RECONSTRUCTING MULTI-CENTURY STREAMFLOW RECORDS IN THE MOBILE-TENSAW DELTA

by

CARLY JONES

MATTHEW THERRELL, COMMITTEE CHAIR
LISA DAVIS
EMILY ELLIOTT

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Geography
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2021

ABSTRACT

Across the Southeastern United States (SEUS) growing populations are increasing demand on water resources and infrastructure. Understanding the long-term natural flow regime of rivers is critical to developing accurate models of water level variability needed for appropriate water resource management. Insufficient hydroclimate records fail to accurately capture the frequency of severe droughts or to document long-term monotonic changes in climate, like increased aridity, humidity, or changes in consumption (Crockett et al., 2010). We used new and existing tree-ring chronologies to reconstruct May-August discharge for the Alabama River during the period 900-2011 CE in order to place the period of instrumental flows (since 1931 CE) into historical context.

A nested principal components regression model was used to reconstruct streamflow, maximizing the use of chronologies with varying time coverage in the network. The regression model applied utilized the mean index chronology as the predictor for the climate-variable that most influences tree growth at our site. The modeled streamflow estimates indicate that streamflow conditions of the instrumental period do not sufficiently represent the full range of Alabama River flow variability beyond the observational period. Although extreme hydroclimate variability is present in the gage record, the tree-ring record suggests that the intensity and duration of flood and drought events that occurred during the 1500s and 1700s was far more severe. These findings imply that basing future water policy on water availability witnessed during the instrumental period could result in devastating water shortages if droughts as intense as those in the 16th and 18th century were to occur in modern times.

LIST OF ABBREVIATIONS AND SYMBOLS

BJS	Bayou Jessamine collection site
CE	Common era
EW	Earlywood width
LW	Latewood width
MJJA	May June July August
MTRD	Mobile-Tensaw River Delta
n	sample size
n_t	Number of trees
p	Probability value as determined by a test of statistical significance
r	Pearson product-moment correlation
r_1	First-order autocorrelation
R^2	Coefficient of determination
r_s	Spearman rank correlation
RW	Total ring width
RWI	Ring width index

ACKNOWLEDGMENTS

This research was supported by the U.S. Environmental Protection Agency Gulf of Mexico Program (EPA-MX-00D67718-0), the University of Alabama Department of Geography, and theUniversity of Alabama Graduate School. I thank the Alabama Forever Wild Program for site access, Matt Gage Director of the University of Alabama Office of Archaeological Research for field support, Dr. Matthew Therrell, Dr. Emily Elliott, and Dr. Lisa Davis for their instruction and guidance. I thank my mother and sister, Cindy Hope and Zoe Jones, and my partner Nick Alti for all of their love and encouragement.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Alabama has abundant water resources with 14 major river systems, 20 major aquifers, and an average of 1,397 mm of yearly precipitation, according to information provided by the Geological Survey of Alabama. Although freshwater resources are plentiful, they are not unlimited. Considerable complexity exists acrosstime and space in the total amount, variability, and quality of water flowing through the state's rivers and reservoirs. The availability of water resources is impacted by anthropogenic factors including rapidly increasing population, nutrient and sediment pollution, land use change, and global climate change, as well as natural forces such as long-term fluctuations due to oceanic- atmospheric interactions and changing geomorphology. Water scarcity issues have intensified inrecent decades, with recent drought and population growth straining water management systemsthroughout the southeastern United States (Maxwell and Soulé, 2009). Recent work on mappingstreamflow decline in the SEUS indicates that the region has experienced a multi-decadal decline in streamflow from 1995 to 2014 (Tootle et al., 2017). Unfortunately, past studies focused on identifying broad-scale climate drivers of water resources have operated on relatively limited temporal scales and failed to fully explain the climatic controls impacting hydroclimatic variability (e.g., McCabe and Wolock, 2014).

Sadeghi and co-authors provide clarification of the extent, duration, and magnitude of SEUS streamflow variability and the associated large-scale climate forcing mechanisms in the 2019 article "Atlantic Ocean Sea Surface Temperatures and Southeast United States." The results of this analysis confirmed an SST region in the North Atlantic as being teleconnected with SEUS streamflow. Sadeghi and colleagues determined that an observed multi-decadal increase in temperatures in this SST region may be associated with the observed recent multi- decadal decline in SEUS streamflow (Li et al., 2011; Sadeghi et al., 2019). The link between El-Niño Southern Oscillation (ENSO) indicators and SEUS streamflow is well established. While past studies have indicated that the storage of water in soil is affected by ENSO precipitation anomalies, the temporal variability of the streamflow response to ENSO is not well understood (Clark et al., 2014). Previous research suggests that in the SEUS, El Niño conditions are associated with increased moisture (e.g., precipitation, streamflow) during winter to early springmonths (JFMA), dryer than normal conditions during the summer (JJA), and increased total moisture for the calendar year (Sadeghi et al., 2019). Additionally, Wang et al. (2012) attribute below average precipitation in coastal MS-AL for the summer following an El Niño, to the eastward shift of the tropical forcing associated with sea surface temperature (SST) anomalies. Understanding the duration and magnitude of SEUS streamflow variability and the connections to large scale climate forcing mechanisms is a critical step toward providing the framework needed by water managers and policy makers to make responsible decisions concerning the availability of water resources within the SEUS (Sadeghi et al., 2019).

In order to establish effective minimum flow and water-level requirements, we must first develop an accurate understanding of the natural flow regime prior to the instrumental period. Direct observations of streamflow and climate in the United States did not begin until the 1890s, and in many cases, instrumental records are significantly shorter. The comparatively short length of instrumental climate records limits the capacity to ascertain the relationships between streamflow and large-scale climatic signals. This limitation can be addressed through the development of climate proxies that record environmental and anthropogenic changes, such as the creation of paleoreconstructions of streamflow and extreme hydroclimatic events (e.g., floods and drought). Tree rings provide a long-term perspective of streamflow variability at centennial to millennial time scales. Analyses of annual growth rings in trees can be used to reconstruct streamflow because the local growing environment for trees generally reflects broader climatic conditions (Cook et al., 1999). Consequently, most studies of hydroclimate variables such as streamflow are conducted in the American Southwest or internationally and comparatively fewer studies have been conducted in the southeastern US (Baker, 2008). However, tree rings have been shown to provide valuable flow information even in humid environments (Crockett etal., 2010), as seen in work by Stahle and others discussed below. Tree-ring studies of streamflow in western US rivers (e.g., Meko and Graybill, 1995; Woodhouse et al., 2006; Mekoet al., 2007; Margolis et al., 2011) highlight the unreliability of the most recent century of stream gauge data and indicate that short instrumental time series fail to capture extreme events and longer-term trends apparent in the paleo record. The development of tree-ring reconstructions of streamflow for closed canopy forest ecosystems of the southeast has presented challenges in the past (Fritts, 1991). In these closed-canopy eastern forests, growth patterns are influenced by competition for light and episodic disturbance, which can mask the growth signal related to climate and streamflow (Fritts, 1991). Consequently, most studies off hydroclimate variables such as streamflow have been conducted in the American Southwest or internationally and comparatively fewer studies have been conducted in the southeastern US (Baker, 2008). However, tree rings have been shown to provide valuable hydroclimate information even in humid environments (Maxwell et al., 2009; Crockett et al., 2010; Stahle et al., 2012), as seen in work by Stahle and others discussed below.

New tree-ring chronologies from the Mobile-Tensaw Delta watershed can supply the high-resolution records of climate variability needed to better understand the impacts of extreme events, multi-decadal trends in rainfall variability, and the influence of regional and large-scale forcing factors on hydroclimate variability (Therrell et al., 2017). The primary objective of this study is to reconstruct multi-century streamflow records of the Alabama River and Mobile Tensaw River Delta, utilizing standard dendrochronological techniques to better understand past and present trends in hydrologic and hydroclimatic extremes within the system. This research is intended to improve the paleoclimate record for the Mobile-Tensaw River Delta and expand the broader understanding of the region's hydrologic variability. This knowledge is critical to the establishment of regulations that balance the water needs of human populations and ecological communities and protect the integrity of natural systems dependent on appropriate maintenance of the hydrological cycle (Giese and Franklin, 1996; Harley, 2007). Previous research conducted in the Suwannee River Basin indicates that in comparison to 20th century conditions, the pre-instrumental period was characterized by below median flow and reduced flow variability. These findings indicate that if experienced today, low flow conditions similar to those that occurred during the 16th and 18th century could create major problems for water planning authorities, communities, and ecological systems. Placing river flowvariability into a broader temporal framework provides context for recent drought events and improves understanding of the likelihood of meeting or exceeding these conditions in the future (Harley, 2007).

