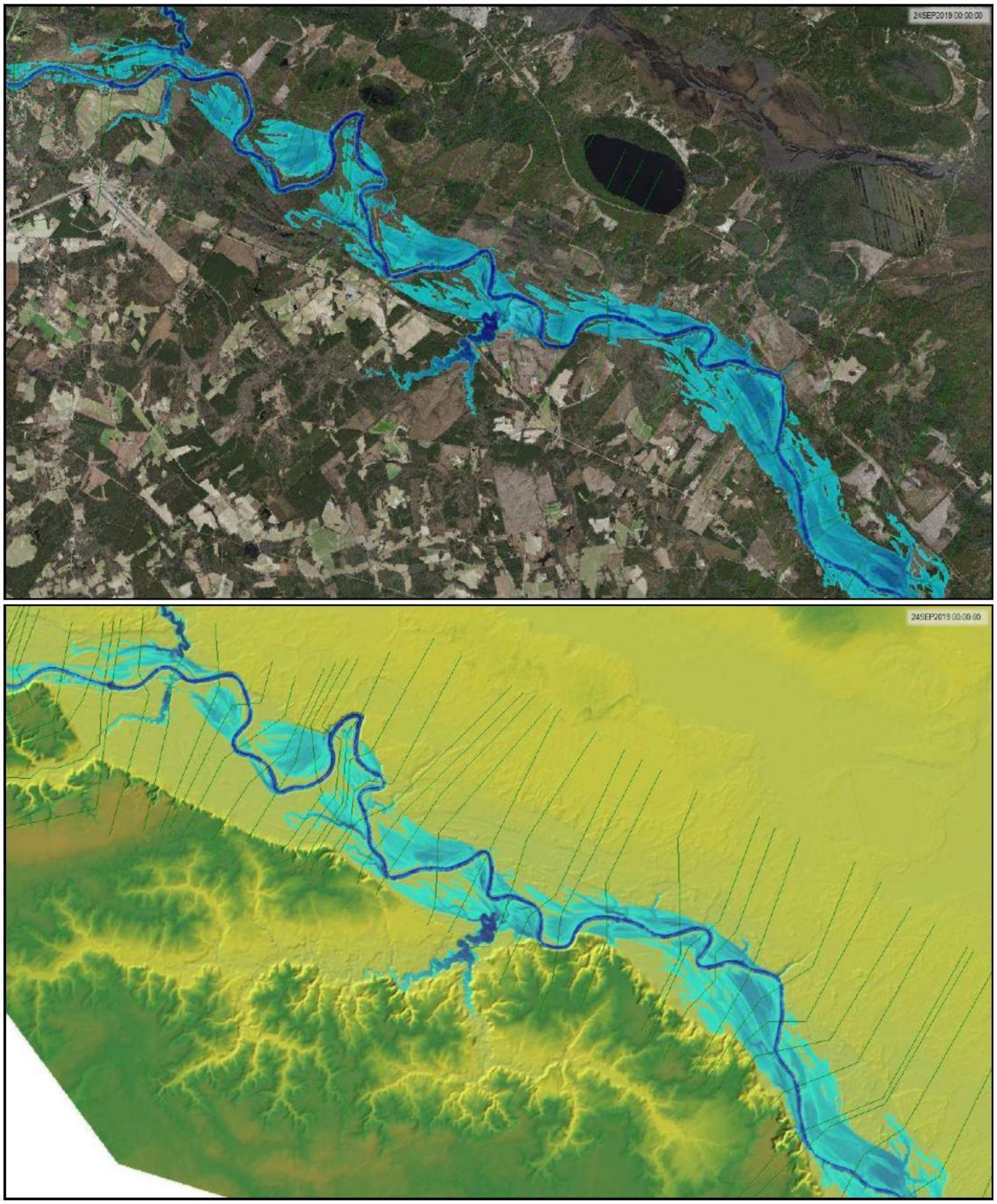
REACH 2 – INUNDATION AT 50,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



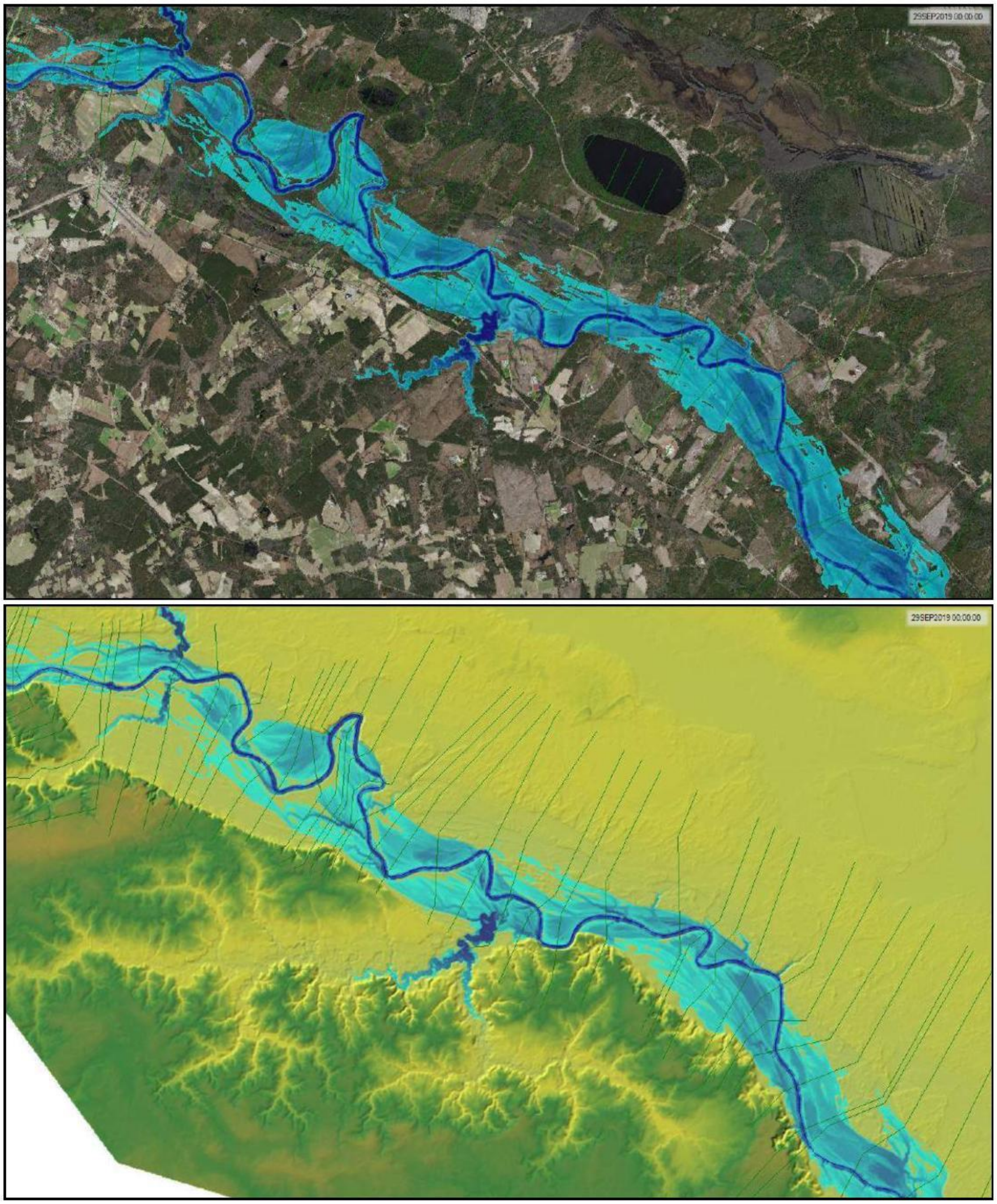
REACH 2 – INUNDATION AT 60,000 CFS
REACH 2 IS LOCATED BETWEEN LILLINGTON AND LOCK AND DAM 3
REPRESENTATIVE LOCATION IS APPROX 25 RIVER MILES DOWNSTREAM OF JORDAN DAM



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



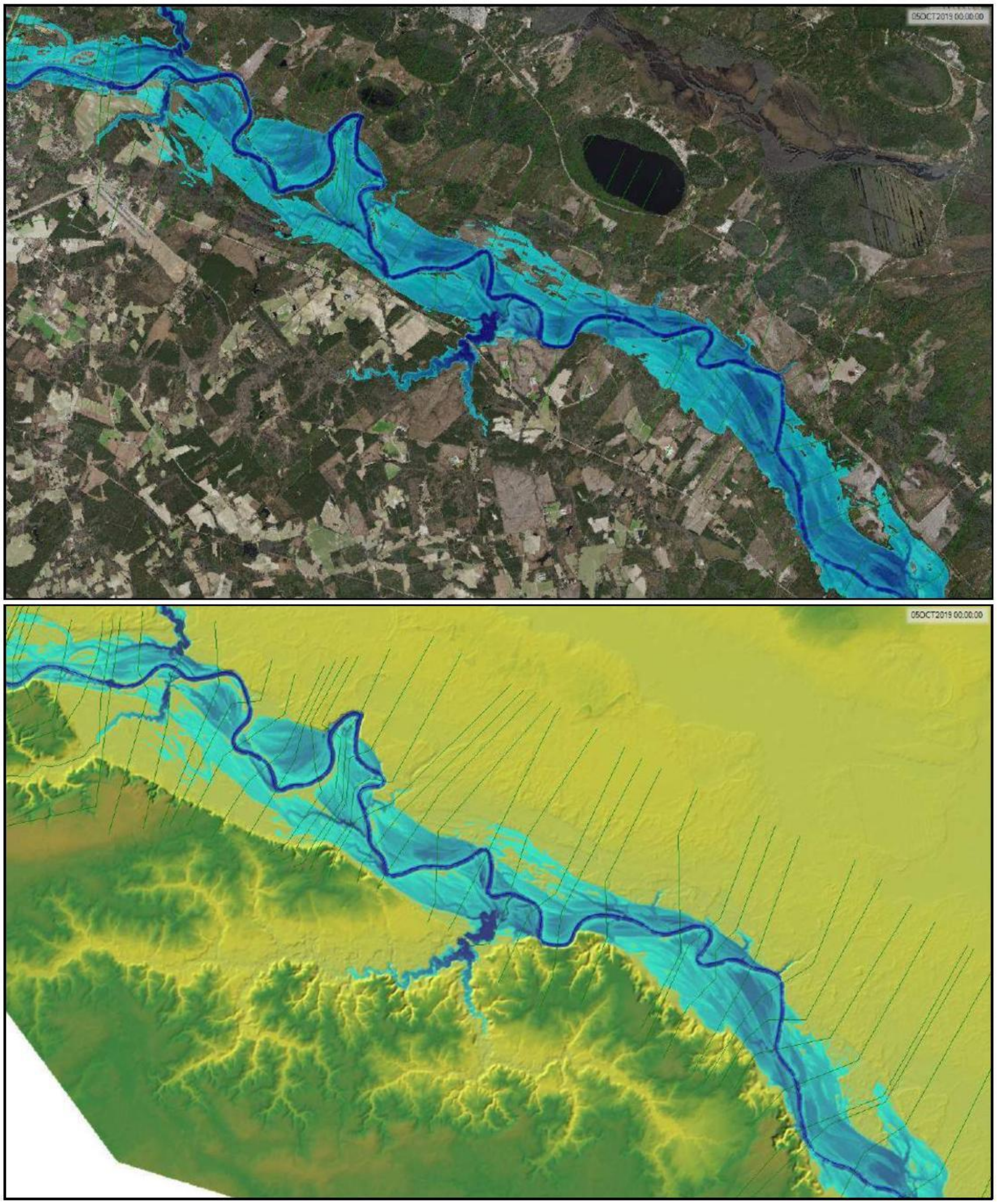
REACH 3 – INUNDATION AT 40,000 CFS
REACH 3 IS LOCATED BETWEEN LOCK AND DAM 3 AND LOCK AND DAM 1
REPRESENTATIVE LOCATION IS APPROX 90 RIVER MILES DOWNSTREAM OF JORDAN DAM



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 2. Lillington hydrology data pre- and post-dam

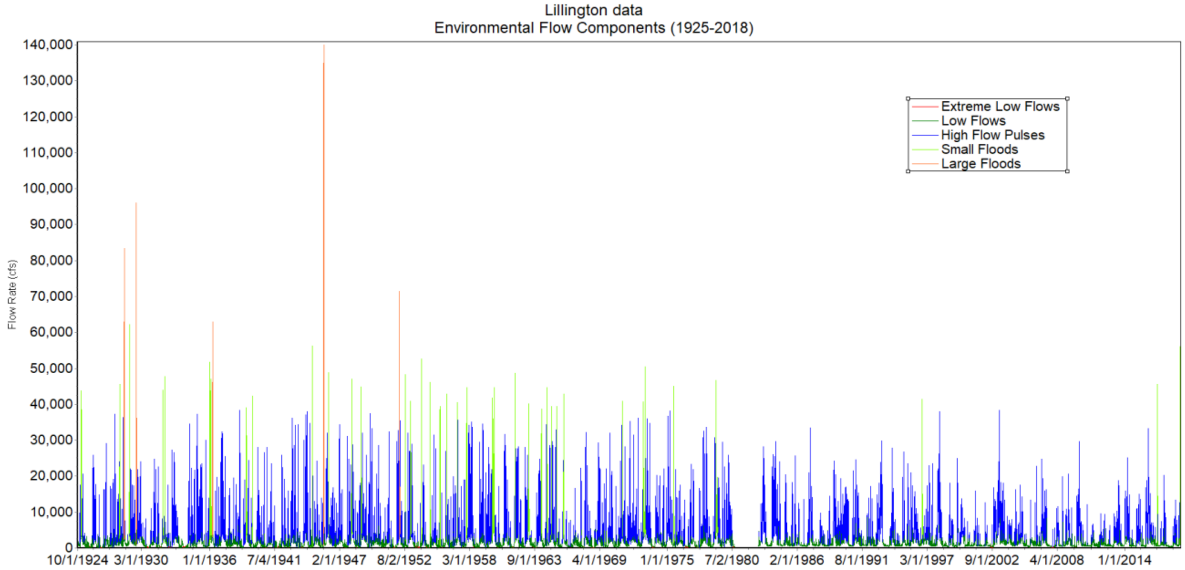


Figure 26. Lillington daily mean data from 1924-2018, omitting years 1980-1983 due to the building of Jordan Dam.

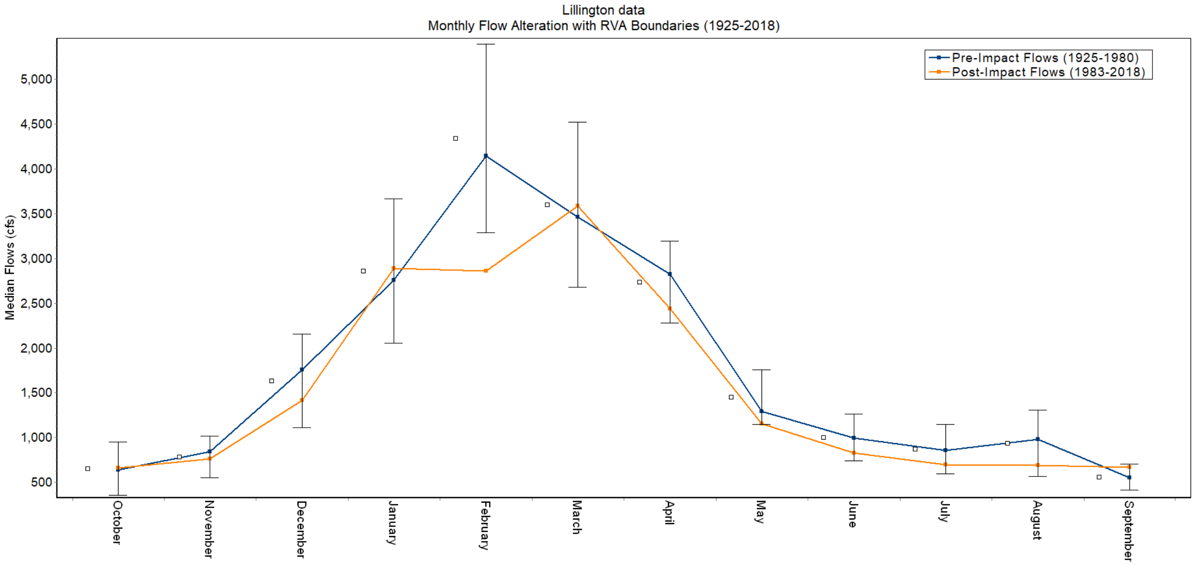


Figure 27. Lillington monthly mean flows.

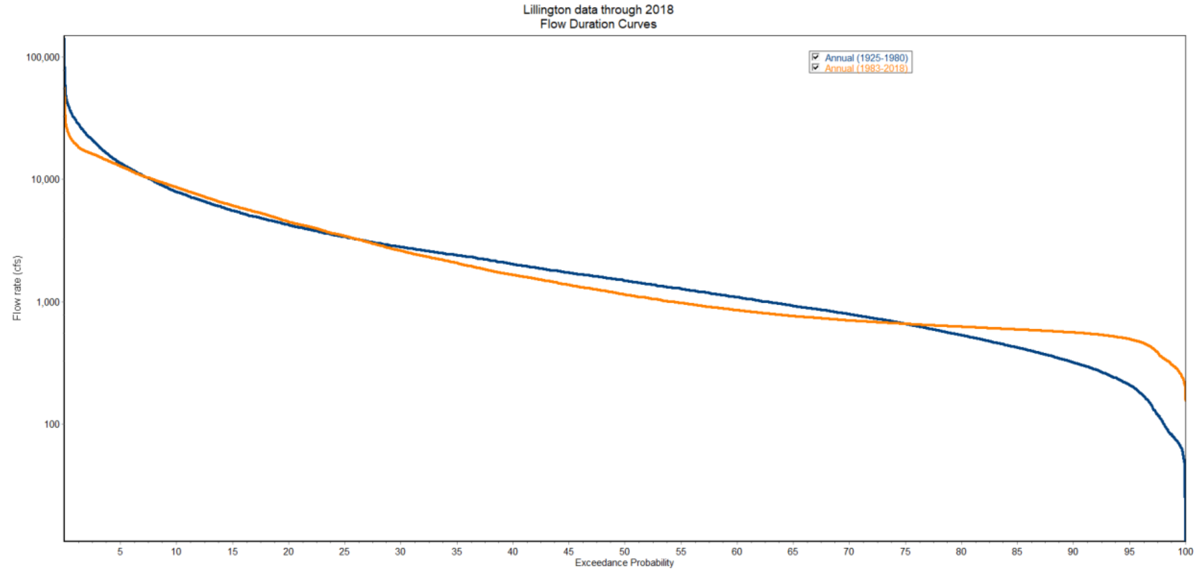


Figure 28. Lillington flow duration curves.