In September of 2019, personnel from the University of Alabama Dendrochronology Research Laboratory collected 32 increment-core samples from 17 living bald cypress trees and six cross-sections from dead trees along Bayou Jessamine in the MTRD (Figure 3). I prepared the samples and assigned exact dates to annual rings through the process of crossdating patterns of relative ring width. I then measured the total ring width of individual dated growth rings to 0.001 mm precision. The accuracy of the sample dating was cross checked and statistically verified using COFECHA software (Holmes, 1983). The Dendrochronology Program Library in R (dplR) was used to process and analyze Bayou Jessamine (BJS) ring width data and build the final BJS chronology. Using the gaged flow record from the USGS 02428401 Alabama River at Claiborne lock and dam, I calibrated tree-ring chronologies from the region with the gage record to form the reconstruction model. After validating the reconstruction model, I applied the model to the tree-ring data for all available years in order to generate the full reconstruction (Figure 7). We produced a 1,111-year reconstruction of mean May-August Alabama River streamflow during the period 900–2011 CE using six nested PCR models.

2. LITERATURE REVIEW

2.1. Foundations of dendrochronology

Crossdating —the cornerstone of dendrochronology— dates back to the mid-1700s, when the French naturalists Duhamel and Bufon assigned dates to annual growth in trees by comparing internal markers across multiple individuals in order to identify the 1709 frost ring in a series of samples. However, dendrochronology did not gain a prominent place in the sciences until 1904, when A.E. Douglass laid out the basic methodology of skeleton plotting and developed the repeatable process of crossdating (Speer, 2009). Calibration is when ring-width measurements are compared to annual phenomena such as meteorological data. Without precise annual dating of the tree rings developed through crossdating, accurate calibration is impossible because the chronology will be misdated by one or more years. (Speer, 2009). Douglass's work to advance the field of dendrochronology was motivated by his interest in tree rings as they related to his work as an astronomer. He hypothesized that solar variability could be represented by the growth patterns of trees, reasoning that certain trees record climate variations. Douglass developed extensive tree-ring chronologies for applications in astronomy and archaeology and was the first researcher to use crossdating extensively (Studhalter 1956).

In 1906, Douglass accepted a position as an Assistant Professor of Physics and Geography at the University of Arizona. While in Tucson, Arizona, he continued his work with tree rings, while teaching physics, and continuing his astronomical pursuits. Douglass was interested in reconstructing a long- term record of sunspots and hypothesized that one could measure variations in solar intensity recorded in tree rings (Meko, 2015).

He later demonstrated that trees record both rainfall levels, and cycles driven by climatic parameters (Douglass, 1909). In 1937, Douglass established the world's first tree-ring laboratory at the University of Arizona and served as its first director until his death in 1962 (Eckstein et al., 1990). He trained many notable students; including Edmund Schulman, Ted Smiley, Florence Hawley, James Giddings, and Emil Haury. Dendrochronolgy remains a highly regarded field of research today thanks to the hard work and determination of these researchers and their European counterparts including Bruno Huber, Walter Liese, Bernd Becker, Dieter Eckstein, and Fritz Schweingruber. Edmund Schulman helped further advance the field of dendrochronology by describing the important considerations of site and species selection, and by identifying wet and dry periods going back over 600 years into the past through the reconstruction of runoff in the upper Colorado River basin (Meko, 2015). Another student of Douglass' Florence M. Hawley, extended Douglass' work to the southeastern United States, through her research dating moundbuilder artifacts from Mississippi and Tennessee. Hawley developed several of the first chronologies from the southeastern United States, challenging the belief that trees in the eastern deciduous forest wouldnot produce datable tree rings (Speer, 2010).

Today, dendroclimatological studies typically use chronologies of tree-ring growth indices to reconstruct a specific climate variable for the pre-instrumental period covered by the chronology. These reconstructions are generally developed using a regression model, where the mean index chronology is the predictor for the climate-variable that most influences tree growth at a given site (Fritts, 2012). The application of dendrochronological methods for problems in ecology grew considerably in the late 1900s. In their book, *Dendroecology: a tool for evaluating variations in past and present forest environments* [1989], Fritts and Swetnam place these applications into one of the following four categories: 1) dating specific ecological events based on associated ring structures or injuries e.g., fire scars; 2) dating and evaluating forest disturbances based on distinctive changes in ring widths or other ring features e.g., insect outbreaks; 3) applying climatic or hydrologic reconstructions to problems in ecology; and 4) inferring variations in animal populations from closely-related variations in climate as reflectedin the tree-ring record.

Another important contribution to collaboration in dendrochronological research was the development of the International Tree-Ring Data Bank (ITRDB), founded by Hal Fritz (ITRDB; Grissino-Mayer and Fritts 1997). This data archive and computer forum arose when participants at an international meeting in 1974 voiced the need for a repository of tree-ring chronologies so that the work of individual researchers could be passed along and preserved through time (Speer, 2009). Then in 1990, the National Oceanographic and Atmospheric Administration (NOAA) took over the operation of the ITRDB and established the World Data Center – Paleoclimatology A (WDC) program in Boulder, Colorado. The ITRDB now holds over 2,000 chronologies from six continents. The ITRDB, international organizations, meetings, and fieldweeks, continue to foster an international tree-ring community. (Speer, 2009). Over the course of the past century, the application of various methods of dendrochronology have expanded and become important to climatological, hydrological, and ecological research. However, dendrochronology remains a young discipline in the realm of sciences, and there are many exciting frontiers yet to be explored.

2.2 Dendrochronology in the southeastern United States

Bald cypress (*Taxodium distichum, Rich*) is a canopy dominant species in the wetlands of the SEUS and is highly valued for its role in carbon and nutrient sequestration, its provision of habitat and detritus in alluvial floodplain ecosystems, and its role in the timber industry

(Mattoon, 1915; Palta et al., 2012). Tree-ring records from bald cypress—the longest-lived tree species found in wetlands of the southeastern United States—have been shown to provide an important biological archive of historical environmental conditions, because the species responds strongly to hydroclimate variability (Stahle et al., 2012; Therrell et al., 2020). Bald cypress tree-ring chronologies have been used to reconstruct spring rainfall for the past 1,000 years in Georgia, North Carolina, South Carolina, explain between 54% to 68% of each state's spring rainfall variance, and are well verified against independent rainfall measurements. These reconstructions explain only 6% to 13% less statewide rainfall variance than is explained by the same number of instrumental rain gage records (Stahle and Cleaveland, 1992).

Tree ring chronologies of bald cypress have been used to reconstruct hydrologic extremes and streamflow, by connecting growth to both annually resolved hydrological data and climatic influences (Keim and Amos, 2012). Existing bald cypress ring width chronologies extend spatially from the northernmost limit of the species' modern range in southern Delaware to the southernmost limits in southern Florida (Stahle et al., 2012). Ring width chronologies covering over 1,000 years have been constructed through analysis of bald cypress annual growth. Many of these existing bald cypress chronologies include tree-ring data from well preserved "subfossil logs" recovered from surface and submerged deposits (Stahle et al., 2012). These remains of trees buried and preserved in alluvial sediments can extend tree-ring records far beyond the timespan represented by living and recently dead individuals (Stahle et al., 2012).

The work of Stahle and colleagues (2012) suggests that large-scale climate forcing including seasonal climatic anomalies largely explains the residual variability of bald cypress growth, demonstrating the potential for analysis of larger-scale climate patterns and shifts as well as local paleoclimatic reconstructions (Napora et al., 2019). Verifiable reconstructions of March through

June precipitation totals representing 50% to 70% of the instrumentally-recorded rainfall variance have been developed using bald cypress tree-ring chronologies. These rainfall reconstructions are dominated by high interannual variability, but decade-scale fluctuations representing some 10% of the reconstructed rainfall variance are also perceptible. Similar decadal variations are evident in the instrumental March-June rainfall data and are believed to reflect changes in large-scale climatic forcing. However, these reconstructions also suggest that the decade-scale oscillations between comparatively wet and dry periods experienced and instrumentally recorded during the 1900s have been an important aspect of growing season rainfall variability over the southeastern US during the past 1,000 to 1,600 years (e.g., Stahle and Cleaveland 1992; Stahle and Cleaveland, 1996).

Although these decadal oscillations only account for about 10% to 13% of the reconstructed and instrumental rainfall variance, they can result in substantial socioeconomic and environmental impacts. Because large-scale atmospheric circulation patterns can strongly influence seasonal climates of the Southeastern United States, the degree to which decadal variations in atmospheric teleconnection patterns influence growing season rainfall is an important question (Stahle and Cleaveland, 1996). An expanded network of streamflow paleoreconstructions throughout the SEUS is needed to place the impact of climate patterns within the observed record into a long-term context and improve understanding of the effect of largescale climate teleconnections within the region (Sadeghi et al., 2019).

2.3 Bald Cypress and streamflow

Bald cypress ring width has been shown to closely correspond with precipitation, particularly growing season moisture, which explains 50-70% of ring width variability (Stahle et al., 2012). Bald cypress tree-ring chronologies are particularly representative of spring rainfall because stratification of the fine root system just below the mean water level by the gradient in dissolved oxygen accentuates the rainfall sensitivity of swamp-grown bald cypress (Stahle and Cleaveland, 1992). Davidson and colleagues found that $\delta^{18}O$, Cl^-, ^3H and hydraulic head measurements in surface water and shallow groundwater in an oxbow lake-wetland in northern Mississippi show that rapid downward flow of surface water into the root zone is initiated when precipitation-induced increases in surface water depth exceed a threshold value. This rapid flowof surface water through the root zone facilitates nutrient uptake and growth through the introduction of oxygen to sediments that would otherwise be anoxic, and in turn enhances the delivery of oxygenated water to the roots (Davidson, 2006).

Even when rooted in regularly saturated soils where water is not a limiting growth factor, bald cypress has been shown respond to increases in precipitation with increased radial growth and appear to integrate rainfall amounts over both time and space (Davidson, 2006). Studies of bald cypress seedlings and trees have indicated that growth is maximal at intermediate levels of flooding (Palta et al., 2012). Intermittent flooding both increases soil moisture and supplies bald cypress with nutrient-rich sediments beneficial to growth (Palta et al., 2012). Under flooded conditions, oxygen deprivation in the rooting zone is minimized through several physiological mechanisms, including production of adventitious roots and air-filled spaces in the roots. However, these tolerance mechanisms are less effective in preventing root hypoxia when flood duration is too long or flood depths are too great (Palta et al., 2012). Additionally, the riverine habitat of bald cypress is believed to enhance the spring rainfall response, because the water levels in riverine cypress swamps assimilate spring rainfall amounts over very large drainage basins (Stahle and Cleaveland, 1992).

Bald cypress forms annual growth rings with distinct light, thin-walled cells in the earlywood and dark, thick-walled cells in the latewood. Patterns of both interannual ring width and anatomical anomalies aid the visual crossdating process. However, tree growth characteristics such as the presence of wedging or locally absent rings, indistinct ring boundaries, and "false" rings can result in inter- and intra-annual anatomical variability within the samples and make crossdating difficult (Figure 1). Often, a false ring is present in years where tree growth slows due to a reduction in the limiting factor for growth, such as soil moisture availability. If it then rains during the growing season and soil moisture is no longer a growth limiting environmental factor, the tree resumes growth and the cells return to earlywoodstructure with thinner cell walls (Fritts 1976; Speer, 2010). False ring formation has been shown to frequently result from rapid reversals in environmental conditions, such as drought followed by increased rainfall (Therrell et al., 2020).

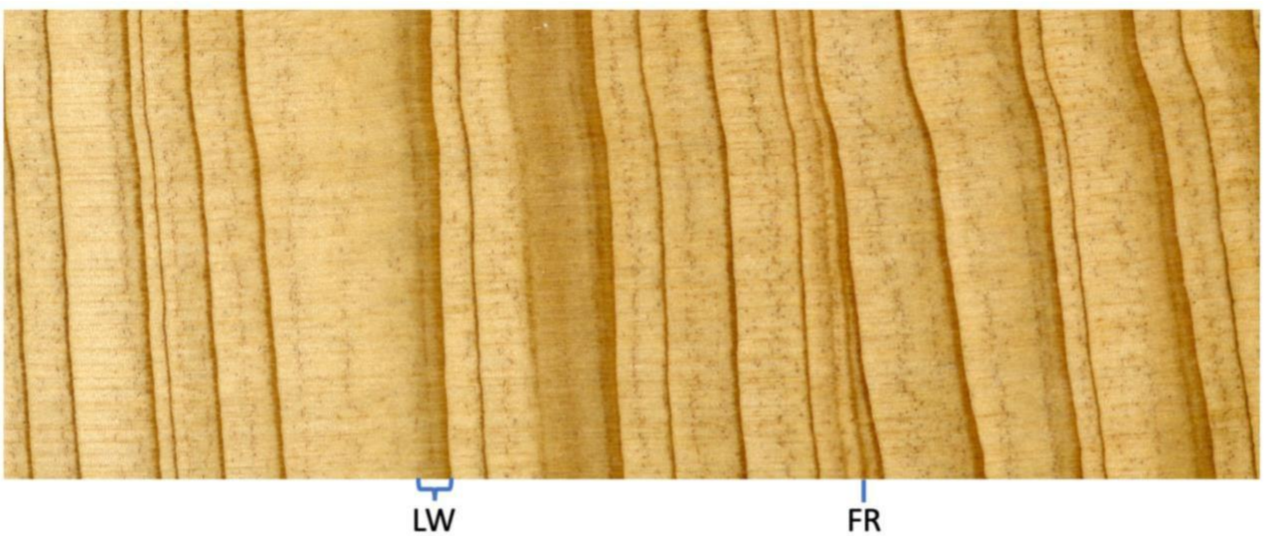

Figure 1. Polished cross-section of *T. distichum* with distinct growth rings showing the light-colored earlywood and darker latewood (LW), including false rings (FR). Narrow rings correspond to years of severe drought.

While the occurrence of false rings in trees is highly variable depending on the growth conditions favorable to each species, they have been well documented in bald cypress (Keim and

Amos, 2012). Young et al. (1993) investigated false ring occurrence in juvenile bald cypress resulting from intermittent inundation stress and found frequent false ring occurrence inbald cypress saplings as compared to mature trees. However, in mature trees, radial growth has been shown to be strongly influenced by streamflow variability rather than inundation stress (Young et al., 1993; Therrell et al., 2020). In the temperate geographic regions home to bald cypress, year-to-year variations in ring widths are typically more critical for accurate crossdating than low- frequency, longer-term trends.

3. MATERIALS AND METHODS

1.1. Study area

Bayou Jessamine is located in Baldwin County, Alabama just west of the town of Stockton, (31° 0’ N, 87° 5” W). Bayou Jessamine lies within the Mobile-Tensaw River Delta (MTRD), between the Tensaw River and Middle River, just south of Richardson Island. The climate of this area is humid subtropical with precipitation averaging around 1,600 mm annually with an October minimum, warm winters with average temperatures of 10°-15°C, and hot summers with average temperatures 24°-30°C. Soils in the area primarily consist of soils of the Levy series (fine, mixed, superactive, acid, thermic typic hydraquents), with poorly drained silt loam or silty clay loam in the surface layer and silty clay below (Aust et al., 2012). The topography of the low gradient, braided river MTRD is typical of a bottomland hardwood forest, and consists of higher natural river levees (i.e., berms, fronts), ridge and swales, and flat backswamps (Aust et al., 2012). Elevation ranges between 10-20 m, with a large portion of the area experiencingprolonged inundation resulting from spring and winter flooding.

Figure 2. Site photos taken during sample collection trip (September, 2019). A; M.D. Therrell taking a cross section sample of a dead bald cypress individual. B; Bald cypress growing in the water and along the banks of Bayou Jessamine.

The Mobile River Watershed is the sixth largest drainage system by area in the nation, covering approximately 65% of the state of Alabama and portions of Georgia, Mississippi, and Tennessee. Freshwater inflows of the Mobile River drain to the Mobile Tensaw River Delta then the Mobile Bay Estuary, the coastal transition zone between the Mobile Bay Watershed and the Gulf of Mexico (Mobilebaynep.com). Containing approximately 43,000 ha of wetlands, 84% of which are forested, the MTRD is Alabama's largest wetland ecosystem and one of the state's most intact preserved areas (Aust et al., 2012). This vast region of wetlands is home to at-risk species and some of the most diverse wildlife in the United States. The MTRD includes sections of Baldwin, Clarke, Mobile, Monroe, and Washington counties in southwestern Alabama.

Portions of the watershed drain the highly developed areas of downtown Mobile and the rapidly urbanizing eastern shore of Baldwin County. The Mobile Bay and MTRD are subject to an unusually large number of factors that may influence or be impacted by streamflow, including the Tennessee-Tombigbee Waterway, the Port of Alabama, commercial fisheries, heavy industry, tourism and recreation, and coastal development. This presents a complex set of challenges concerning both maintaining the area's ecological integrity and improving community resilience to hydroclimatic extremes.

The Mobile River basin is the fourth largest in the United States in terms of streamflow.

The mean annual streamflow of the Mobile River is approximately 1,812 cubic meters per second (m^3/s). The Alabama River Basin contributes 951 m^3/s of streamflow to the Mobile River, and the Tombigbee River Basin contributes 855 m^3/s annually. The Cahaba, Coosa, and Tallapoosa River Basins are major tributaries of the Alabama River, contributing about 71% of the Alabama River Basin's mean annual streamflow. The Black Warrior River Basin is the primary tributary to the Tombigbee River, contributing about 32% of the mean annual streamflow to the Tombigbee River Basin (Mobile River Basin Study).