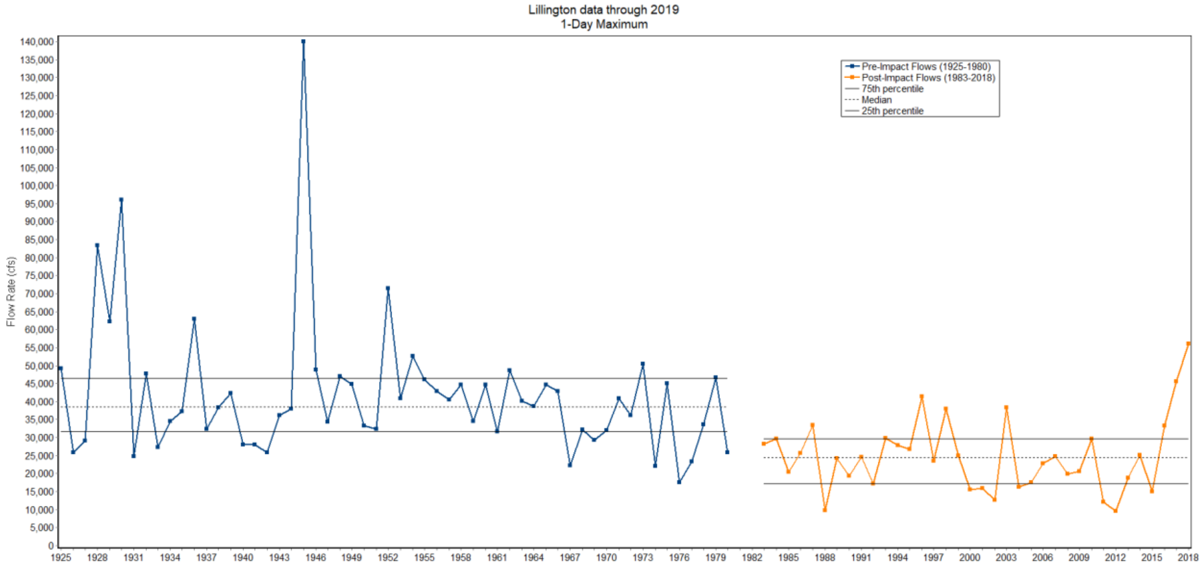


Figure 29. Lillington 1-day maximum flows.

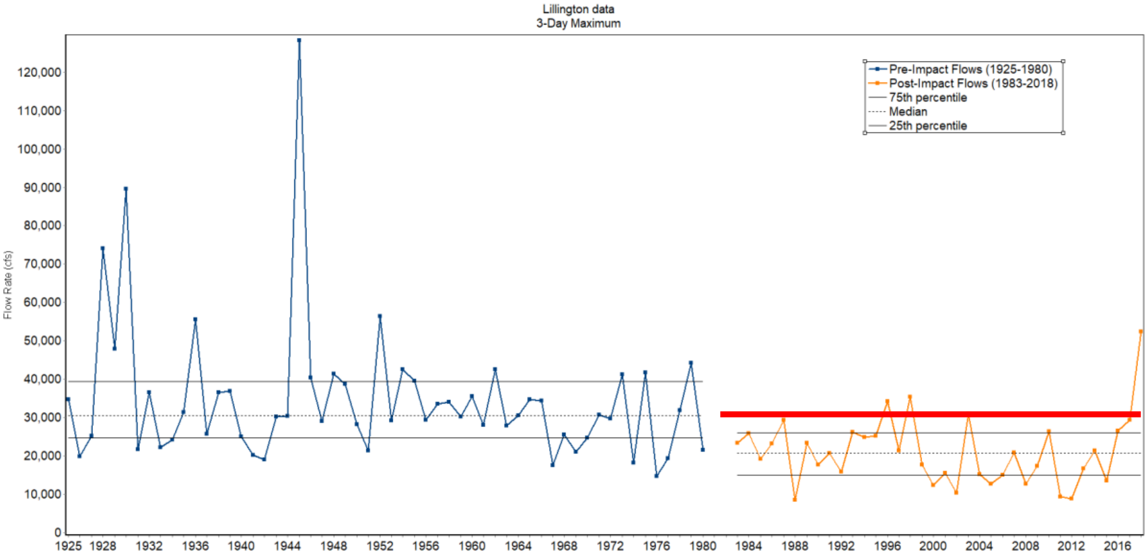


Figure 30. Lillington 3-day maximum flows. Red line indicates National Weather Service Flood Stage.

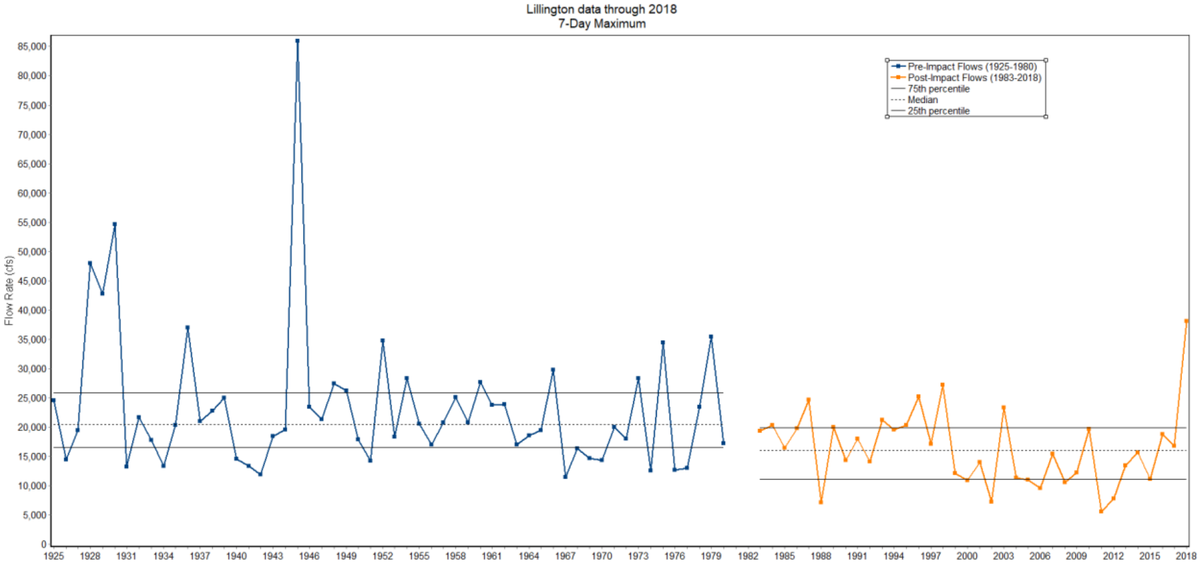


Figure 31. Lillington 7-day maximum flows.

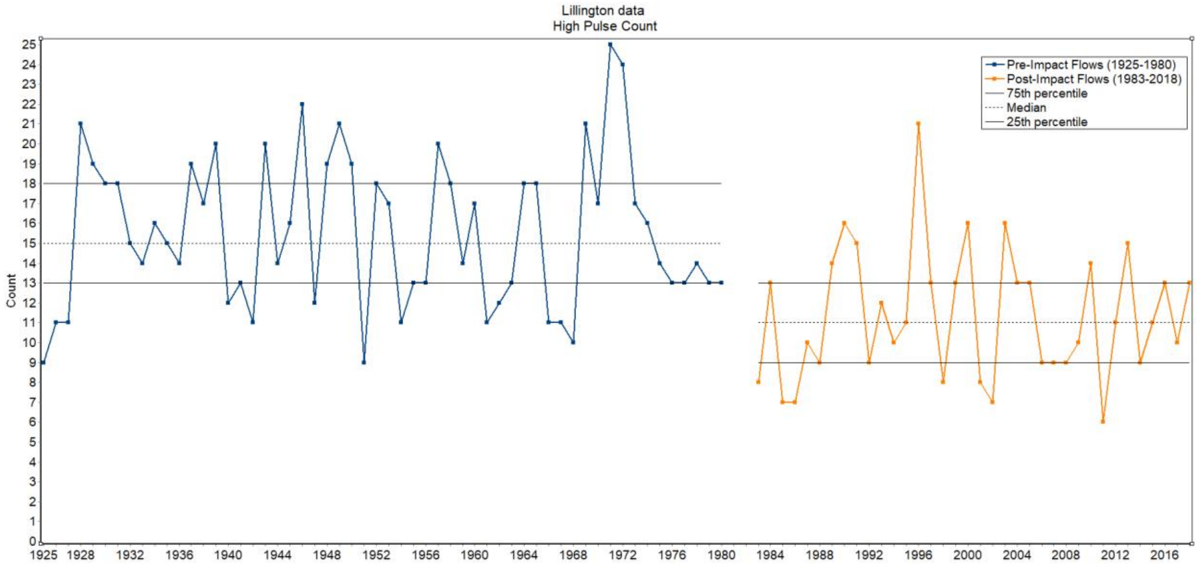


Figure 32. Lillington number of high pulse events.

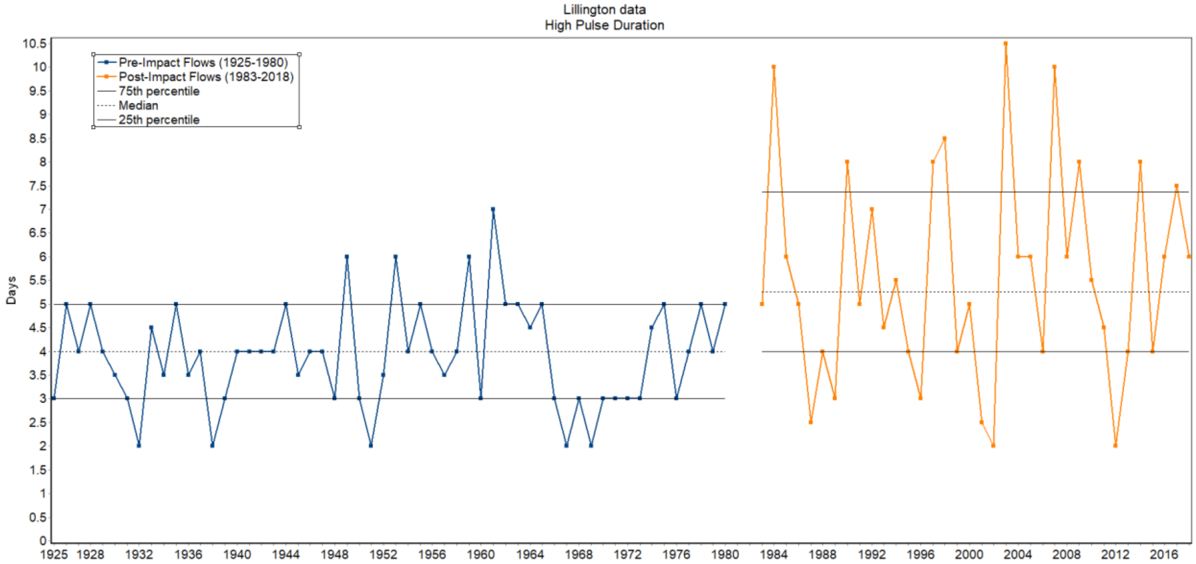


Figure 33. Lillington duration of high pulse events.

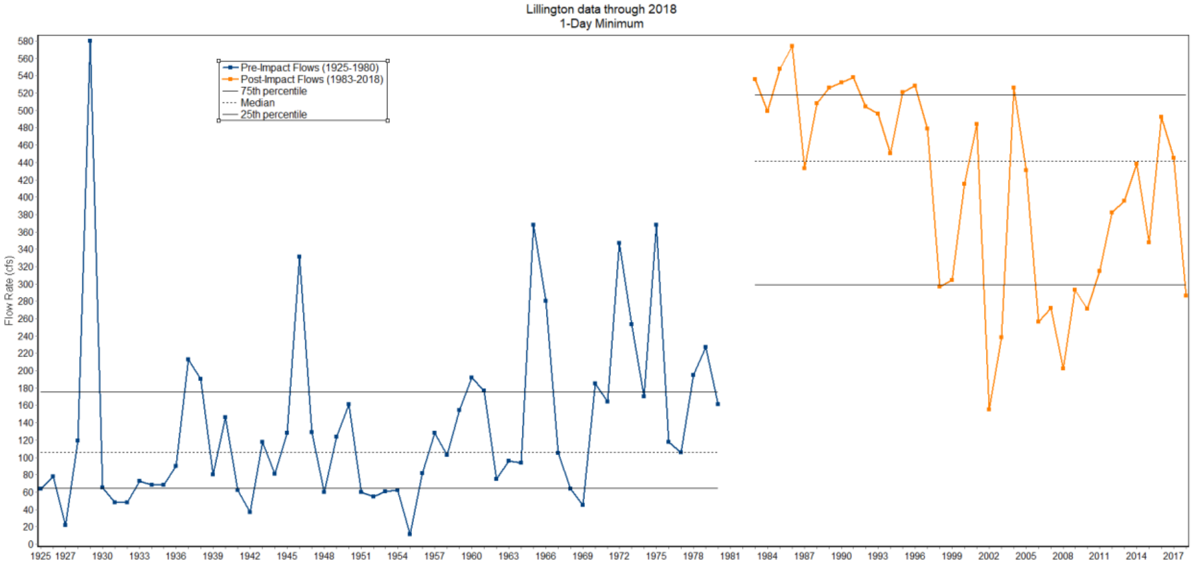


Figure 34. Lillington 1-day minimums.

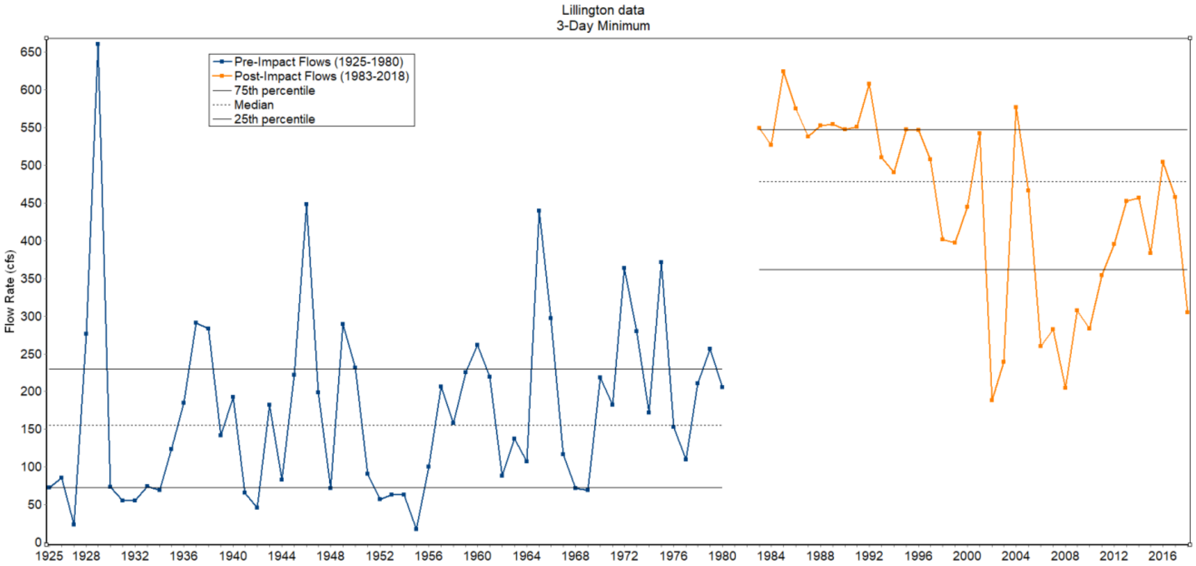


Figure 35. Lillington 3-day minimums.

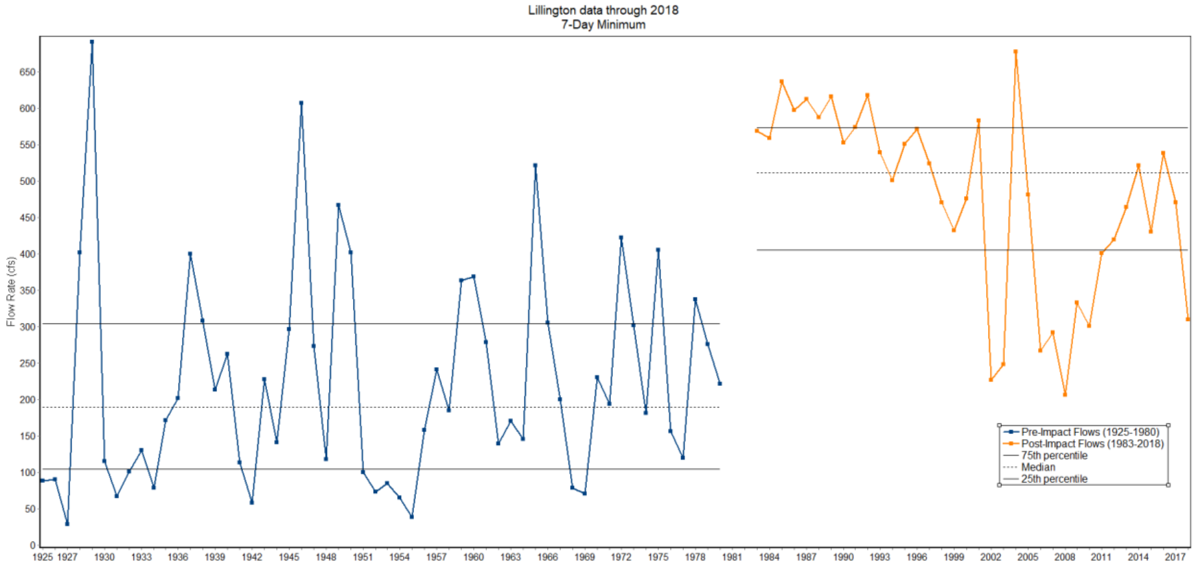


Figure 36. Lillington 7-day minimums.

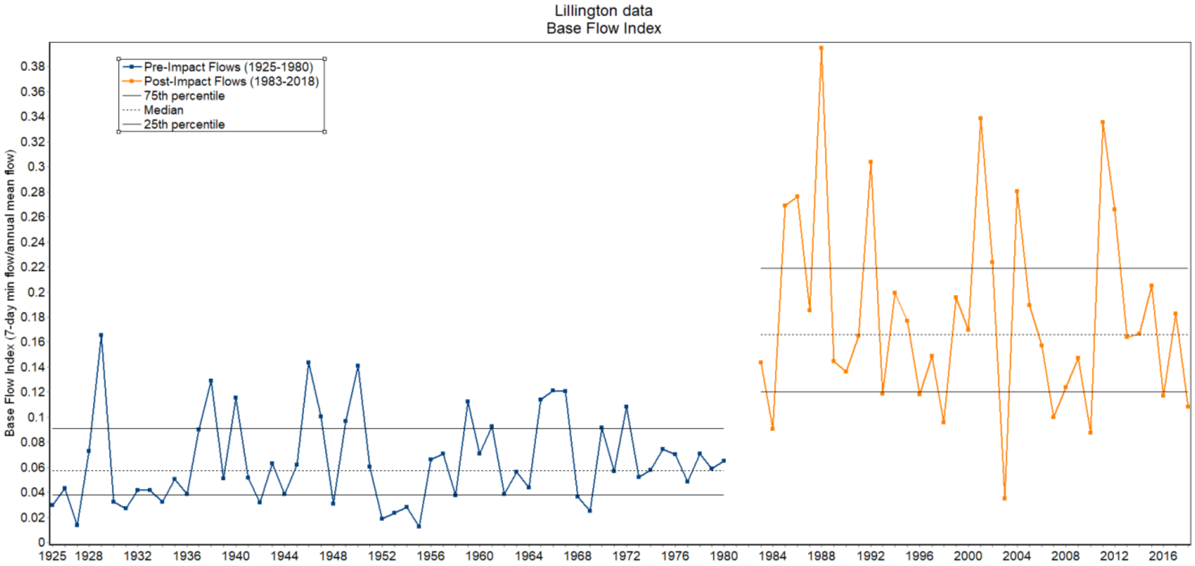


Figure 37. Lillington baseflow index.