Upstream reservoirs, flood-control and navigation locks and dams, and hydroelectric plants regulate flow in these major feeder streams. Close to 20 large dams and other water control structures have been built on the Alabama/Coosa/Tallapoosa and the Tombigbee/Black Warrior river systems since 1923 and in the late 1920s a large causeway was built within the MTRD. This dike-like structure has sealed off many naturally open bays from direct contact with the Gulf (Delta Final Report, 2006). These hydrological modifications have altered the seasonal variation and volume of flows and consequently impacted the ecological function of the estuary on both a local and system-wide basis (Delta Final Report, 2006).

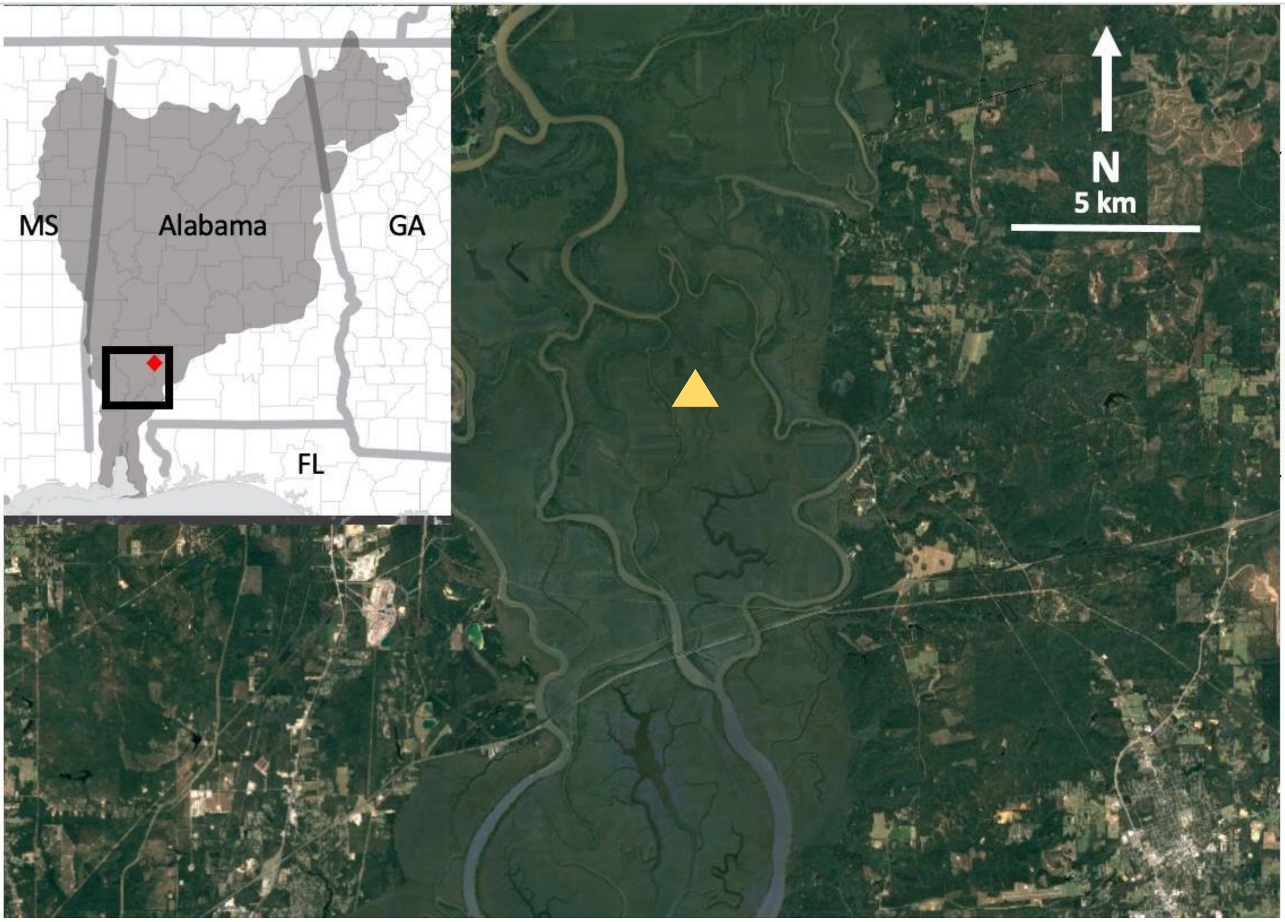

Figure 3. Study Area. Sources of data used in the study include the tree-ring collection site at Bayou Jessamine, indicated by yellow triangle; and the USGS 02428401 Alabama River Gage at Claiborne, AL, indicated by red diamond. Mobile River watershed area shown in grey.

1.2. Data collection and analysis

In September of 2019, personnel from the University of Alabama Dendrochronology Research Laboratory collected 32 increment-core samples from 17 living bald cypress trees and six cross-sections from dead trees along Bayou Jessamine in the MTRD (Figure 3). When possible, multiple cores were extracted from each tree on opposite sides of the trunk with a 5-mm diameter Swedish increment borer. Collecting multiple increment-core samples from each tree aides in crossdating and reduces noise introduced from within-tree variation of ring width (Fritts, 1976). Increment core sampling targeted trees representative of the full range of age classes and topographical positions.

I prepared and processed the increment cores using standard dendrochronological techniques. After samples were dried, I mounted the increment cores, then prepared transverse surfaces of the samples using a WSL Core-Microtome and progressively finer grit sandpaper until cellular structure was visible under a microscope. I assigned exact dates to annual rings through the process of crossdating patterns of relative ring width using the skeleton plot method; a graphical technique emphasizing the narrowest tree rings (Stokes, 1996). I aligned these skeleton plots among individual series in order to identify potential false rings or locally absent rings (Crockett et al., 2010). False rings (or inter-annual density fluctuations) were identified by a thin band of darker and narrower, thick-walled tracheids within a wider annual band of earlywood or earlywood-like cells in the latewood (Copenheaver et al., 2017; Therrell et al., 2020).

I measured the total ring width of individual dated growth rings to 0.001 mm precision using Measure J2X computer software and a Velmex measurement stage (VoorTech Consulting, Holderness, NH, 2007). The accuracy of the sample dating was then cross checked and statistically verified using COFECHA software (Holmes, 1983). COFECHA filters measurement series with a smoothing spline, applies an autoregressive model and log transformation, and computes correlation coefficients for 25-year-lagged, 50-year series segments with a master mean-value chronology, flagging segments that do not meet a critical correlation value and providing correlation coefficients for alternative dating solutions (Meko, 2015). A good strategy to help determine the optimal segment length in cases where measurement series average less than 100 years, is to select a segment length approximately half the average length of all series being tested (Speer, 2010). Individual cores that did not meet the critical correlation value (99%

confidence level (0.3281)) were flagged by COFECHA and then visually inspected for possible dating inaccuracies. After identifying sources of the error, I re-dated and reanalyzed the core with COFECHA. Cores that could not be dated accurately using both graphical and statistical techniques were not used in subsequent analyses (Crockett et al., 2010). Of the nineteen cores (13 trees) retained in the analysis, two “A” flags were assigned to dated segments (BJS10A; 1950-1999 and BJS15A; 1925-1974). One “B” flag was assigned to series BJS06A, indicating that a higher correlation exists for this segment at a different dated position. Each tree-ring series was smoothed using a spline with a 50% frequency response cutoff equal to two-thirds the length of each series (67% spline) (Cook and Peters, 1981).

Table 1. Correlations of 50-year dated segments, lagged 25 years. Flags: A= correlation under the critical correlation 99% confidence level (0.3281) but highest as dated; B = correlation higher at other than dated position.

Series	Timespan	1775-1824	1800-1849	1825-1874	1850-1899	1875-1924	1900-1949	1925-1974	1950-1999	1975-2014
BJS01A	1900-2019						.59	.57	.48	.46
BJS01B	1900-2019						.55	.52	.46	.44
BJS02A	1894-2019					.68	.67	.62	.58	.53
BJS02B	1884-2019					.48	.54	.69	.58	.47
BJS03A	1859-2000				.45	.65	.58	.56	.60	.60
BJS03B	1869-1999				.62	.63	.61	.51	.56	
BJS06A	1865-2019				.18B	.38	.51	.46	.57	.45
BJS10A	1870-1981				.55	.56	.57	.39	.32A	
BJS11A	1904-2019						.47	.58	.48	.47
BJS12A	1872-2019				.50	.55	.57	.55	.58	.44
BJS12C	1920-2019						.58	.60	.72	.58
BJS13A	1901-2019						.56	.43	.60	.45
BJS13B	1899-2019					.54	.52	.62	.68	.56
BJS14B	1907-2019						.57	.60	.47	.35
BJS15A	1890-2015					.55	.46	.26A	.54	.35
BJS20A	1891-1972					.53	.47	.37		
BJS21A	1874- 1986				.59	.61	.62	.49	.39	
BJS22A	1776-1960	.78.74		.72	.62	.63	.72	.66		
BJS22B	1776-1959	.78.77		.73	.63	.68	.72	.74		

3.3 Chronology development

The Dendrochronology Program Library in R (dplR) was used to process and analyze Bayou Jessamine (BJS) ring width data. The chronology was made using the “crn” function, which defaults to building a mean-value chronology by averaging the rows of the rwi data using Tukey’s biweight robust mean (function tbrm in dplR) (Bunn, 2010).

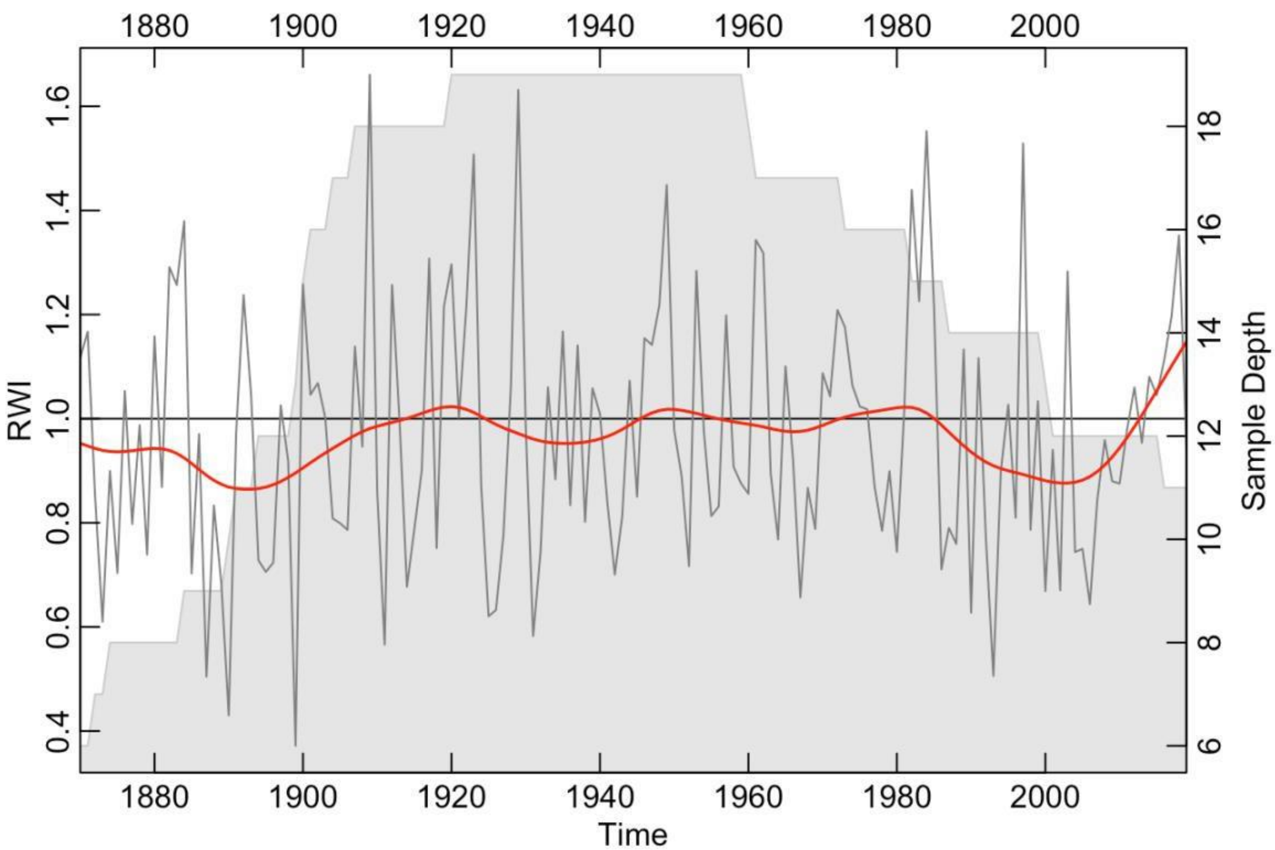

Figure 4. Bayou Jessamine chronology from 1877-2019 with 30-year smoothing spline.

Spline curves are helpful for detrending because they can be fit to virtually any trend found in tree-ring series (Speer, 2010F). Flexible splines of shorter lengths remove a larger amount of the environmental signal contributing to the formation of ring patterns, while a less flexible spline removes less of the low-frequency trends and allows the series to retain more signals (e.g., competition, local disturbances; Grissino-Mayer, 2001). The signal to noise ratio offers an important measure of the amount of desired information recorded in the tree-ring record versus the amount of unwanted random variation coming from environmental factors other than the signal of interest, that may mask crossdating.

The measured ring width for each year is divided by the value predicted from the spline for the same year, resulting in a dimensionless annual index (RWI). Tree-ring series can be highly autocorrelated because persistence in ring widths may carry over from one year to the next (Grissino-Mayer, 2001). Tree growth during an individual year is often affected by the previous year's growing conditions. For example, drought stress from one year may slow growth the following year, while a favorable growing season can allow a tree to build up an excess of carbohydrates, resulting in more growth the following year than it would have otherwise (Fritts, 1976; Crockett, 2010.) This property introduces a low-frequency trend that potentially masks the yearly, high-frequency variation necessary for accurate crossdating (Grissino-Mayer, 2001).

3.4 Streamflow reconstructions

I collected mean instrumental monthly streamflow data from the Claiborne Lock and Dam gage on the Alabama River for the period 1932-2011 from the U.S. Geological Survey (USGS Latitude 31°36'48", Longitude 87°33'02" gage #02428401). The gage at Claiborne lies 24 km northwest of Monroeville, AL and the contributing drainage area is 55,614 km^2. The monitoring location lies along the Alabama River in Monroe County, Alabama. The gage at Claiborne represents one of the longest continuous records of streamflow for the lower Alabama River. The monthly hydrograph at Claiborne, illustrates a unimodal precipitation distribution (Figure 5), with peaks during the months of March and April.

The primary mode of streamflow recharge occurs in March and April in the form of heavy rain associated with cold fronts moving through the region. Throughout the summer months, frequent convective thunderstorms in addition to hurricanes and other tropical storms deliver the primary recharge inputs. The instrumental flow record demonstrates that flood and drought events have occurred sporadically in the Mobile River Basin throughout the past 80 years. The lowest mean annual gage height (3.02 ft) occurred on December 2, 2007 as a result of one of the most extreme droughts during the instrumental period. The maximum monthly gage height reached 56.6 ft on March 25, 1990 as two separate storm systems produced record breaking floods across Alabama, Florida, and Georgia, (Pearman, 1991).

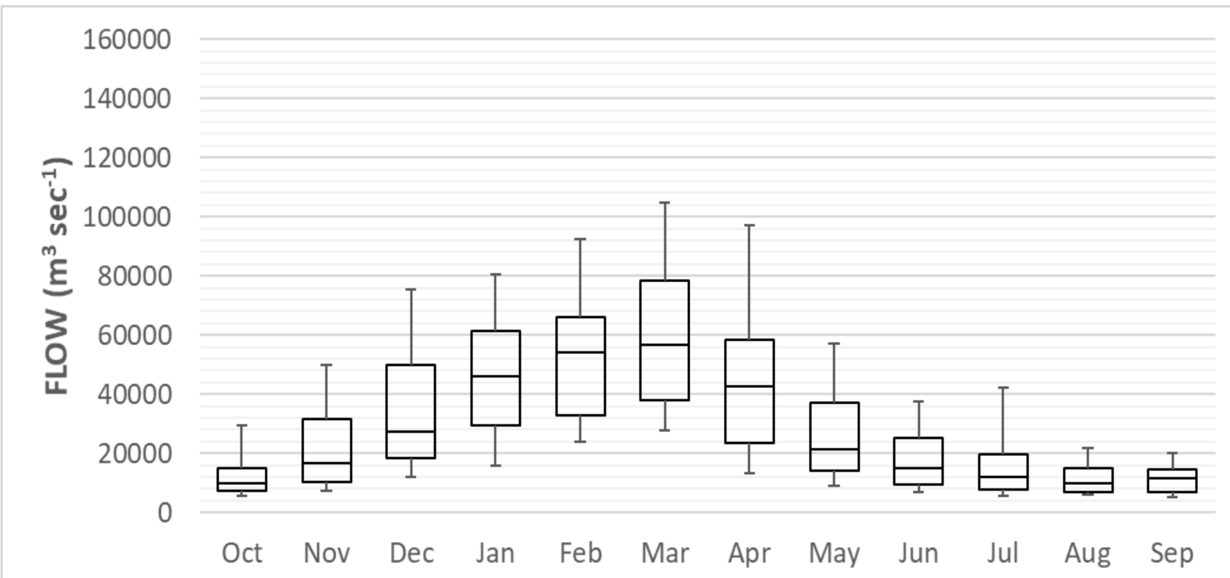

Figure 5. Monthly mean daily streamflow hydrograph of the Alabama River at Claiborne lock and dam gauging record, 1932-2011 ($m^3 sec^{-1}$). The box plots show the median (center line), 25th and 75th percentiles (lower and upper box ends), 10th and 90th percentiles (lower and upper whiskers).