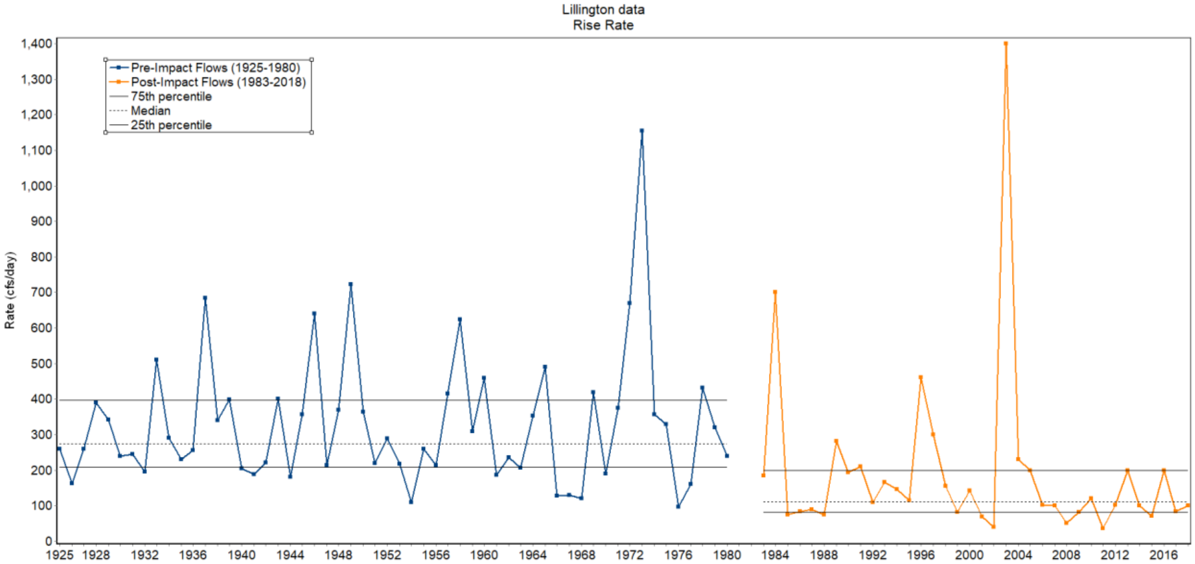


Figure 38. Lillington rise rate.

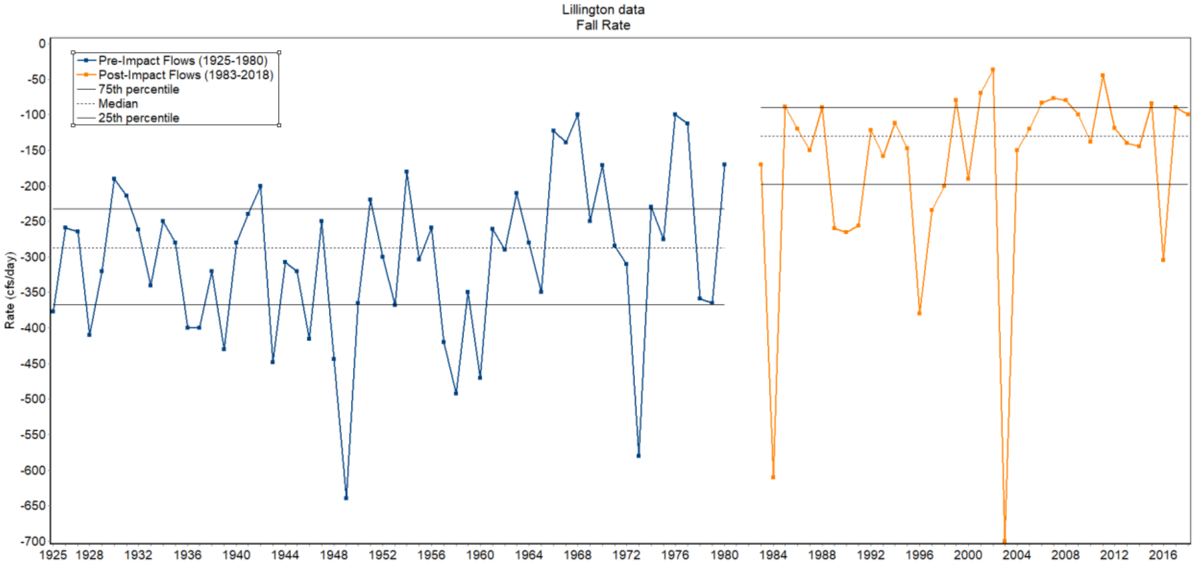


Figure 39. Lillington fall rate.

Appendix 3: LD3 hydrology data pre- and post-dam

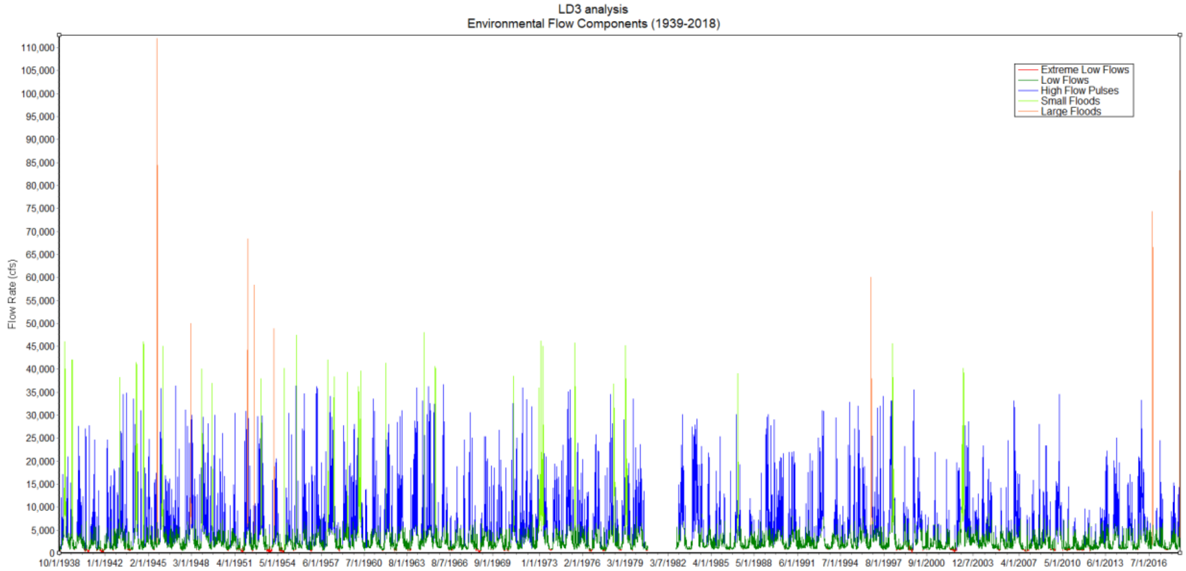


Figure 40. LD3 hydrograph 1939-2018 with years 1980-1983 removed for dam creation effects.

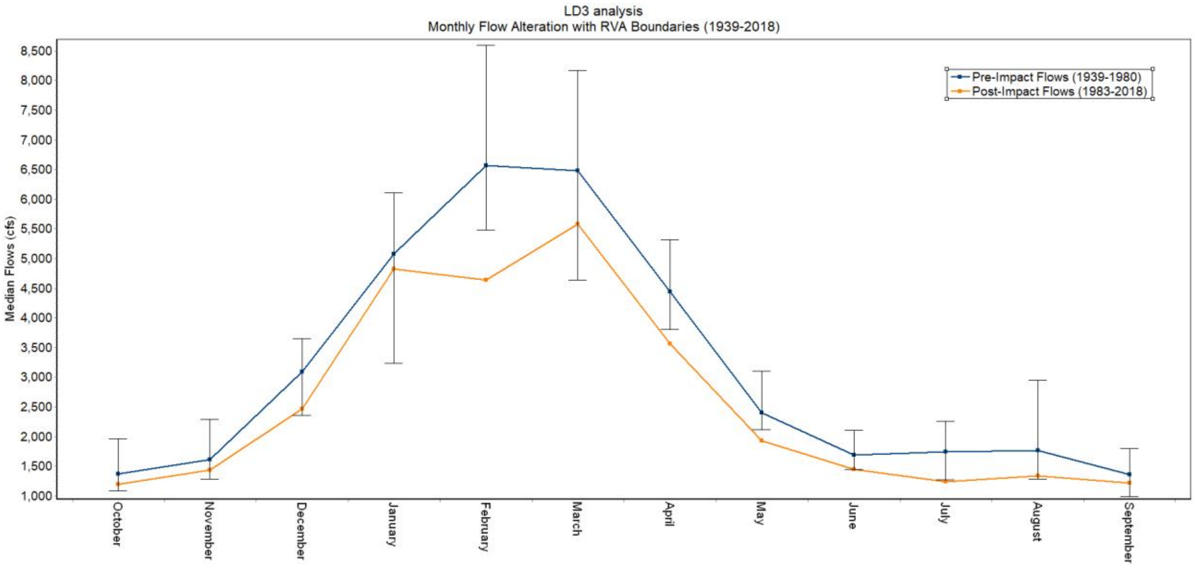


Figure 41. LD3 median monthly flows.

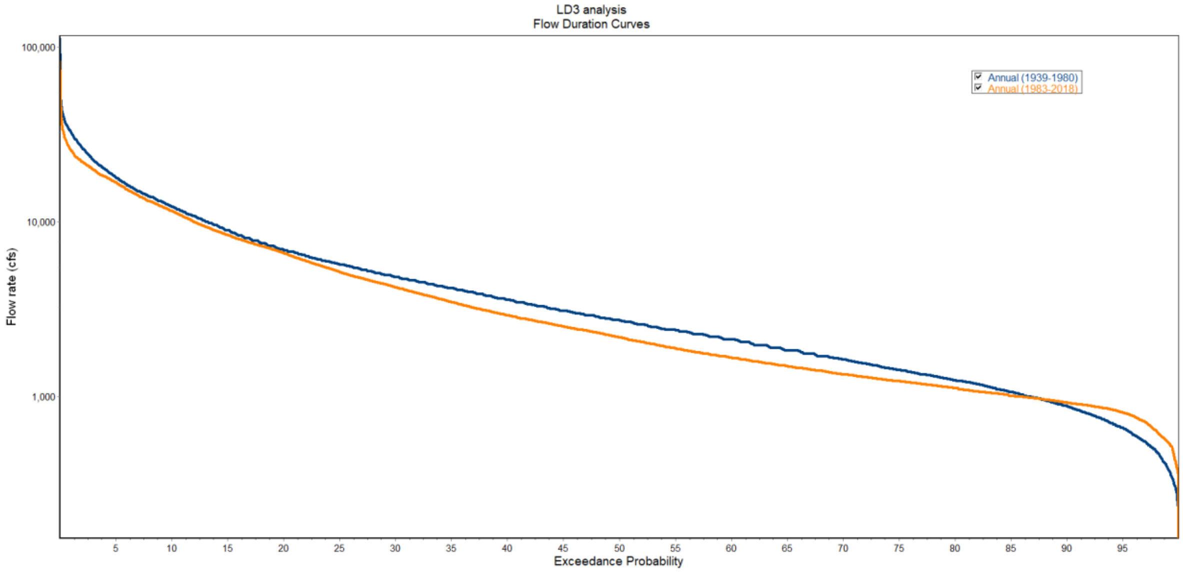


Figure 42. LD3 flow duration curves.

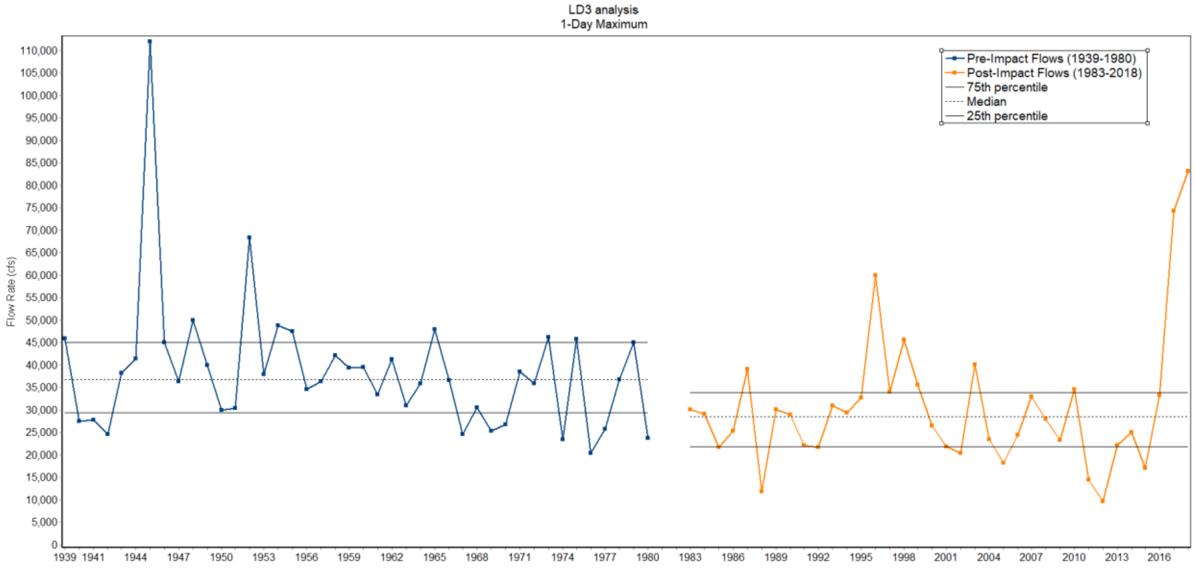


Figure 43. LD3 1-day maximums.

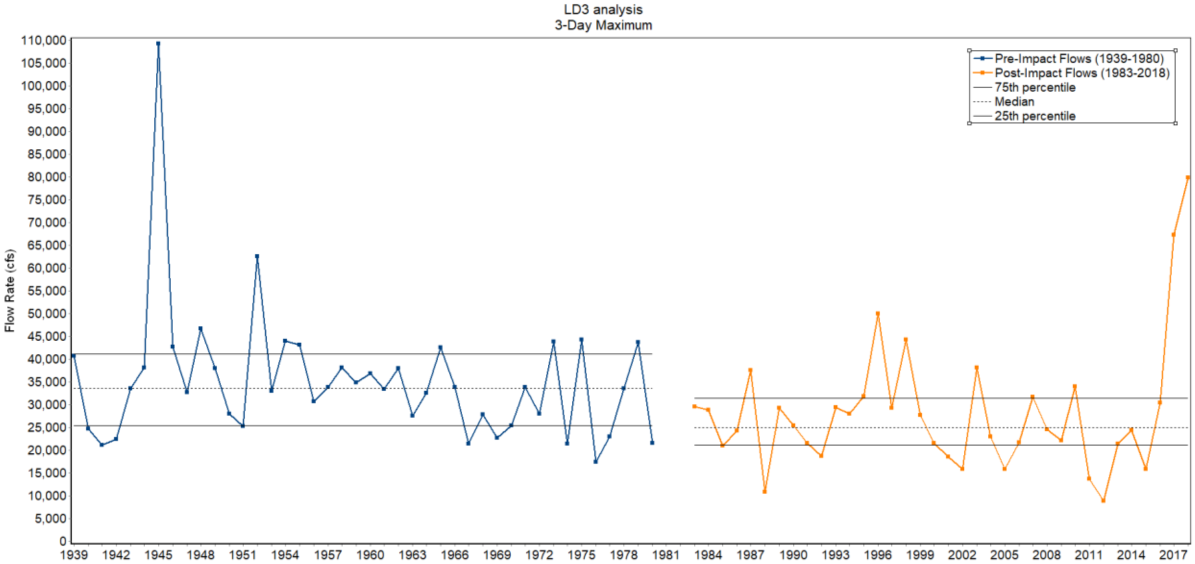


Figure 44. LD3 3-day maximums.

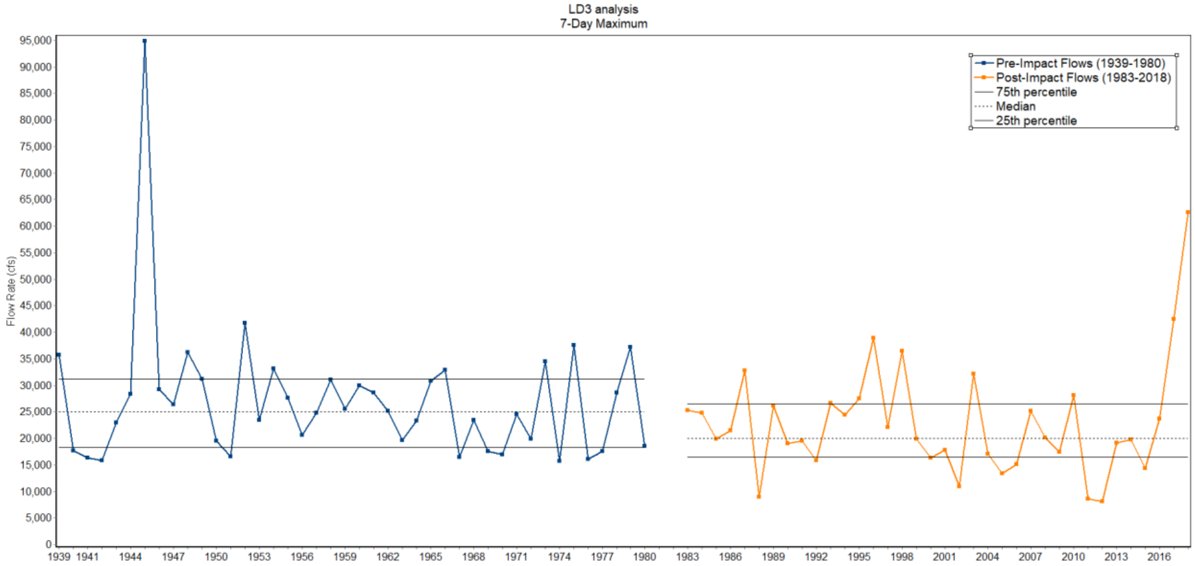


Figure 45. LD3 7-day maximums.

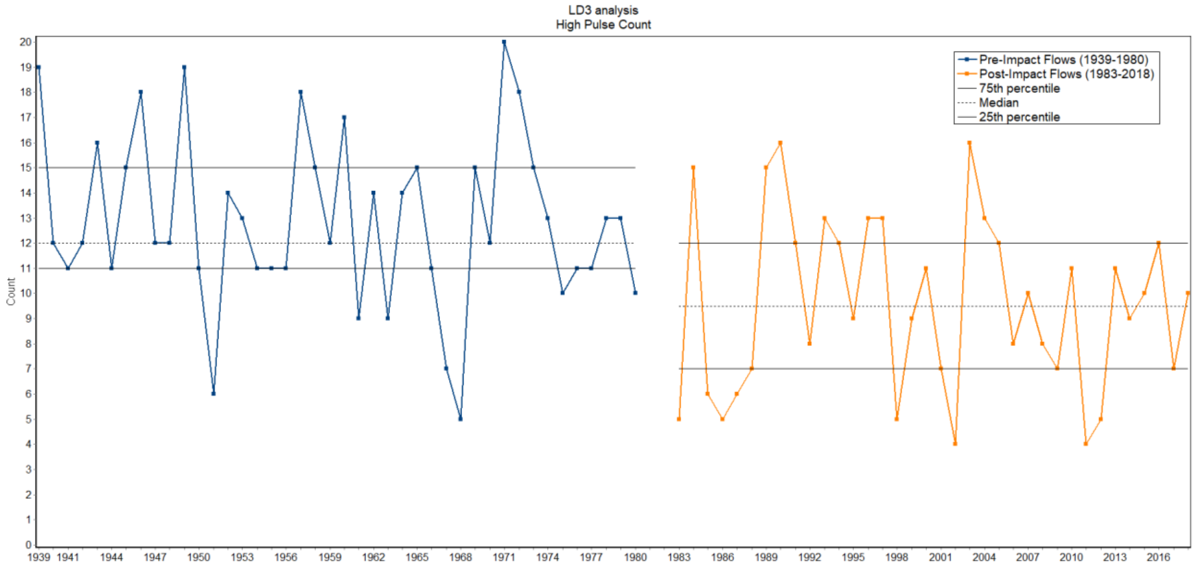


Figure 46. LD3 high pulse count.

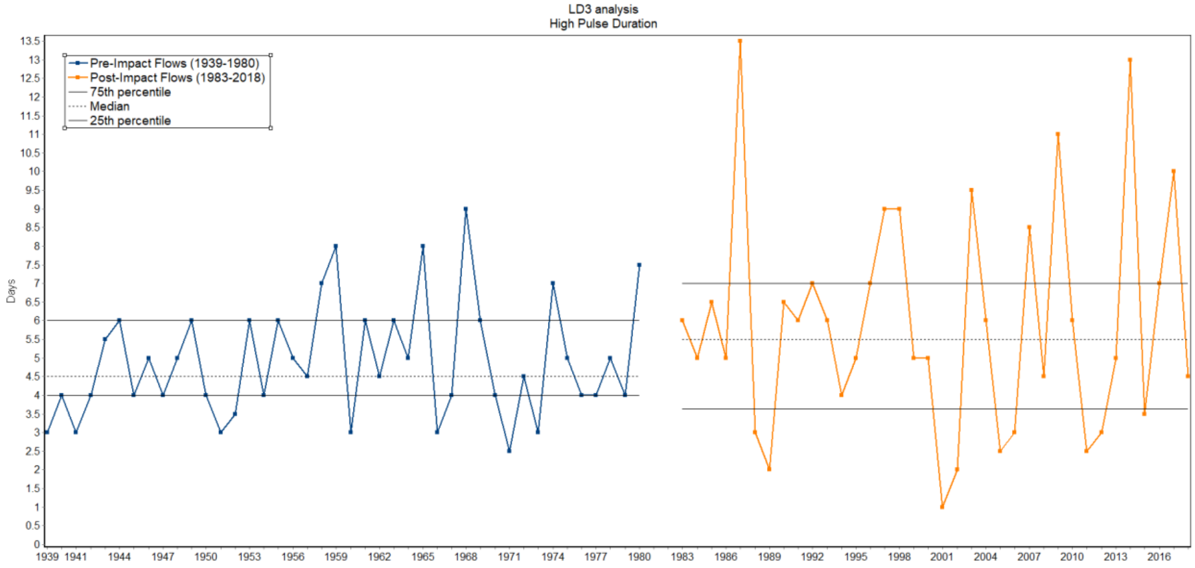


Figure 47. LD3 high pulse duration.

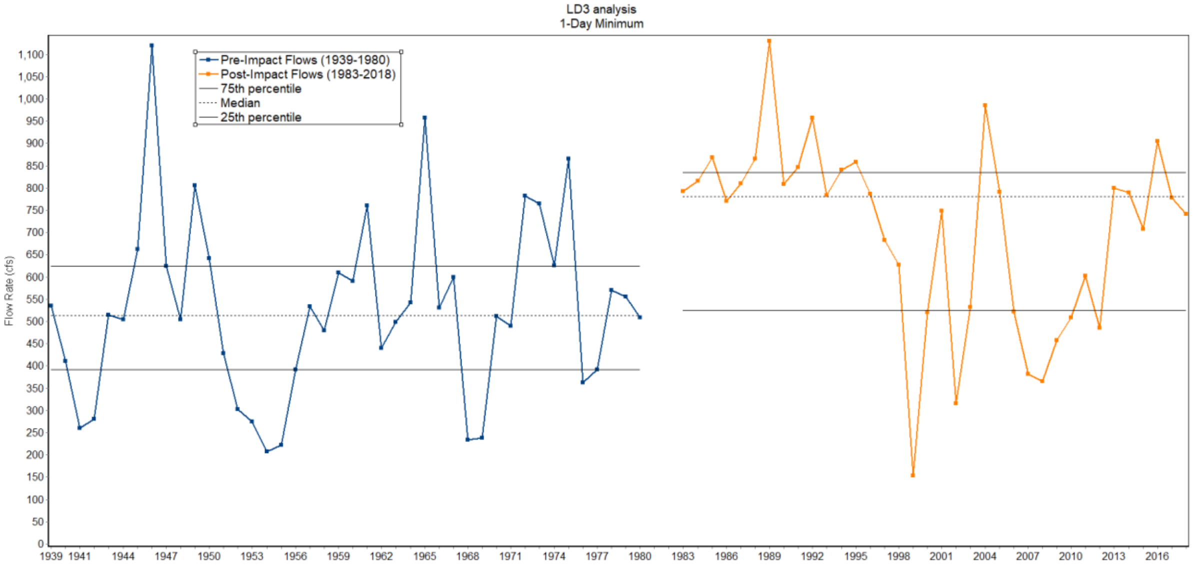


Figure 48. LD3 1-day minimums.

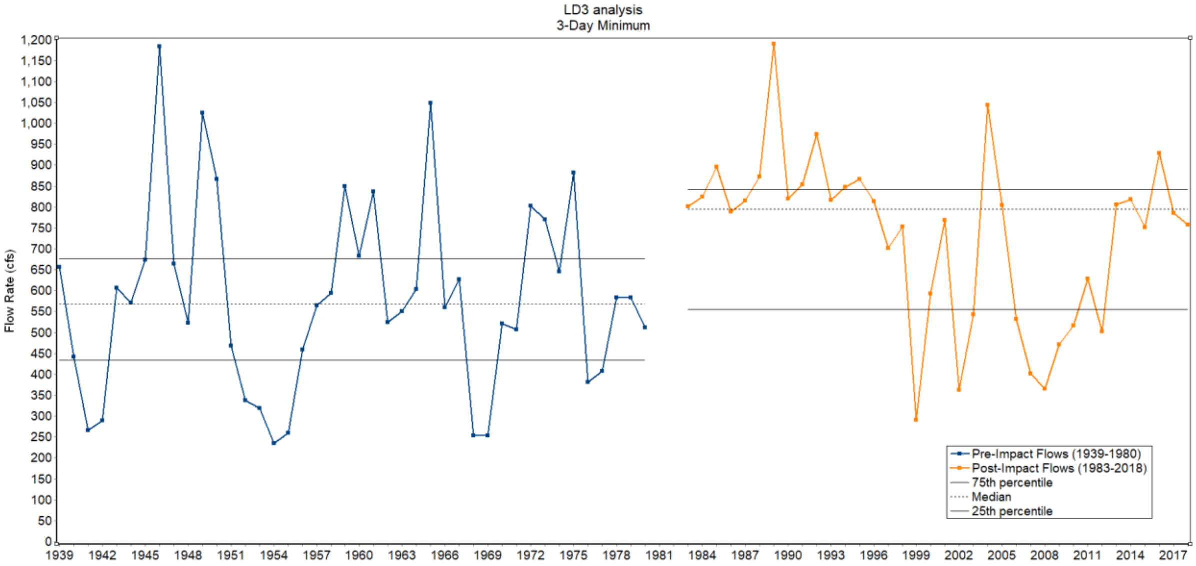


Figure 49. LD3 3-day minimums.

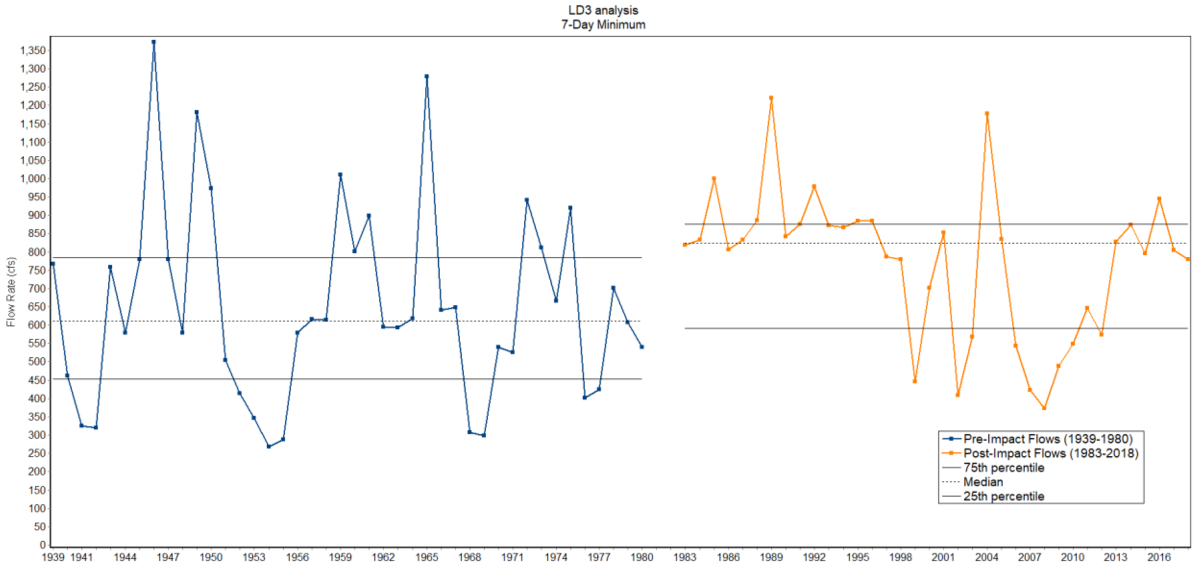


Figure 50. LD3 7-day minimums.

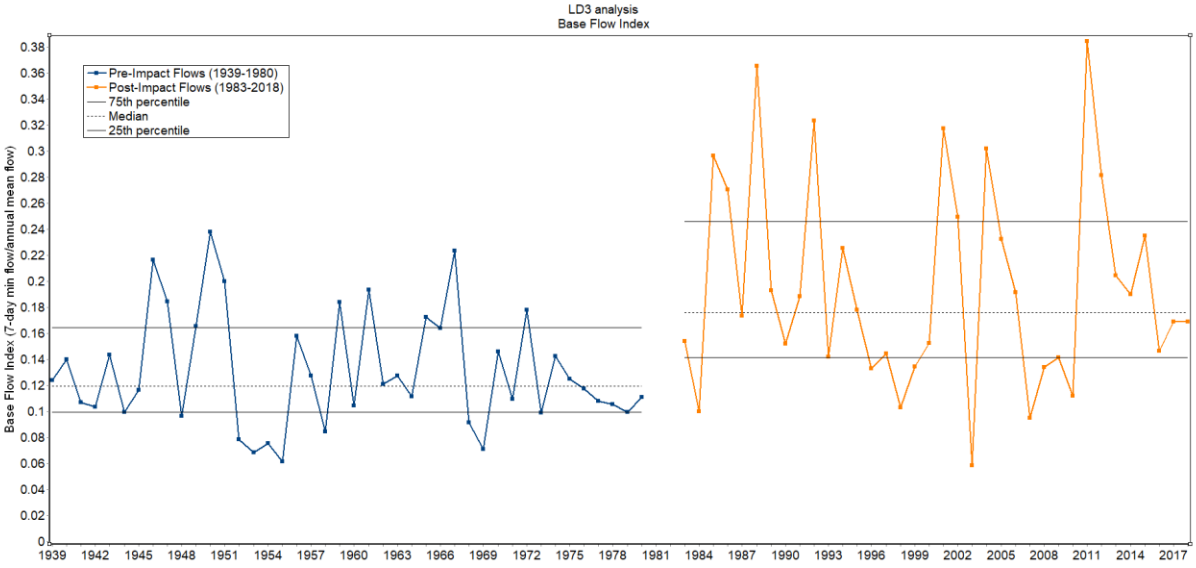


Figure 51. LD3 baseflow index.

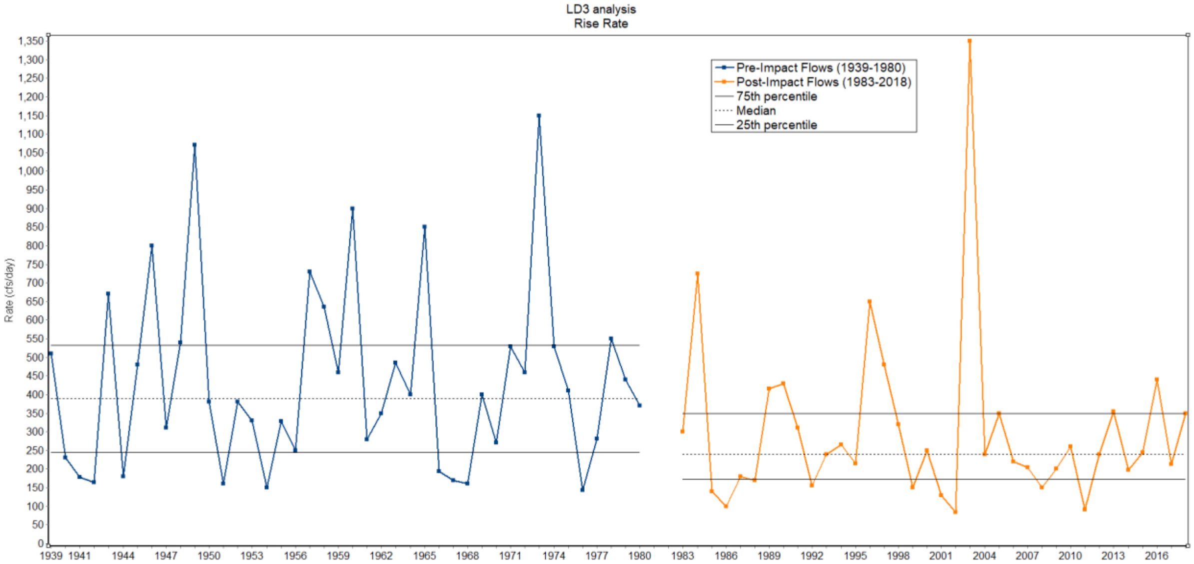


Figure 52. LD3 rise rate.

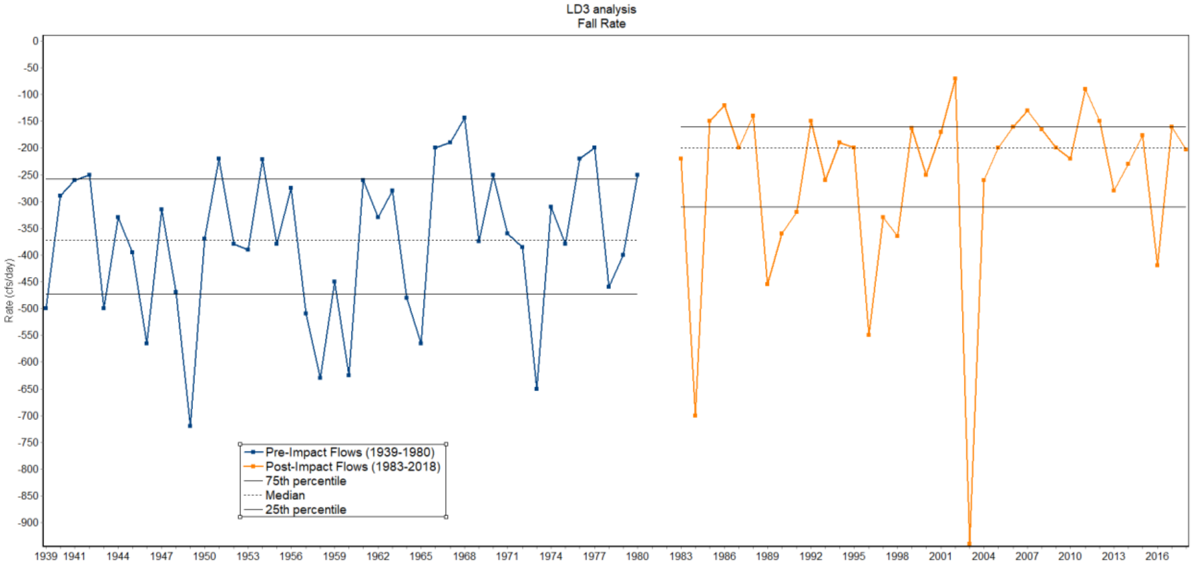


Figure 53. LD3 fall rate.

Appendix 4: LD1 hydrology data pre- and post-dam

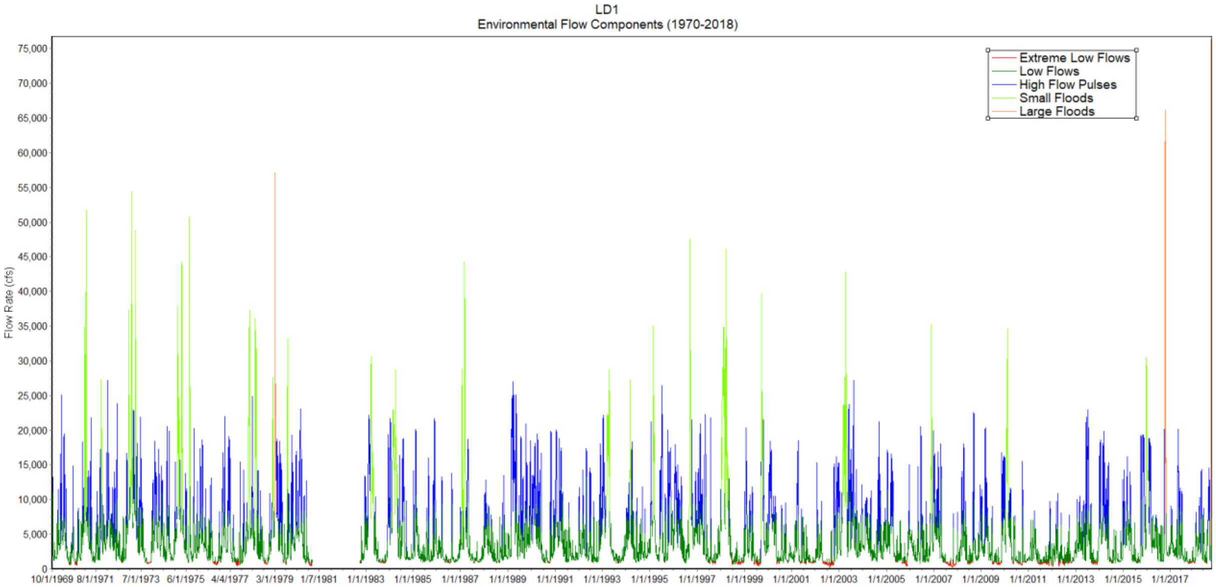


Figure 54. LD1 mean daily flow from 1970-2018 with the years 1980-1983 removed to accont for the creation of Jordan dam.