The beginning and end of the water year is typically chosen for a particular region to coincide with normal dry periods in order to minimize the possibility of an anomalous large precipitation event skewing the average annual value (Crockett et al., 2010). I divided water years as starting October 1st and ending September 30th as is done by the USGS. Water years were calculated for the flow data assuming they start on the first day of each month (Crockett et

al., 2010). Streamflow reconstructions were developed following methods described in Harley (2017). We used the program PPR to develop a model of Alabama River by first comparing each tree-ring chronology to monthly discharge records over the instrumental period, using correlation to determine the climatic window captured in the tree-ring chronologies. Monthly, seasonal, and calendar-year averages of discharge (m^3 / s^{-1}) were then correlated with the tree-ring chronologies to determine whether portions of the year or the whole year correlate best withannual tree growth. Results of this analysis indicated the strongest relationship between treegrowth and Alabama River discharge was for the months of May–August, which
aligns with South Alabama's growing season.

Using the gaged flow record from the USGS 02428401 Alabama River at Claiborne lock and dam, I calibrated tree-ring chronologies from the region with the gage record to form the reconstruction model. All tree-ring collections within the area of significant correlation between precipitation and Alabama River discharge were considered as potential contributors to our reconstruction. A total of eight chronologies (Table 2), together covering the period 900–2019 CE, were compiled for the region based on their proximity to the moisture-sensitive footprint, with seven chronologies coming from the ITRDB. We used mean May–August Alabama River discharge (m^3 / s^{-1}) as the dependent variable of a nested principal components regression (PCR) to accommodate the varying temporal length of the chronologies through time (Meko, 1997; Cook et al., 1999, 2002, Harley et al., 2017). Predictors for each nest included the chronologies for the current year, as well as the chronologies lagged by +1 year to include effects that previous year water availability has on current year tree growth (Fritts, 1976, Harley et al., 2017). A principal components analysis (PCA) was conducted on the matrix of predictors to reduce the dimensionality of the tree-ring data for each nest. The first model nest was calibrated for the period 1976–2010 and included all eight chronologies. The following models were calculated in 25-year nest intervals backwards in time, including fewer chronologies as they dropped out. For each nest, principal components variables were added stepwise into the model in order of their explanation of residual variance. After calculating each nest, we merged together flow estimates along with each set of calibration and verification statistics in 25-year steps for the entire reconstruction length (Harley et al., 2017).

The instrumental data from 1976-2010 was split into two periods for calibration (1976–1995) and verification (1995–2010) of the nested PCR models. Calibration models were tested and verified using the reduction of error statistic (RE) and coefficient of efficiency (CE) (Fritts, 1976; Cook et al., 1999; Harley et al., 2017). An RE range from -1 to +1 indicates that the calibration model is more skillful than the mean of the instrumental data during the calibration period. The CE is more difficult to pass (value >0), as it depends on the verification period mean for a baseline of predictive skill. The Akaike Information Criterion (AIC), which includes a penalty term for increasing the number of predictors in the model, was used to determine the final subset of PCs in the regression model. Using PCR, chronology beta weights were calculated in order to evaluate the relative importance of chronologies with regard to explaining flow variability during the period 1976-2010. Because the autocorrelation between the gage record and reconstructed stream flow displays a similar pattern, we are confident that our reconstruction of Alabama River streamflow does not incorporate a substantial amount of non-climatic factors from the tree rings (Harley et al., 2017). After the reconstruction model was validated, I applied the model to the tree-ring data for all available years in order to generate the full reconstruction (Figure 7).

4. RESULTS

We produced a 1,111-year reconstruction of mean May-August Alabama River streamflow during the period 900–2011 CE using six nested PCR models. The full reconstruction model (900-2010) explained 71.9% of variance in May-August Alabama River discharge. For the period 1794-2010, 77% of variance in May-August discharge was explained by the model. 77% of variance was explained in model 2 (1780-2010). 73.2% of variance was explained in model 3 (1540-2010). 72.4% of variance was explained in model 4 (1500-2010). 72.3% of variance was explained in model 5 (1280-2010). Nested PCR models calibrated during the early period (1976–1995) and late period (1995–2010) remained robust through time, and despite the reduction in number of predictor chronologies backward in time, reconstruction power remained high. A total of eight predictor chronologies representing three different species, *Pinus palustris* (n=2), *Quercus lyrata* (n=1) *and Taxodium distichum* (n=5), were retained from the original candidate pool of 129 chronologies and included in the streamflow reconstruction model. The strong beta weights from the included chronologies reconfirm that *Taxodium distichum* and multiple other species found in the SEUS can be utilized to expand tree-ring based hydroclimatic research in this region.

Table 2.
Tree-ring chronologies used in the Alabama River reconstruction. Bold weight font indicates collections not previously published. Chronologies downloaded from the International Tree-Ring Data Bank are noted with regular weight font.

Site Name	State	Species[a]	Period	Latitude (°N)	Longitude (°W)
Bayou Jessamine (RW)	**AL**	**TADI**	**1777-2019**	**31.00**	**87.90**
Choctawhatchee (EW)	FL	TADI	900-2014	30.45	88.02
Choctawhatchee (LW)	FL	TADI	900-2014	30.45	88.02
Choctawhatchee (RW)	FL	TADI	900-2014	30.45	88.02
Lower Peace River (LW)	GA	PIPA	1272-2013	30.72	83.25
Moody Tract (RW)	GA	QULY	1794-2020	31.93	82.32
Ichuway (LW)	GA	PIPA	1497-2017	31.71	81.83
Pascagoula River (RW)	MS	TADI	1466-1992	30.58	88.02

a. TADI = *Taxodium distichum*; PIPA = *Pinus palustris*; QULY = *Quercus lyrata*.
b. Series refers to the number of tree cores in the chronology

Table 3.
Individual chronology correlations with flow. * indicates passing value.

Site Name	Time Period	Pearson	Spearman	Robust Pearson
Bayou Jessamine (RW)	1976-2010	0.560*	0.564*	0.545*
Choctawhatchee (EW)	1976-2010	0.857*	0.829*	0.854
Choctawhatchee (LW)	1976-2010	0.714*	0.713*	0.711
Choctawhatchee (RW)	1976-2010	0.852*	0.833*	0.847*
Lower Peace River (LW)	1976-2010	0.337*	0.347*	0.369*
Moody Tract (RW)	1976-2010	0.581*	0.562*	0.600*
Ichuway (LW)	1976-2010	0.250*	0.242*	0.245*
Pascagoula River (RW)	1976-2010	0.666*	0.603*	0.646*

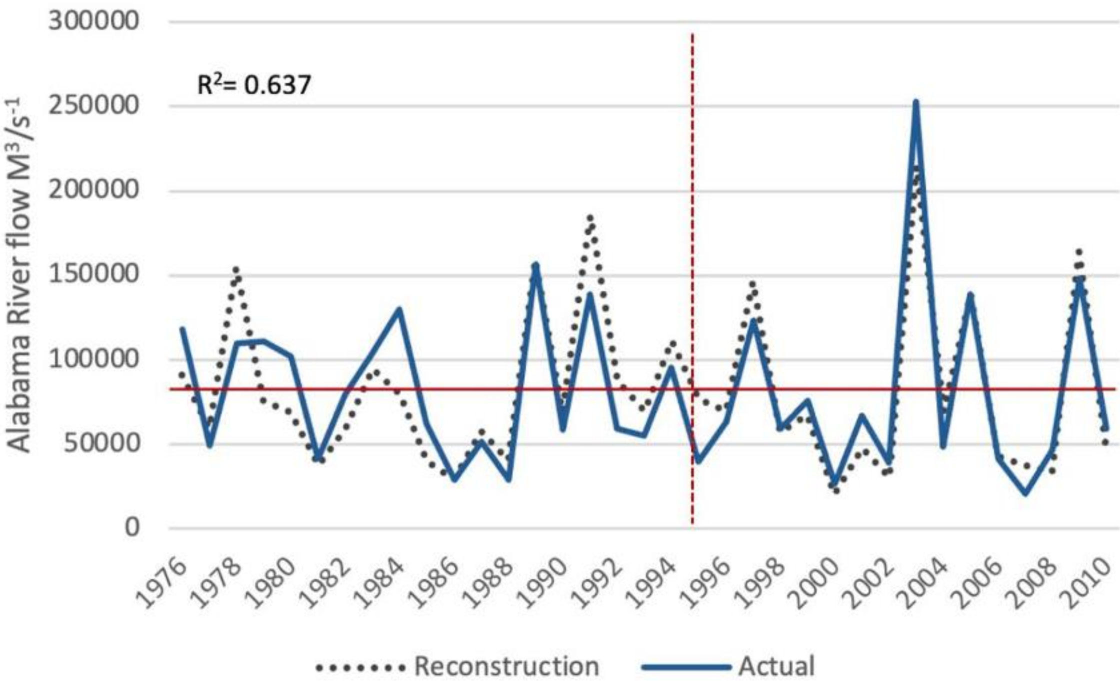

Figure 6. Final reconstruction model (dashed black line) and instrumental data (solid blue line) shown for the period 1976–2010 CE. Dotted vertical line separates the cross calibration (1976–1995) and verification (1995–2010) periods. The solid red horizontal line denotes common period mean discharge (84736.3 M^3/S)

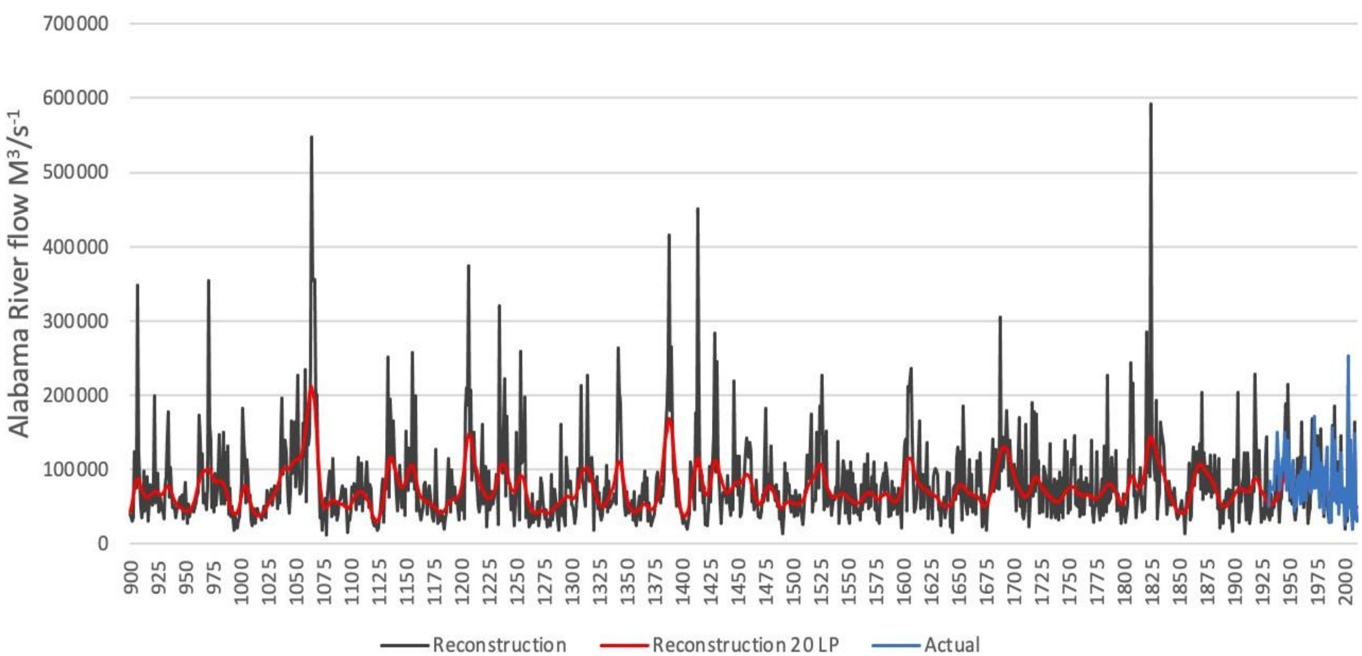

Figure 7. Final reconstruction model (grey line), 20-year low pass filter of reconstruction (red line), and instrumental data (blue line) shown for the period 1600-2011 CE.

5. DISCUSSION AND CONCLUSIONS

1.3. Discussion

In recent history, intense periods of drought have occurred in the gage record, such as in August of 2000, when D4 drought effected 77.9% of the state of Alabama (Figure 6) (https://www.drought.gov/states/alabama). However, low flow events that far surpass instrumental droughts in terms of both severity and duration occurred during the 16^{th} and mid-19^{th} centuries, a finding that aligns with other studies of long-term precipitation and streamflow variability in the SEUS (e.g., Stahle and Cleaveland, 1992; Seager et al., 2009; Harley et al., 2017). It should be noted that our study is not entirely independent, as several of the chronologies included in this analysis are also included in Harley's (2017) research. Our research indicates that instrumental period streamflow conditions of the Alabama River do not sufficiently capture the full range of variability beyond the observational period. This reconstruction puts streamflow discharge during the instrumental period in perspective relative to the past 1,000 years and reveals patterns in hydroclimatic regimes (Figure 7).

Within the observational period, the maximum departure above and below the instrumental-period mean flow (84736.37 m^3/s^{-1}) occurred in 2003 (253012 m^3/s^{-1}) and 2007 (20448 m^3/s^{-1}) respectively. Although the instrumental period contained drastically high and low reconstructed flows, pluvial and drought events that occurred before the instrumental period were longer in duration and more intense than those observed during the past century (Harley et al., 2017). Several multi-year droughts are indicated within the reconstruction, with three extreme periods of drought occurring from 1670-1680, 1840-1860, and from 1885-1900.

Mean flow during the period 1840–1860 was 54312.078 m^3/s^{-1}, which is 64% of mean flow during theinstrumental period (84736 m^3/s^{-1}). These periods of extreme dryness have been identified in several past hydroclimate reconstructions across the SEUS (Stahle et al., 1992; Cleaveland, 2000; Harley et al., 2017; Kam et al. 2020). Additionally, as indicated in the reconstruction data (Figure 8), periods of multi-year pluvial activity are present in the 1600s-1610s, 1680s-1690s, 1820s-1830s, and 1860s-1870s. These findings are consistent with both historical and reconstructed records from southeastern rivers, suggesting the region experienced severe pluvialepisodes during these time periods (Seager et al., 2009; Harley et al., 2017; Kam et al. 2020).

Full understanding of the region's hydrologic parameters in addition to awareness of past pluvial events and droughts is critical when making water policy decisions. Instrumental observations for the streamflow gage at Clairborne began in the 1930s CE, but the statistically skillful reconstructions presented in this study provide insight into streamflow as far back as the 900s CE. Long term information on flow variability is key to addressing concerns amongst water managers, stakeholders, and governments regarding the potential cause(s) of recent streamflow declines across the SEUS (Sadeghi et al., 2019). A recent study of twenty-six unimpaired SEUS streamflow stations identified a decreased pattern of flow over the past ∼25 years with more frequent droughts being observed in the last several decades (Sadeghi et al., 2019). This observed streamflow decline largely correlates with AMO and ENSO climatic drivers and is consistent with recorded streamflow variations across the SEUS. Additional research into the teleconnections and climate drivers impacting this region will be needed to better understand ongoing changes in water availability (Sadeghi et al., 2019).

This research reconfirms the viability of developing moisture-sensitive tree ring chronologies from subtropical locations and using these chronologies to reconstruct streamflow conditions for a region where long-term data do not exist. These chronologies are valuable proxies for water resources and provide critical long-term information on flow variability. Accordingly, reconstruction data should be considered in the development of water conservation practices, water demand modeling, and state-wide policies (Harley, 2017). Future work in this area should aim to update existing site chronologies and develop chronologies from new moisture-sensitive sites in order to spatially and temporally expand the SEUS tree-ring network. We recommend additional paleo-reconstructions of coastal rivers in the SEUS be conducted to provide more insight into historical climate patterns and associated climate drivers in this region (Vines et al., 2021). This expanded network of chronologies and streamflow reconstruction data should then be integrated into management practices and water demand modeling through collaborations with resource managers and policy makers.

5.2 Conclusions and Policy Implications

The Southeastern United States has experienced unprecedented population growth and increased resource demand throughout the past several decades, with water shortages only exacerbated by numerous severe droughts. Drought impacts in the region range from declining aquifers, dry reservoirs, reduced stream flows, and degradation of ecosystems, to increasing interstate conflict and costly litigation processes (Engström et al., 2021). Flash droughts, which typically occur during the summer months as a result of high temperatures in combination with low levels of precipitation are especially concerning for the SEUS, where agriculture and forestry represent substantial parts of the regional economy (Otkin et al., 2018; Engström et al., 2021). Streamflow decline and water shortages over the past several decades initiated two major legal conflicts between Alabama, Florida, and Georgia, known as “the tri-state water wars” (Bearden and Andreen, 2017). One conflict is among Alabama, Florida, and Georgia over the water in the Apalachicola-Chattahoochee-Flint (ACF) system and a second between Alabama and Georgia over the water in the Alabama-Coosa-Tallapoosa (ACT) system. Since 1990, the three states have been engaged in litigation on minimum in-stream flows to maintain ecosystems, fisheries and energy demands while satisfying a growing thirst in metropolitan areas like Atlanta, Georgia (Sadeghi et al., 2019).