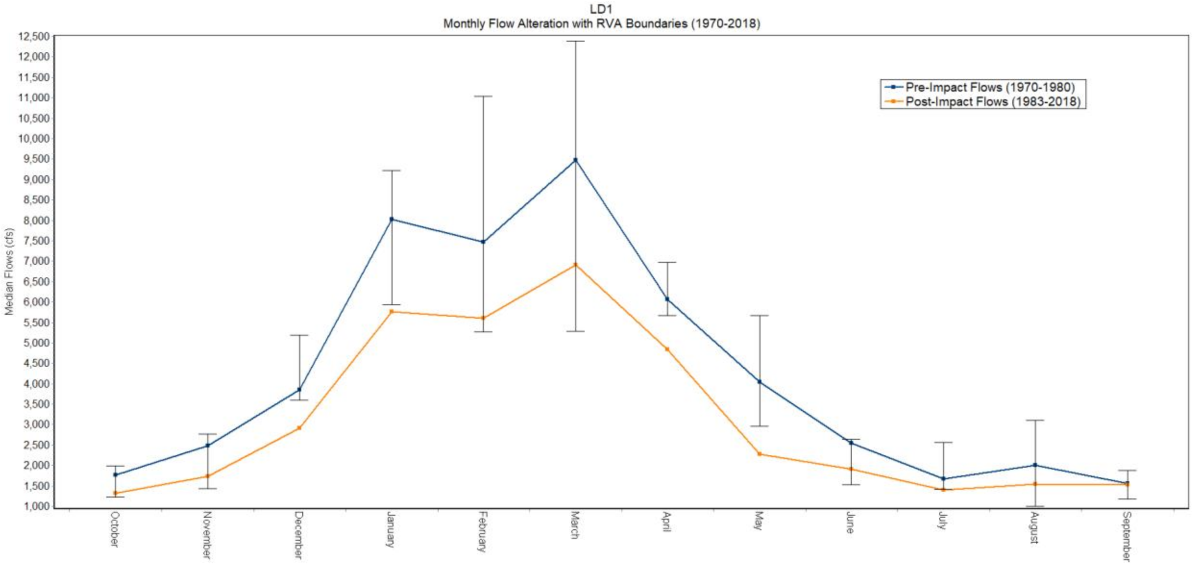


Figure 55. LD1 monthly median flows. Use comparisons with caution due to lack of pre-dam length of data.

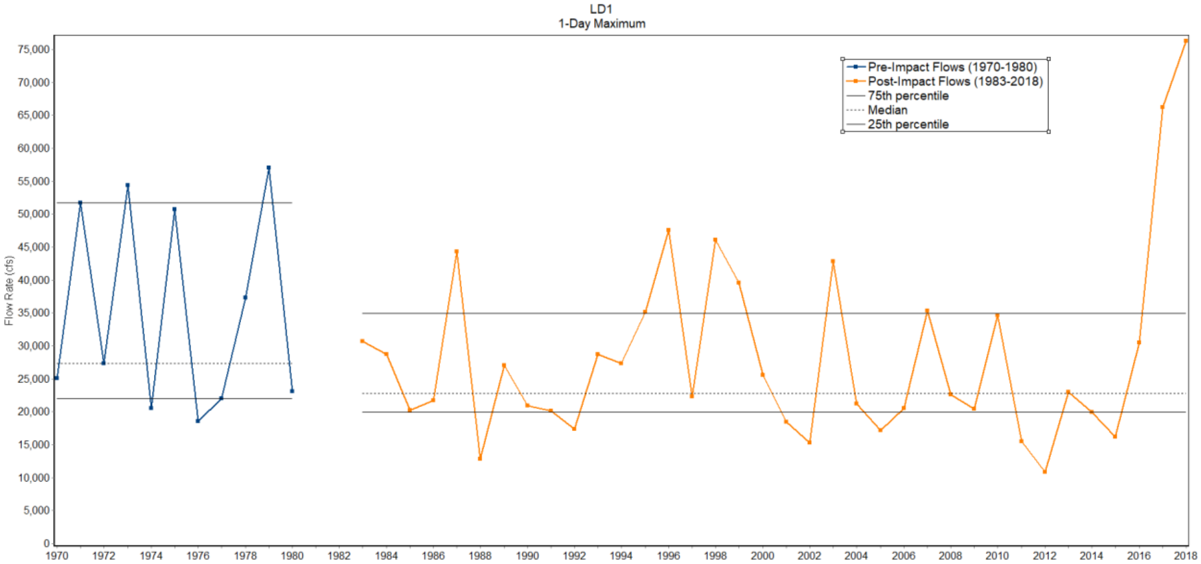


Figure 56. LD1 1-day maximums. Use comparisons with caution due to lack of pre-dam length of data.

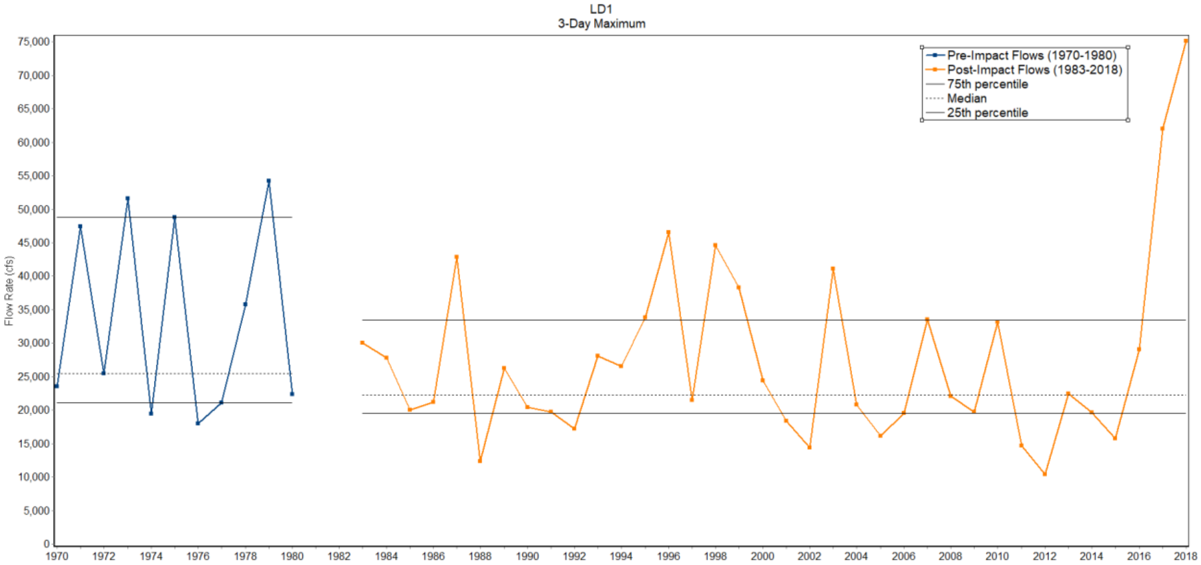


Figure 57. LD1 3-day maximums. Use comparisons with caution due to lack of pre-dam length of data.

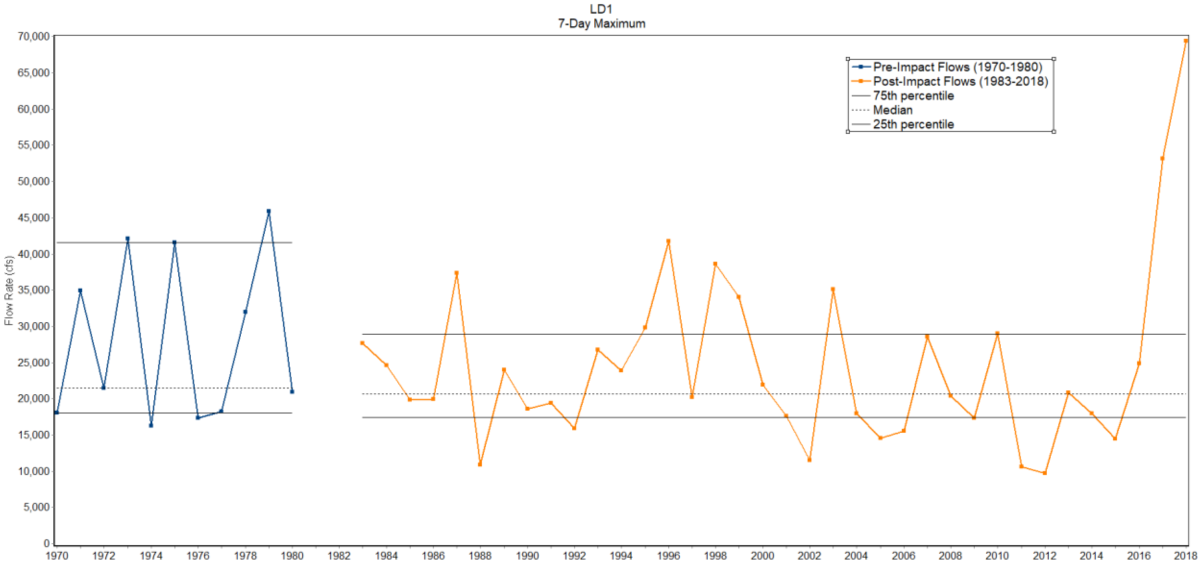


Figure 58. LD1 7-day maximums. Use comparisons with caution due to lack of pre-dam length of data.

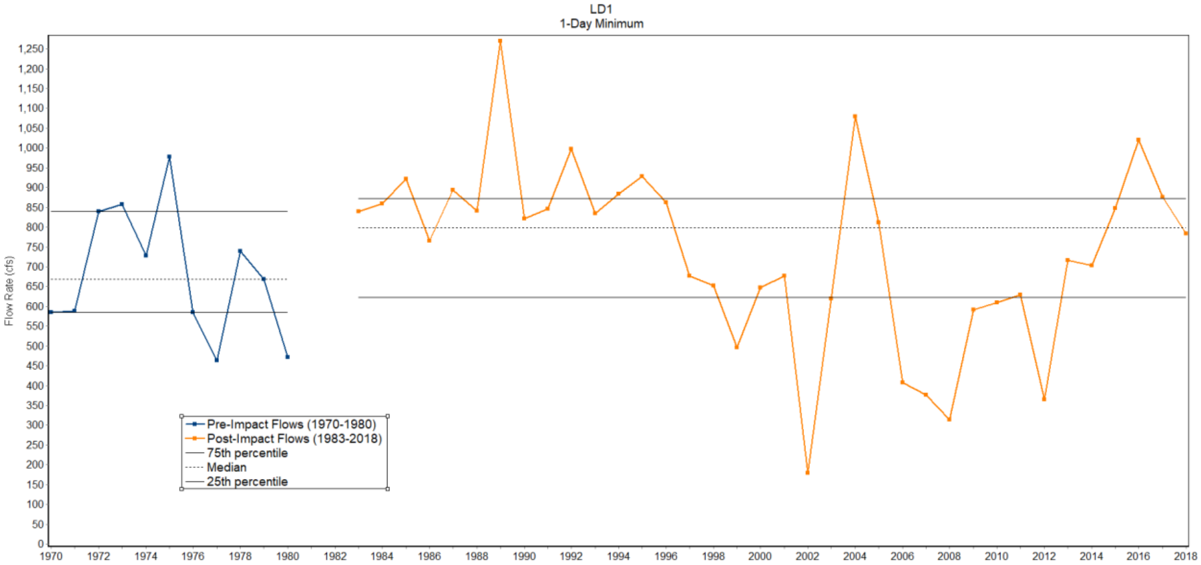


Figure 59. LD1 1-day minimums. Use comparisons with caution due to lack of pre-dam length of data.

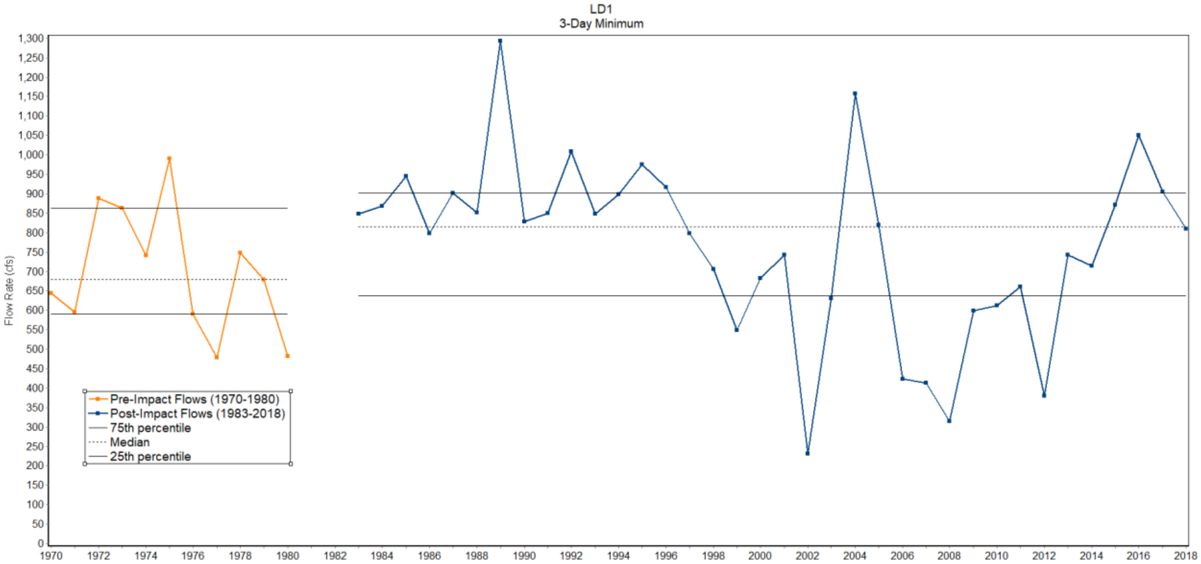


Figure 60. LD1 3-day minimums. Use comparisons with caution due to lack of pre-dam length of data.

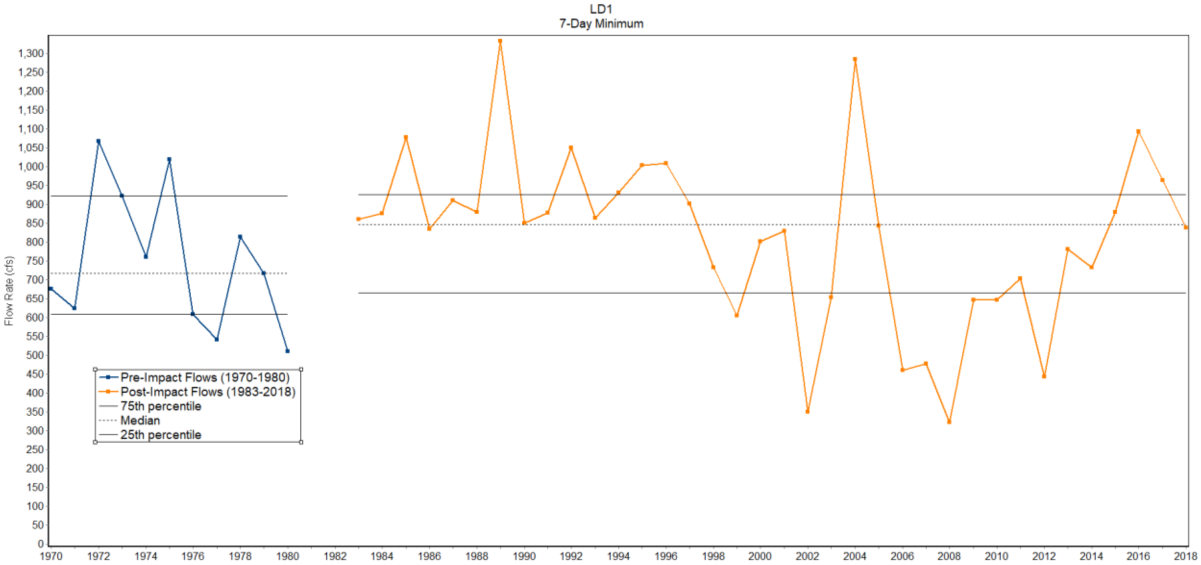
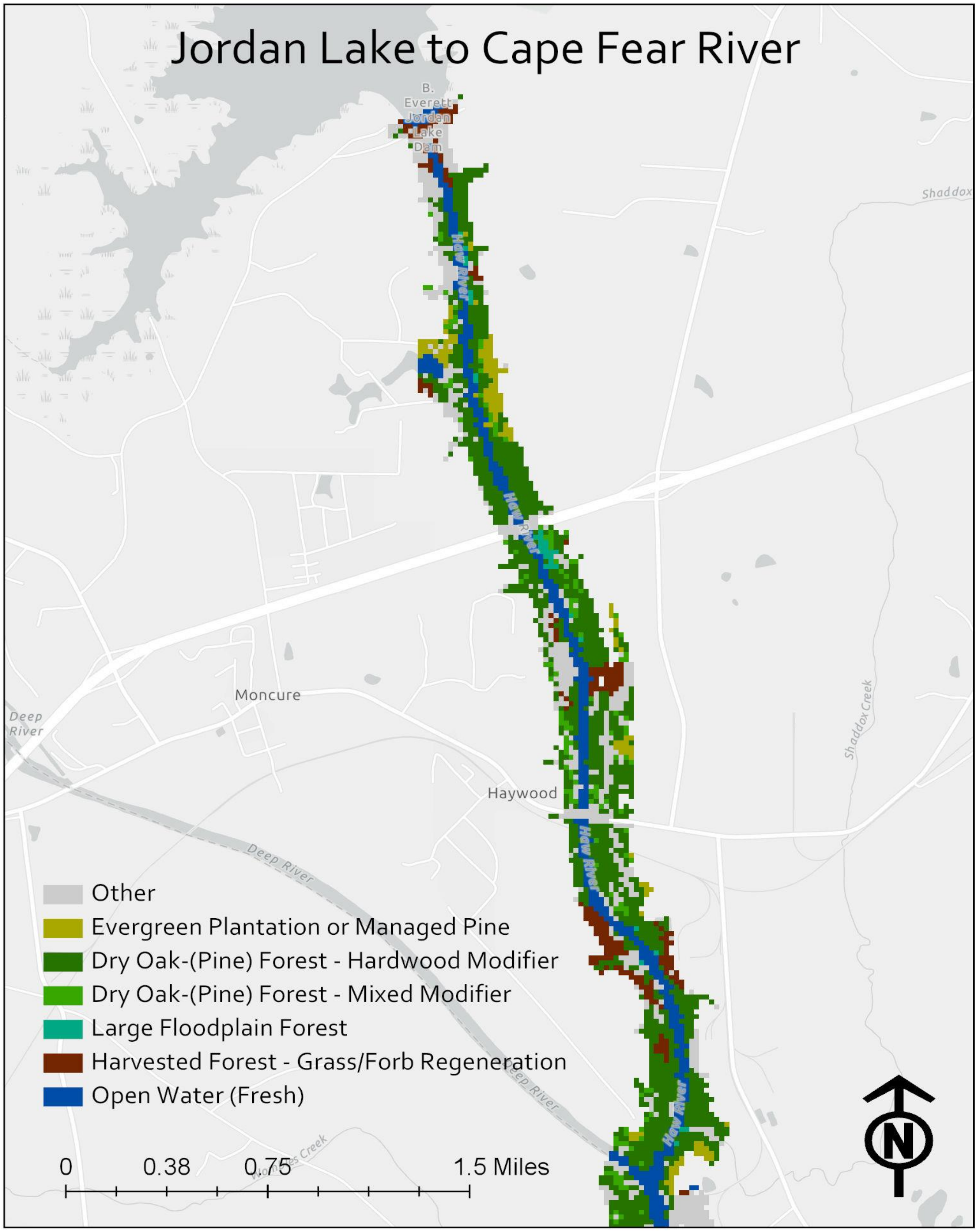
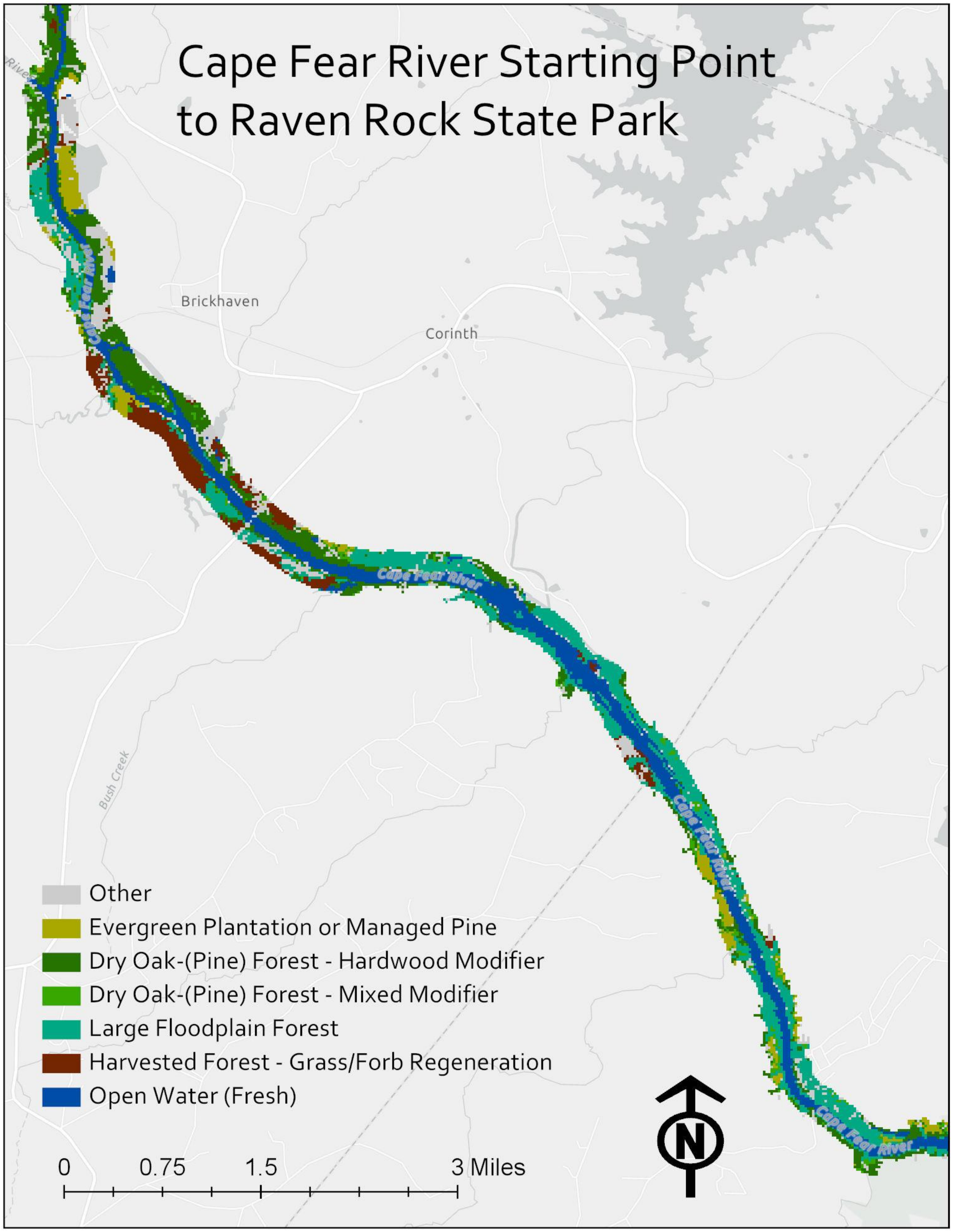
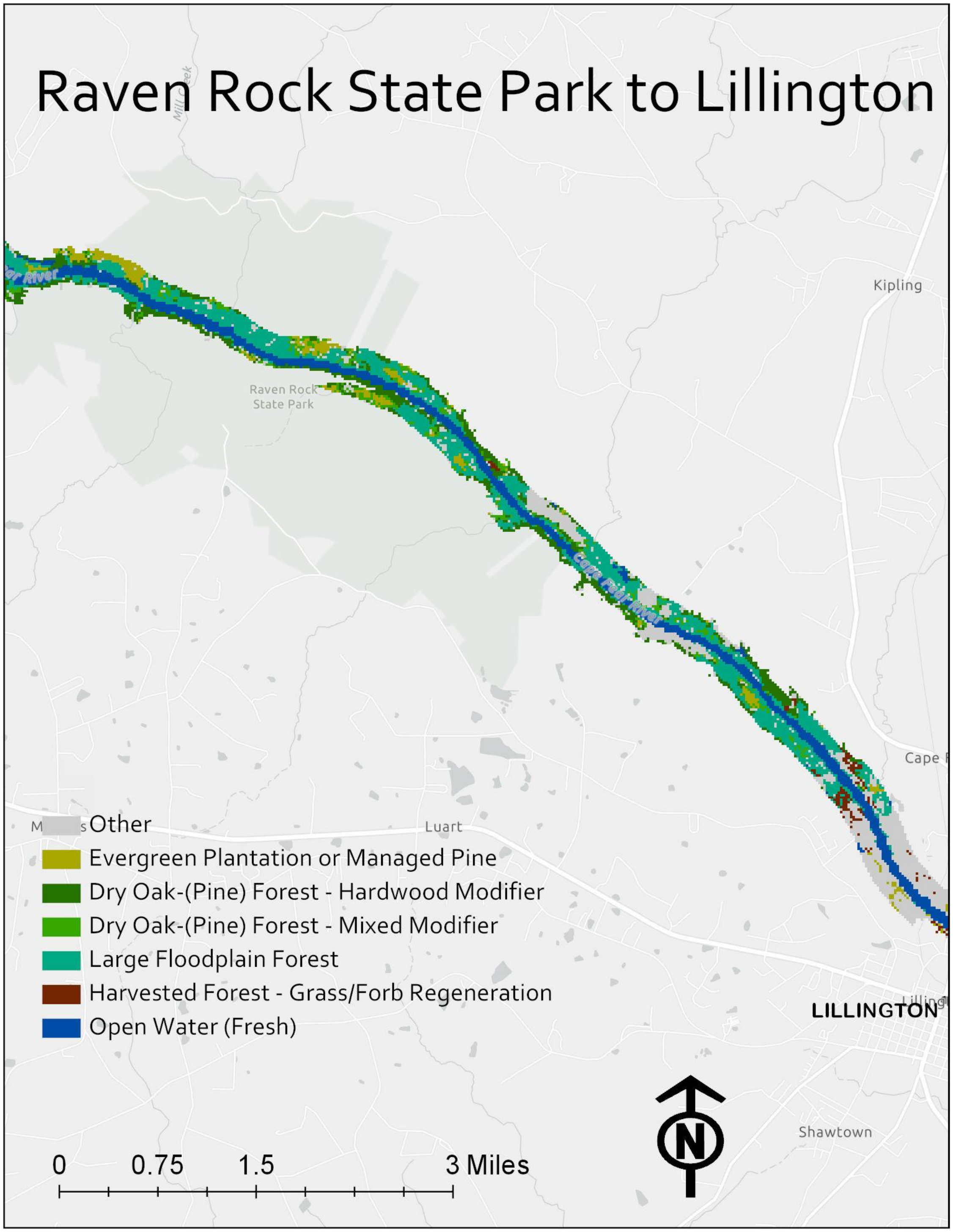


Figure 61. LD1 7-day minimums. Use comparisons with caution due to lack of pre-dam length of data.

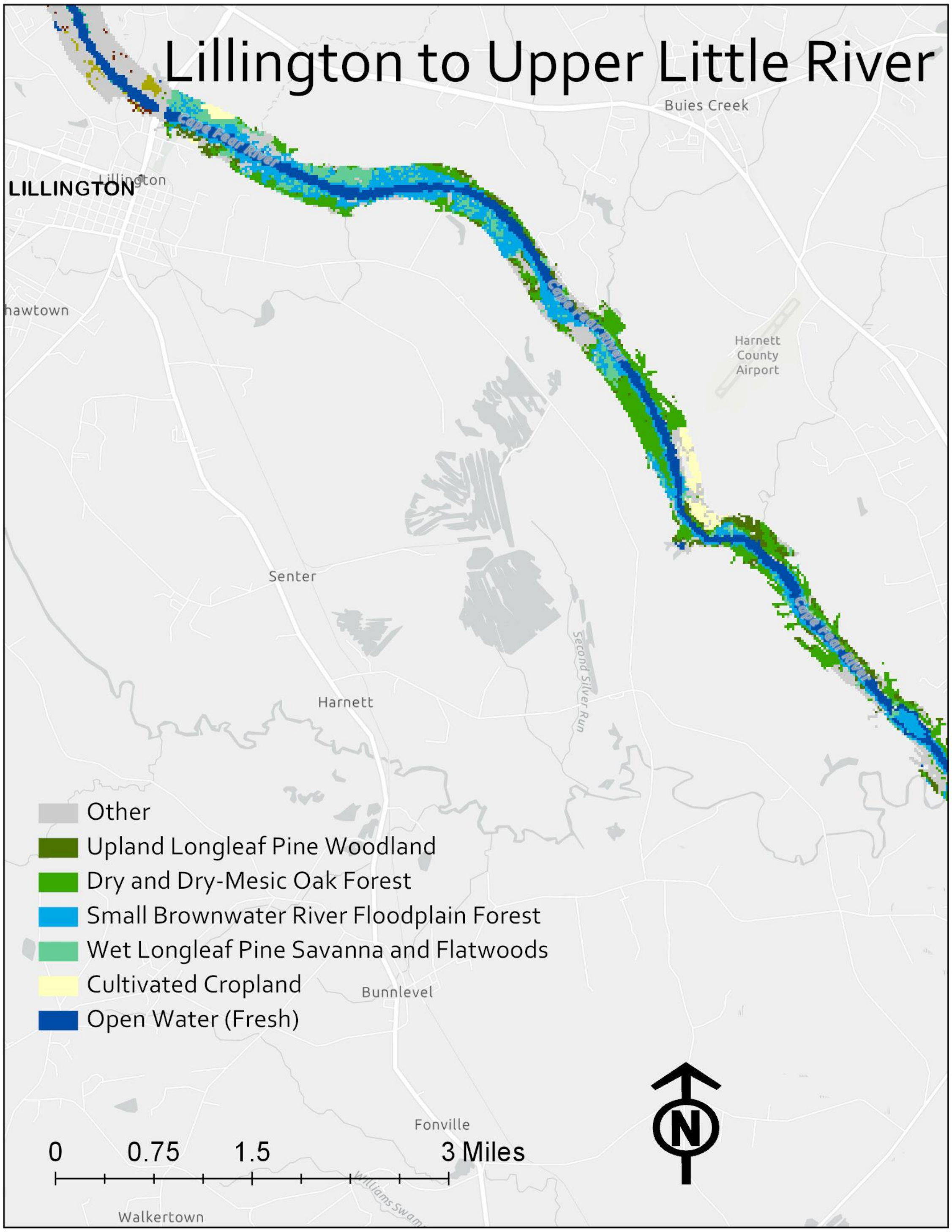
Appendix 5. Floodplain vegetation on the mainstem Cape Fear from Jordan Lake to LD1



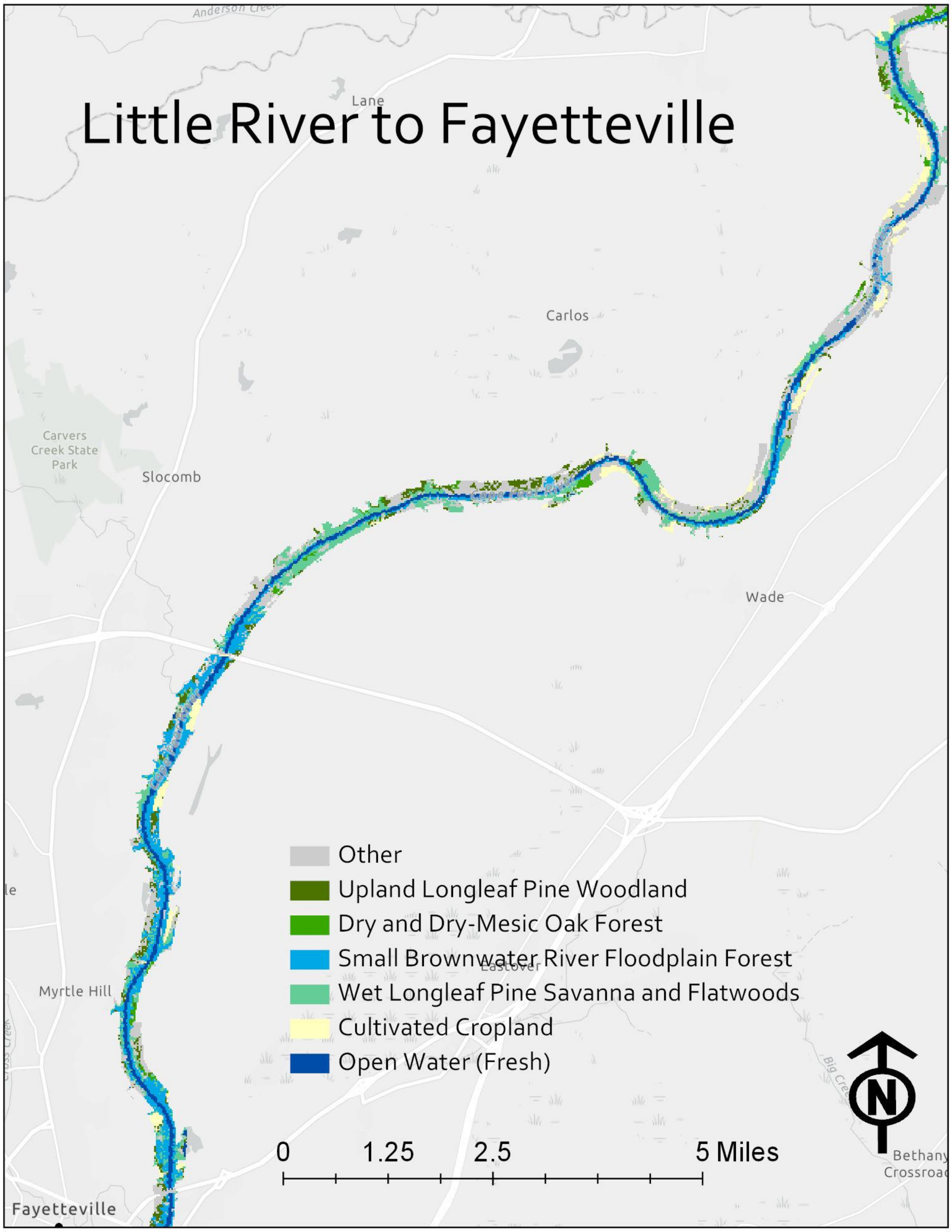

Cape Fear River Starting Point
to Raven Rock State Park
River
Brickhaven
Corinth
Cape Fear River
Cape Fear River
Cape Fear River
Cape Fear River
Bush Creek
Other
Evergreen Plantation or Managed Pine
Dry Oak-(Pine) Forest - Hardwood Modifier
Dry Oak-(Pine) Forest - Mixed Modifier
Large Floodplain Forest
Harvested Forest - Grass/Forb Regeneration
Open Water (Fresh)
0
0.75
1.5
3 Miles
N

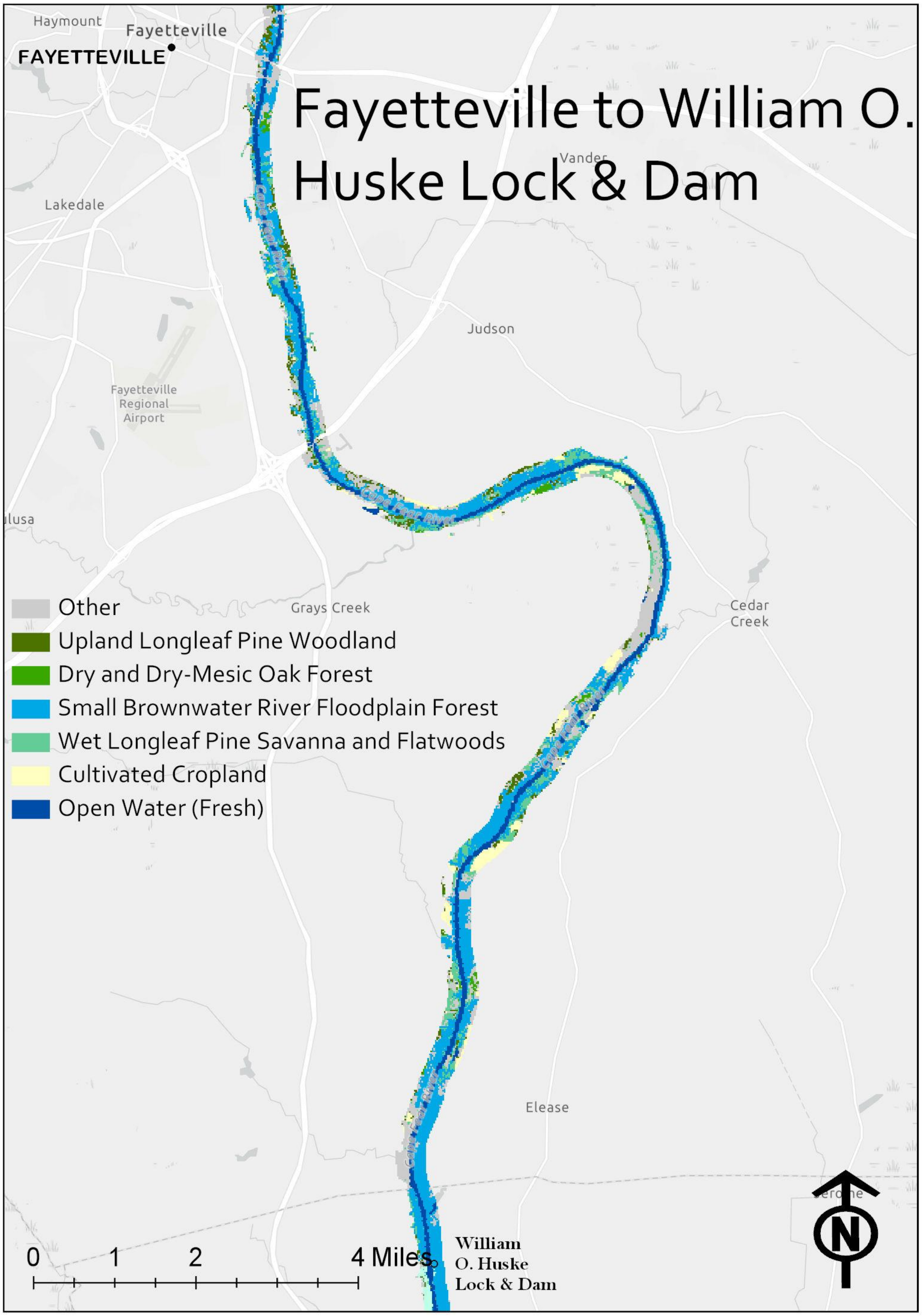


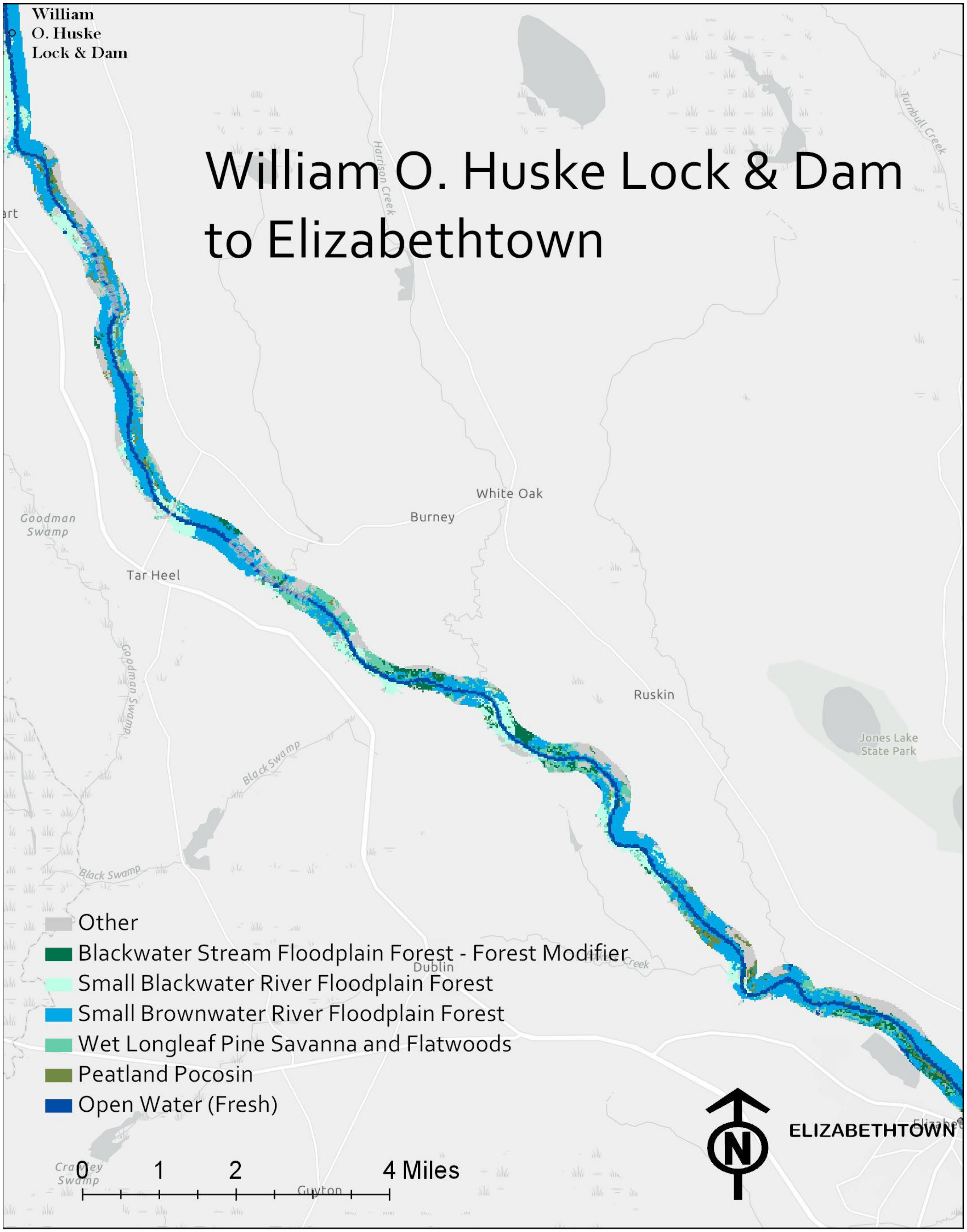
Raven Rock State Park to Lillington

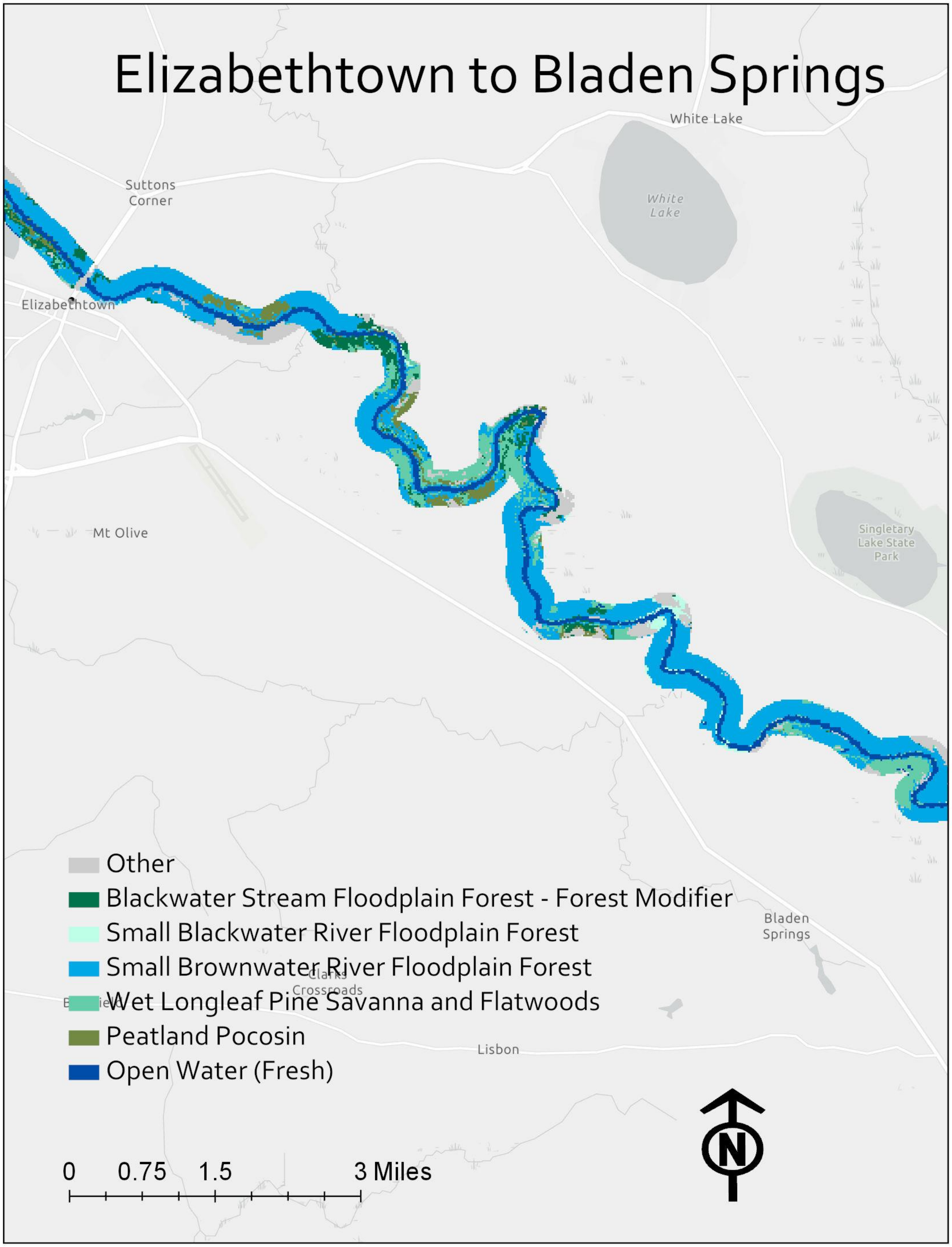

Lillington to Upper Little River
Buies Creek
LILLINGTON
Lillington
Cape Fear River
hawtown
Harnett County Airport
Senter
Second Silver Run
Harnett
Bunnlevel
Fonville
Walkertown
Williams Swamp
Other
Upland Longleaf Pine Woodland
Dry and Dry-Mesic Oak Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Cultivated Cropland
Open Water (Fresh)
0
0.75
1.5
3 Miles
N


Upper Little River to Little River
Erwin
Averasboro
Linden
Other
Upland Longleaf Pine Woodland
Dry and Dry-Mesic Oak Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Cultivated Cropland
Open Water (Fresh)
0
0.5
1
2 Miles
N


Little River to Fayetteville
Anderson Creek
Lane
Carlos
Carvers Creek State Park
Slocomb
Wade
Eastover
Myrtle Hill
Fayetteville
Bethany Crossroad
Other
Upland Longleaf Pine Woodland
Dry and Dry-Mesic Oak Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Cultivated Cropland
Open Water (Fresh)
0
1.25
2.5
5 Miles
N


Fayetteville to William O. Huske Lock & Dam
Haymount
Fayetteville
FAYETTEVILLE
Vander
Lakedale
Judson
Fayetteville Regional Airport
lusa
Grays Creek
Cedar Creek
Other
Upland Longleaf Pine Woodland
Dry and Dry-Mesic Oak Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Cultivated Cropland
Open Water (Fresh)
Elease
0
1
2
4 Miles
William O. Huske Lock & Dam
N


William O. Huske Lock & Dam
William O. Huske Lock & Dam
to Elizabethtown
Harrison Creek
Turnbull Creek
White Oak
Burney
Goodman Swamp
Tar Heel
Goodman Swamp
Ruskin
Jones Lake State Park
Black Swamp
Black Swamp
Dublin
Creek
Crawley Swamp
Guyton
ELIZABETHTOWN
N
Other
Blackwater Stream Floodplain Forest - Forest Modifier
Small Blackwater River Floodplain Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Peatland Pocosin
Open Water (Fresh)
0
1
2
4 Miles


Elizabethtown to Bladen Springs
White Lake
Suttons Corner
White Lake
Elizabethtown
Mt Olive
Singletary Lake State Park
Bladen Springs
Clarks Crossroads
Lisbon
Other
Blackwater Stream Floodplain Forest - Forest Modifier
Small Blackwater River Floodplain Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Peatland Pocosin
Open Water (Fresh)
0
0.75
1.5
3 Miles
N

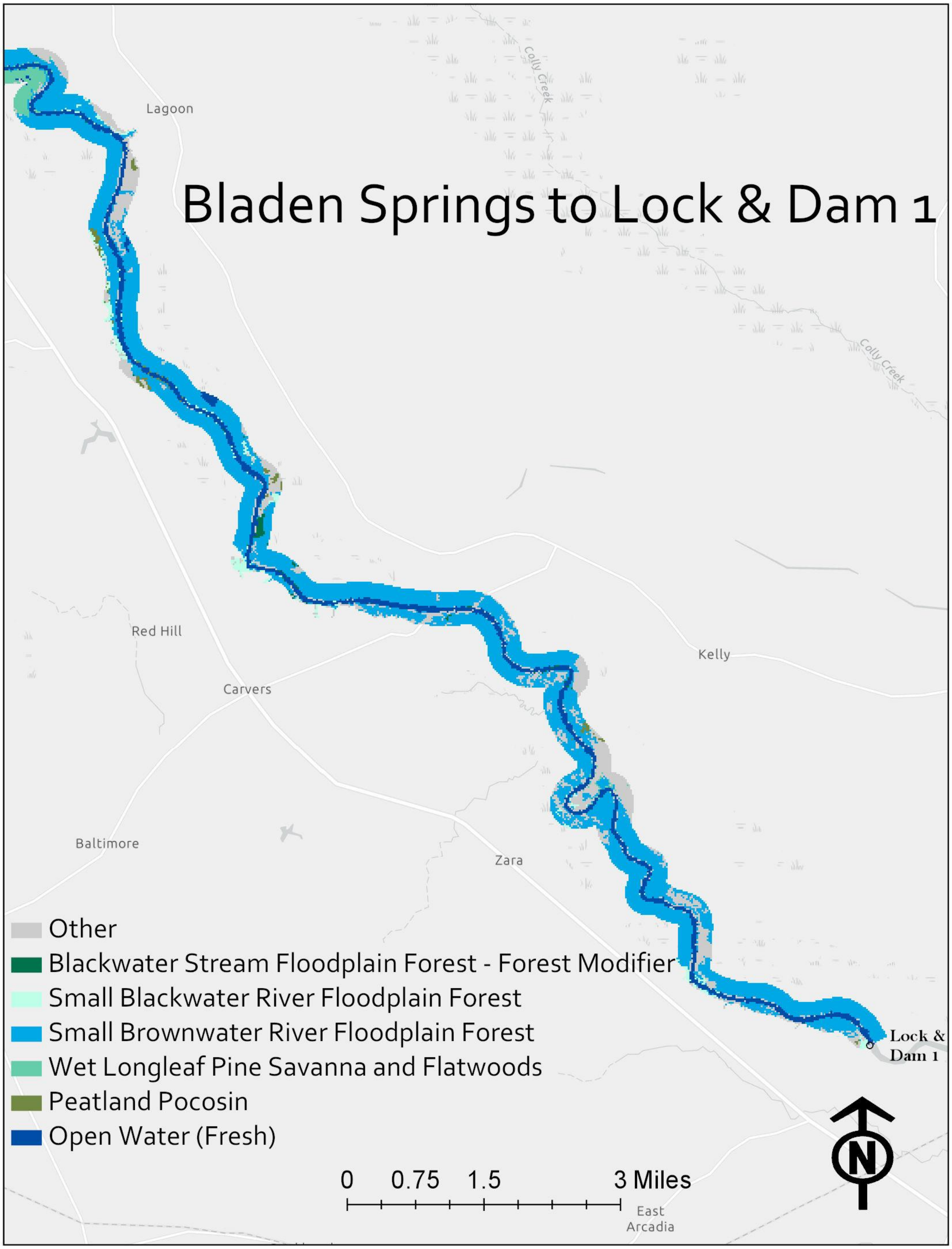

Bladen Springs to Lock & Dam 1
Colly Creek
Lagoon
Colly Creek
Red Hill
Kelly
Carvers
Baltimore
Zara
Lock & Dam 1
Other
Blackwater Stream Floodplain Forest - Forest Modifier
Small Blackwater River Floodplain Forest
Small Brownwater River Floodplain Forest
Wet Longleaf Pine Savanna and Flatwoods
Peatland Pocosin
Open Water (Fresh)
0
0.75
1.5
3 Miles
N
East Arcadia

Table 9. Description of vegetation categories

Ecosystem	**Dominant Vegetation**
Large Floodplain Forest	Box Elder (*Acer negundo*), River Birch (*Betula nigra),* Green Ash (*Fraxinus pennsylvanica*), Sweetgum (*Liquidambar styraciflua*), Tulip Poplar (*Liriodendron tulipifera*), American Sycamore (*Platanus occidentalis*), Swamp Chestnut Oak (*Quercus michauxii*), Cherrybark Oak (*Quercus pagoda*), Loblolly Pine (*Pinus taeda*), Virginia Pine (*Pinus virginiana*), Black Willow (*Salix nigra*), Sugarberry (*Celtis laevigata*), Spicebush (*Lindera benzoin*), American Water-Willow (*Justicia americana*)
Dry-Oak (Pine) Forest	Mockernut Hickory (*Carya alba*), Pignut Hickory (*Carya glabra*), White Oak (*Quercus alba*), Scarlet Oak (*Quercus coccinia*), Southern Red Oak (*Quercus falcata*), Chestnut Oak (*Quercus prinus*), Northern Red Oak (*Quercus rubra*), Post Oak (*Quercus stellata*), Black Oak (*Quercus velutina*), Flowering Dogwood (*Cornus florida*)
Small Brownwater River Floodplain Forest	Box Elder (Acer negundo), Sugarberry (*Celtis laevigata*), Green Ash (*Fraxinus pennsylvanica*), Sweetgum (*Liquidambar styraciflua*), Water Tupelo (*Nyssa aquatica*), American Sycamore (*Platanus occidentalis*), Swamp Chestnut Oak (*Quercus michauxii*), Cherrybark Oak (*Quercus pagoda*), Swamp Laurel Oak (*Quercus laurifolia*), Bald Cypress (*Taxodium distichum*)
Wet Longleaf Pine Savanna and Flatwoods	Slash Pine (*Pinus elliottii*), Longleaf Pine (*Pinus palustris*), Pond Pine (*Pinus serotina*), Large gallberry (*Ilex coriacea*), Fetterbush (*Lyonia lucida*), Pineland threeawn (*Aristida stricta*), Toothache Grass (*Ctenium aromaticum*), Carolina dropseed (*Sporobolus pinetorum*), Wireleaf Dropseed (*Sporobolus teretifolius*)
Dry and Dry-Mesic Oak Forest	Sweetgum (*Liquidambar styraciflua*), White Oak (*Quercus alba*), Southern Red Oak (*Quercus falcata*), Water Oak (*Quercus nigra*), Post Oak (*Quercus stellata*)

Upland Longleaf Pine Woodland	Bluejack Oak (*Quercus incana*), Turkey Oak (*Quercus laevis*), Sand Post Oak (*Quercus margarettiae*), Sand Laurel Oak (*Quercus hemisphaerica*), Longleaf Pine (*Pinus palustris*)
Peatland Pocosin	Sweetbay Magnolia (*Magnolia virginiana*), Pond Pine (*Pinus serotina*), Staggerbush (*Lyonia mariana*), Swamp Titi (*Cyrilla racemiflora*), Loblolly Bay (*Gordonia lasianthus*), Large Gallberry (*Ilex coriacea*), Inkberry (*Ilex glabra*), Fetterbush (*Lyonia lucida*), Swamp Bay (*Persea palustris*), Honeycup (*Zenobia pulverulenta*), Laurel Greenbrier (*Smilax laurifolia*)
Blackwater Stream Floodplain Forest	Swamp Tupelo (*Nyssa biflora*), Sweetbay Magnolia (*Magnolia virginiana*), Swamp Laurel Oak (*Quercus laurifolia*), Bald Cypress (*Taxodium distichum*)
Small Blackwater River Floodplain Forest	River Birch (*Betula nigra*), Sweetgum (*Liquidambar styraciflua*), Swamp Tupelo (*Nyssa biflora*), Planertree (*Planera aquatica*), Water Oak (*Quercus nigra*), Pond Cypress (*Taxodium ascendens*), Bald Cypress (*Taxodium distichum*), Coastal Plain Willow (*Salix caroliniana*), Black Willow (*Salix nigra*)

Appendix 6. Impaired Waters and Surface Water Classifications

North Carolina DEQ has a 2018 assessment of impaired waters which can be found here: http://portal.ncdenr.org/c/document_library/get_file?uuid=b3692eed-6b8f-4a65-b2de-9285d2befb98&groupId=38364. The state also has an online web mapper to view impaired waters according to the 2012 assessment: https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=b17139e0934a4ca1a2d5a895d21350c4.

With very few exceptions, all surface waters in North Carolina carry a classification. North Carolina Department of Environmental Quality (NCDEQ) maintains Surface Water Classifications on the website NC Surface Water Classifications found here: https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=6e125ad7628f494694e259c80dd64265

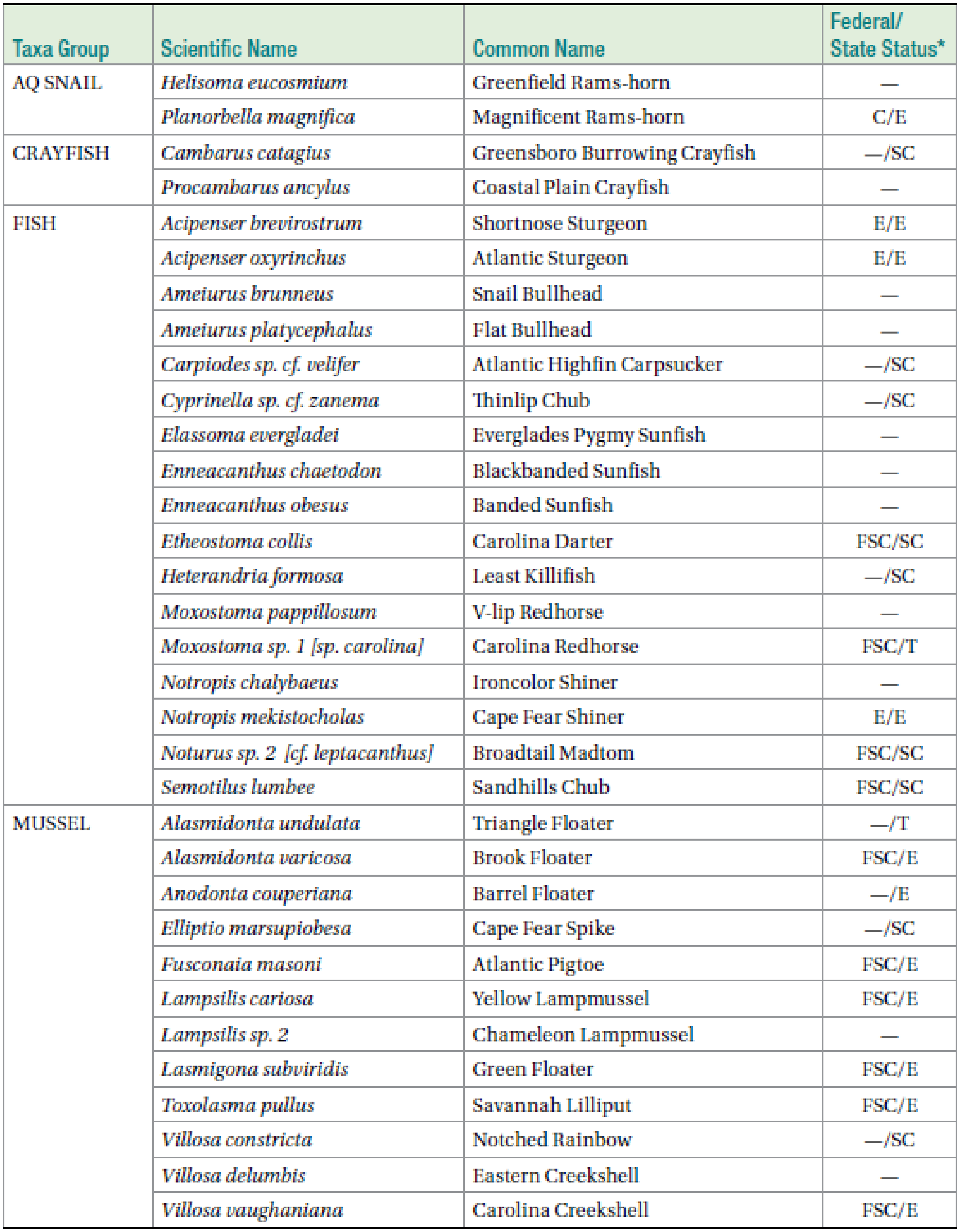
Surface Water Classifications are designations applied to surface water bodies, such as streams, rivers and lakes, which define the best uses to be protected within these waters (for example swimming, fishing, drinking water supply) and carry with them an associated set of water quality standards to protect those uses. Surface water classifications are one tool that state and federal agencies use to manage and protect all streams, rivers, lakes, and other surface waters in North Carolina. Classifications and their associated protection rules may be designed to protect water quality, fish and wildlife, or other special characteristics. Each classification has associated standards that are used to determine if the designated uses are being protected. (NCDEQ, 2018)

The following table provides classifications for each segment of the river beginning at the confluence and moving downstream to the Atlantic.

Stream Index	Section	Classification
18-(1)	From junction of Haw River and Deep River to a point 0.5 mile upstream of N.C. Hwy. 42	WS-IV
18-(4.5)	From a point 0.5 mile upstream of N.C. Hwy. 42 to N.C. Hwy. 42 (Sanford water supply intake)	WS-IV;CA
18-(5.5)	From N.C. Hwy. 42 to a point 0.6 mile downstream of mouth of Daniels Creek	WS-V
18-(10.5)	From a point 0.6 mile downstream of mouth of Daniels Creek to a point 0.2 mile downstream of Neills Creek	WS-IV
18-(16.3)	From a point 0.2 mile downstream of Neills Creek to Lillington water supply intake	WS-IV;CA
18-(16.7)	From Lillington water supply intake to Upper Little River	WS-IV
18-(20.3)	From Upper Little River to Dunn water supply intake (includes Erwin Mills water supply intake)	WS-IV;CA
18-(20.7)	From Dunn water supply intake to a point 8.2 mile upstream of Carvers Creek	WS-V
18-(23.5)	From a point 8.2 miles upstream of Cravers Creek to a point 0.5 mile upstream of City of Fayetteville water supply intake	WS-IV

18-(25.5)	From a point 0.5 mile upstream of City of Fayetteville water supply intake to City of Fayetteville water supply intake	WS-IV;CA
18-(26)	From City of Fayetteville water supply intake to a point approximately 1 mile upstream of Grays Creek.	C
18-(26.25)	From a point approximately 1 mile upstream of Grays Creek to a point approximately 0.5 mile upstream of Smithfield Packing Company's intake	WS-IV
18-(26.5)	From a point approximately 0.5 mile upstream of Smithfield Packing Company's intake to Smithfield Packing Company's intake (approximately 2 miles upstream of County Road 1316)	WS-IV;CA
18-(26.75)	From Smithfield Packing Company's intake (approximately 2 miles upstream of County Road 1316) to mouth of Hammond Creek	C
18-(49)	From mouth of Hammond Creek to mouth of Drunken Run (near mile 53)	WS-V
18-(53.5)	From mouth of Drunken Run (near mile 53) to a point 0.6 mile upstream of Lock # l near Acme	WS-IV
18-(58.5)	From a point 0.6 mile upstream of Lock # 1 near Acme to Lock # 1 (City of Wilmington water supply intake)	WS-IV;CA
18-(59)	From U. S. Corps of Engineers Lock #1 near Acme to a point 0.5 mile upstream of raw water supply intake at Federal Paper Board Corporation (Riegelwood)	WS-IV;Sw
18-(62.5)	From a point 0.5 mile upstream of raw water supply intake at Federal Paper Board Corporation (Riegelwood) to raw water supply intake at Federal Paper Board Corporation (Riegelwood), located 0.6 mile upstream of Livingston Creek	WS-IV;Sw,CA
18-(63)	From raw water supply intake at Federal Paper Board Corporation (Riegelwood) to upstream mouth of Toomers Creek	C;Sw
18-(71)	From upstream mouth of Toomers creek to a line across the river from Snows Point (through Snows Marsh) to Federal Point	SC
18-(87.5)	From a line across the river from Snows Point (through Snows Marsh) to Federal Point to Atlantic Ocean	SA;HQW

Appendix 7: Species of concern, copied from the NC Wildlife Action Plan 2015



Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Helisoma eucosmium*	Greenfield Rams-horn	—
	Planorbella magnifica	Magnificent Rams-horn	C/E
CRAYFISH	*Cambarus catagius*	Greensboro Burrowing Crayfish	—/SC
	Procambarus ancylus	Coastal Plain Crayfish	—
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Ameiurus brunneus	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. velifer	Atlantic Highfin Carpsucker	—/SC
	Cyprinella sp. cf. zanema	Thinlip Chub	—/SC
	Elassoma evergladei	Everglades Pygmy Sunfish	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Heterandria formosa	Least Killifish	—/SC
	Moxostoma pappillosum	V-lip Redhorse	—
	Moxostoma sp. 1 [sp. carolina]	Carolina Redhorse	FSC/T
	Notropis chalybaeus	Ironcolor Shiner	—
	Notropis mekistocholas	Cape Fear Shiner	E/E
	Noturus sp. 2 [cf. leptacanthus]	Broadtail Madtom	FSC/SC
	Semotilus lumbee	Sandhills Chub	FSC/SC
MUSSEL	*Alasmidonta undulata*	Triangle Floater	—/T
	Alasmidonta varicosa	Brook Floater	FSC/E
	Anodonta couperiana	Barrel Floater	—/E
	Elliptio marsupiobesa	Cape Fear Spike	—/SC
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lampsilis sp. 2	Chameleon Lampmussel	—
	Lasmigona subviridis	Green Floater	FSC/E
	Toxolasma pullus	Savannah Lilliput	FSC/E
	Villosa constricta	Notched Rainbow	—/SC
	Villosa delumbis	Eastern Creekshell	—
	Villosa vaughaniana	Carolina Creekshell	FSC/E

Appendix 8: Freshwater bivalves in the Cape Fear and their habitat/flow requirements.

Freshwater Bivalves	Habitat/Flow Requirements	Biological Information
Alewife Floater (*Anodonta implicata*)	Clean sand/gravel substrates in relatively fast flowing water	IUCN status – G5 (secure) The alewife floater is a long-term brooder-eggs are fertilized in August and glochidia released the following spring. A known host is the alewife which is a predominantly saltwater fish that migrates in the spring into freshwater to spawn. There are at least 4 freshwater fish host as well.
Atlantic Pigtoe (*Fusconaia masoni*) NC Endangered	Medium to large streams. Clean, swift water with stable gravel or sand and gravel substrate. Often found at the downstream edge of riffle areas.	IUCN status – G1 (critically endangered) The time period for glochidia to develop varies between 30 to-60 days and depends on the host fish. Females are fully gravid the first week in July. Larvae are released in Jul and Aug. At least 9 known fish host, mostly shiners and dace. USFWS and Nature serve
Barrel Floater (*Anodonta couperiana*) NC Endangered	Ponds and slow-flowing streams with mud or sand bottoms.	IUCN status – G4 (secure) Barrel floaters are long-term spawners (brachytictic). Glochidia host unknown but suspect centrarchid sp. to be host.
Brook Floater (*Alasmidonta varicosa*) NC Endangered	Swift current in run-riffle complexes & pools with clean gravel/sand/cobble substrates ; not documented in CF below Jordan	IUCN status – G3 (vulnerable) Fertilization occurs in summer with glochidia release the following spring, longer-term spawner (brachytictic). Gravid females are found August to May. At least 7 fish hosts have been documented. Nature serve
Cape Fear Spike (*Elliptio marsupiobesa*) NC Special Concern	Muddy, loose, sandy substrates below log jams, or firm, sandy substrates	IUCN status – G3(Q) (Q-Large populations appear to be declining somewhat but the species is still relatively stable in its limited range in North Carolina.) Gravid females found around the middle of June. Nothing is known about fish hosts.
Carolina Creekshell (*Villosa vaughaniana*) NC Endangered	Silty sand or clay along the banks of small streams, as well as mixed sand and gravel; not documented from mainstem CF	IUCN status: G2/G3 (It appears to be extirpated from the type locality in South Carolina, but a few new sites discovered in the same basin; and it is threatened by some habitat loss (mostly due to its restricted range) in North Carolina. Occurrences are scattered and density is low at all or nearly all sites.) This species is brachytictic: Spawning occurs in the summer, and the larvae are released the following spring. Fish hosts include Bluegill, Green Sunfish, Pumpkinseed, Redbreast Sunfish
Chameleon Lampmussel (*Lampsilis* sp.)	Varies	IUCN status – G2 (Imperiled) Life history attributes are completely lacking including growth, fecundity, larval duration and glochidial hosts. NatureServe
Creeper (*Strophitus undulatus*) NC Threatened	Headwater streams, large river, and lakes to a depth of 4 meters. Silt, sand, gravel, and mixed substrates.	IUCN status – G5 (Secure) The creeper is a long-term brooder, (brachytictic) with eggs fertilized in the summer and glochidia released the following spring. They are fish host generalist with at least 15 species of fish and 1 species of salamander know to serve as host. (NatureServe)
Eastern Creekshell (*Villosa delumbis*)	Mud or soft sand, as well as mixed sand/gravel/cobble	IUCN status -G4 (Apparently Secure) (Species ranges widely from Ocmulgee River, GA north to the Cape Fear River in North Carolina and is generally

		secure throughout range, although populations are declining.) Glochidial hosts include Largemouth Bass, Bluegill, Green Sunfish, Redbreast Sunfish, Redear, Warmouth
Eastern Lampmussel (*Lampsilis radiata*)	Medium to coarse sands in streams, rivers, and blackwater swamps	G5 (Secure) This species is a long-term brooder with eggs fertilized in mid to late summer and glochidia released the following spring. At least 10 fish species have been documented as fish hosts. NatureServe
Eastern Pondmussel (*Ligumia nasuta*)	Variable	G4 (Apparently Secure) This species is a long-term brooder with fertilization in late summer and glochidial release the following spring. Host fish include Bluegill, Pumpkinseed, Largemouth Bass. NatureServe
Notched Rainbow (*Villosa constricta*) NC Special Concern	Sand/gravel substrates, often in stable banks among tree root mats	G3 (Vulnerable) Watters et al. Gravid females found in the Neuse basin in North Carolina in May, June, July and August. To date the most effective host found is *Etheostoma flabellare* (Fantail Darter), but because this fish is rare in the Cape Fear basin where *Villosa constricta* is more common, other host(s) are hypothesized. NatureServe
Pod Lance (*Elliptio folliculata*)	Found in clay, in association with rooted aquatic vegetation in canals, and in smalls creeks to large rivers	I N a – G3/G2 (Imperiled) Glochidial host fish is not known. NatureServe
Rayed Pink Fatmucket (*Lampsilis splendida*)	Muddy and sandy areas in streams, rivers, and blackwater swamps; not documented in CF River	I N a – G3 (Vulnerable) Rare in the Cape Fear basin. Glochidial host fish includes Largemouth Bass. NatureServe
Roanoke Slabshell (*Elliptio roanokensis*)	Coarser substrates, such as a mix of gravel and cobble in relatively fast flowing water	G3 (Vulnerable) The Cape Fear River population has significantly declined since the mid-1970s. Little is known about the life history of this species. Host fish include Blueback Herring, Gizzard Shad, White Perch. NatureServe
Savannah Lilliput (*Toxolasma pullus*) NC Endangered	Creeks, rivers, and impounded habitats. . Found in both soft banks and sand/gravel/cobble runs and pools; not documented in CF below Jordan	I N a – G2 (Imperiled) The only stable population in North Carolina is the University Lake population (Haw drainage) in Orange County (Hanlon and Levine 2004). This species is a long-term brooder, brooding in August with hybrid bluegill (*Lepomis macrochirus x Lepomis cyanellus*) suitable as fish hosts (Hanlon and Levine 2004). Gravid females have been observed between late April through early August, but not during mid-September. Successful transformation likely occurs on other Lepomis species. NatureServe

Triangle Floater (*Alasmidonta undulata*) NC Threatened	No preference for particular habitat. Found in silt/sand in slower moving waters, gravel/sand in riffles and runs, and from crevices in bedrock	I N a – G4 (Apparently Secure) This species is a long-term brooder, with fertilization taking place in summer and glochidial release taking place the following spring. Gravid specimens have been reported nearly year round (Ortmann, 1919; Clark, 1981) There are 10 known fish hosts. NatureServe
Yellow Lampmussel (*Lampsilis cariosa*) NC Endangered	Found in many different habitats; often found in sand and other soft substrates in flowing, medium sized rivers and medium to large creeks	G3/G4 (Vulnerable) Area of occupancy has decline even more than range extent as most occurrences are represented by small populations having poor viability with few individuals. Reproductive biology of *Lampsilis cariosa* has not been extensively studied. It is a long-term brooder with eggs fertilized in late summer and glochidia released the following spring. Confirmed host fish include yellow perch (*Perca flavescens*) and white perch (*Morone americana*) in coastal areas (Wick and Huryn, 2003; Wick, 2005) as well as Largemouth Bass, Black Crappie, White Bass. NatureServe

Appendix 9. Reptiles and amphibians in the Cape Fear, and their habitat/flow requirements

Reptiles and Amphibian Species	**Habitat/Flow Requirements**
American Alligator	Prefer brackish waters and inhabit swamps, creeks, rivers, tidal marshes, canals, ponds, lakes, and reservoirs
Carolina Swamp Snake	Cypress ponds, swamps, Carolina bays, and other shallow water bodies with dense aquatic vegetation
Diamondback Terrapin	Brackish and salt water such as protected waters behind barrier islands, salt marshes, estuaries, tidal creeks, and flats hidden among the marsh and cord grass.
Eastern Chicken Turtle	Heavily-vegetated aquatic habitats in shallow, still waters, particularly ephemeral and seasonal wetlands with abundant vegetation.
Glossy Crayfish Snake	Cypress swamps, Carolina bays, roadside ditches, and the margins of heavily-vegetated ponds and lakes
Green Seaturtle	Near the coastline and around islands, in bays and protected shores, especially in areas with seagrass beds. Rarely in open ocean
Kemp's Ridley Seaturtle	Shallow areas with sandy and muddy bottoms
Leatherback Seaturtle	Open ocean
Loggerhead Seaturtle	Coastal bays and estuaries, as well as in the shallow water along the continental shelves of the Atlantic Ocean
Rainbow Snake	Cypress swamps, tidal or brackish water, and flowing-water habitats such as blackwater creeks, streams, and rivers with vegetation and debris.
Carolina Gopher Frog	Isolated ephemeral ponds such as Carolina Bays, limesinks, and flatwoods ponds to breed. Adults live as fossorial species, inhabiting crayfish holes, root channels, rodent borrows, or other subterranean structures.
Dwarf Salamander	Inhabit the edges of ponds in pine forests or savannas, around swamps and bottomland hardwood forests, and Carolina bays. Migrate to ponds, swamps, or bays to breed.
Eastern Tiger Salamander	Live in burrows, but emerge to breed in vernal pools, fishless ponds, and slow moving streams
Four-toed Salamander	Live in forests surrounding swamps, bogs, marshes, and temporary bodies of water free of fish. Breed in ponds, bogs, marshes, and streams.
Mabee's Salamander	Live in soil near bogs, ponds, and swamps. Breed and lay their eggs on vegetation or detritus of ephemeral or shallow, still water without fish.
Mole Salamander	Live in floodplain forest near swampy areas or upland forests near bodies of water that are used as breeding ponds.
Oak Toad	Inhabit pine flatwoods, savannas, sandhills, some pocosins, and maritime forests. Breed in ephemeral ponds.
Ornate Chorus Frog	Inhabit longleaf pine stands and pine savannas. Breed in ephemeral ponds, Carolina bays, and ditches.

Pine Barrens Treefrog	Inhabit pine forests and sandhills. Breed in Carolina bays, pocosins, spring-fed pools, and bogs adjacent to pine forests.
River Frog	Inhabit blackwater rivers and breen in oxbow lakes, ponds, borrow pits, swamps, or other permanent water along the Cape Fear River
Southern Chorus Frog	Inhabit pine flatwoods, wet meadows, forested wetlands, and wet roadside ditches. Breed in shallow water.