A reliable clean water supply is critical to continued economic development in the agricultural, manufacturing, extraction, transportation, and recreational sectors of the SEUS (Engström et al., 2021). Although Alabama's state legislature is resistant to accept the reality of climate change, local and county stakeholders generally place great importance on riparian rights and other issues concerning water availability. A collaborative, science-based regional water resources management plan that could guide economic development, decrease the potential for intra-state conflict, and address potential drought-related scenarios is urgently needed (Engström et al., 2021). The development of such a management plan, including an integrated risk assessment guide, information on past floods, droughts, and changing streamflow, as well as present and future hydroclimatic extremes, is needed to place instrumental flows in a more accurate historical context; and thereby improve environmental risk management and mitigation strategies throughout Alabama and the Southeast.

REFERENCES

Aust, W. M., McKee, S. E., Seiler, J. R., Strahm, B. D., & Schilling, E. B. (2012). Long-term sediment accretion in bottomland hardwoods following timber harvest disturbances in theMobile-Tensaw River Delta, Alabama, USA. *Wetlands*, 32(5), 871-884.

Bearden, B. L., & Andreen, W. L. (2017). Update on the tri-state water wars. *The Wave*, *37*, 15-21.

Bunn, A. G. (2010). Statistical and visual crossdating in R using the dplRlibrary. *Dendrochronologia*, 28(4), 251-258.

Clark, C., Nnaji, G. A., & Huang, W. (2014). Effects of El-Niño and La-Niña sea surfacetemperature anomalies on annual precipitations and streamflow discharges in southeastern United States. *Journal of Coastal Research*, (68), 113-120.

Cleaveland, M. K. (2000). A 963-year reconstruction of summer (JJA) stream flow in the WhiteRiver, Arkansas, USA, from tree-rings. *The Holocene*, *10*(1), 33-41.

Cook, E. R., Meko, D. M., Stahle, D. W., & Cleaveland, M. K. (1999). Drought reconstructionsfor the continental United States. *Journal of Climate*, *12*(4), 1145-1162.

Cook, E. R., Meko, D. M., & Stockton, C. W. (1997). A new assessment of possible solar and lunar forcing of the bidecadal drought rhythm in the western United States. *Journal ofClimate*, *10*(6), 1343-1356.

Cook, E. R., & Peters, K. (1981). The smoothing spline: a new approach to standardizing forestinterior tree-ring width series for dendroclimatic studies.

Copenheaver, C. A., Matiuk, J. D., Nolan, L. J., Franke, M. E., Block, P. R., Reed, W. P., ... &Martini, G. (2017). False Ring Formation in Bald Cypress (Taxodium distichum). *Wetlands*, *37*(6), 1037-1044.

Crockett, K., Martin, J. B., Grissino-Mayer, H. D., Larson, E. R., & Mirti, T. (2010). Assessmentof Tree Rings as a Hydrologic Record in a Humid Subtropical Environment 1. *JAWRA Journal of the American Water Resources Association*, *46*(5), 919-931.

Davidson, G. R., Laine, B. C., Galicki, S. J., & Threlkeld, S. T. (2006). Root-zone hydrology:Why bald cypress in flooded wetlands grow more when it rains. *Tree-Ring Research*, *62*(1), 3-12.

Eckstein, D., Innes, J., Kairiukstis, L., Kocharov, G. E., Nash, T. H., Kincaid, W. B., ... & Ogden, J. (1990). Tree-ring/environment interactions and their assessment. In *Methods of Dendrochronology* (pp. 219-288). Springer, Dordrecht.

Engström, J., Praskievicz, S., Bearden, B., & Moradkhani, H. (2021). Decreasing water resourcesin Southeastern US as observed by the GRACE satellites. *Water Policy*.

Fritts, H. C. (1991). Reconstructing large-scale climatic patterns from tree-ring data: t diagnostic analysis. University of Arizona Press.

Fritts, H.C. (2012). *Tree rings and climate*. Elsevier.

Fritts, H.C. (2001). *Tree Rings and Climate*. Blackburn Press.

Giese, G. L., & Franklin, M. A. (1996). *Magnitude and frequency of low flows in the SuwanneeRiver Water Management District*, *Florida* (Vol. 96, No. 4308). US Department of the Interior, US Geological Survey.

Grissino-Mayer, H. D., & Fritts, H. C. (1997). The International Tree-Ring Data Bank: an enhanced global database serving the global scientific community. *The Holocene*, *7*(2),235-238.

Grissino-Mayer, H. D. (2001). Evaluating crossdating accuracy: a manual and tutorial for thecomputer program COFECHA.

GSA/OGB, www.gsa.state.al.us/gsa/groundwater/waterinfo.

Harley, G. L., Maxwell, J. T., Larson, E., Grissino-Mayer, H. D., Henderson, J., & Huffman, J.(2017). Suwannee River flow variability 1550–2005 CE reconstructed from a multispecies tree-ring network. *Journal of Hydrology*, *544*, 438-451.

Holmes, R. L. (1983). Computer-assisted quality control in tree-ring dating and measurement.

Kam, J.H., Tootle, G.A., Therrell, G.A., Elliott, E.A. (2020). Future Streamflow in a Southeastern US watershed incorporating a Paleo Perspective - St. Marys River, Florida. Journal of Climate, *In Preparation*.

Keim, R. F., & Amos, J. B. (2012). Dendrochronological analysis of baldcypress (Taxodiumdistichum) responses to climate and contrasting flood regimes. *Canadian Journal of Forest Research*, *42*(3), 423-436.

Li, W., Li, L., Fu, R., Deng, Y., & Wang, H. (2011). Changes to the North Atlantic subtropicalhigh and its role in the intensification of summer rainfall variability in the southeastern United States. *Journal of Climate*, *24*(5), 1499-1506.

Mattoon, W. R. (1915). *The southern cypress* (No. 272). US Department of Agriculture.

Margolis, E. Q., Meko, D. M., & Touchan, R. (2011). A tree-ring reconstruction of streamflow inthe Santa Fe River, New Mexico. *Journal of Hydrology*, *397*(1-2), 118-12.

Maxwell, J. T., & Soulé, P. T. (2009). United States drought of 2007: historicalperspectives. *Climate Research*, *38*(2), 95-104.

McCabe, G. J., & Wolock, D. M. (2014). Spatial and temporal patterns in conterminous UnitedStates streamflow characteristics. *Geophysical Research Letters*, *41*(19), 6889-6897.

Meko, D., & Graybill, D. A. (1995). Tree-ring reconstruction of upper Gila River discharge. *JAWRA Journal of the American Water Resources Association*, *31*(4), 605-616.

Meko, D. M., Woodhouse, C. A., Baisan, C. A., Knight, T., Lukas, J. J., Hughes, M. K., & Salzer, M. W. (2007). Medieval drought in the upper Colorado River Basin. *GeophysicalResearch Letters*, *34*(10).

Meko, M. D. (2015). *Tree-ring anatomical variability and flooding near the White River- Mississippi River confluence* (Doctoral dissertation, University of Alabama Libraries).

“Mobile Bay National Estuary Program.” *The Landscape - Mobile Bay National Estuary Program*, http://www.mobilebaynep.com/the_watersheds/tensaw_apalachee_watershed/the_landsca pe.

“Mobile Bay National Estuary Program.” *The Watershed - Mobile Bay National EstuaryProgram*, http://www.mobilebaynep.com/the_landscape/watershed_map/.

Napora, K. G., Cherkinsky, A., Speakman, R. J., Thompson, V. D., Horan, R., & Jacobs, C. (2019). Radiocarbon Pretreatment Comparisons of Bald Cypress (Taxodium Distichum)wood samples from a massive buried deposit on the Georgia Coast, USA. *Radiocarbon*, *61*(6).

Otkin, J. A., Svoboda, M., Hunt, E. D., Ford, T. W., Anderson, M. C., Hain, C., & Basara, J. B.(2018). Flash droughts: A review and assessment of the challenges imposed by rapid- onset droughts in the United States. *Bulletin of the American Meteorological Society*, *99*(5), 911-919.

Palta, M. M., Doyle, T. W., Jackson, C. R., Meyer, J. L., & Sharitz, R. R. (2012). Changes in diameter growth of Taxodium distichum in response to flow alterations in the SavannahRiver. *Wetlands*, *32*(1), 59-71.

Pearman, J. L. (1991). *Floods of February and March 1990 in Alabama, Georgia, and Florida* (Vol. 91, No. 4089). Department of the Interior, US Geological Survey.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sadeghi, S., Tootle, G., Elliott, E., Lakshmi, V., Therrell, M., Kam, J., & Bearden, B. (2019). Atlantic Ocean sea surface temperatures and southeast United States streamflow variability: Associations with the recent multi-decadal decline. *Journal ofHydrology*, *576*, 422-429.

Seager, R., Tzanova, A., & Nakamura, J. (2009). Drought in the southeastern United States: Causes, variability over the last millennium, and the potential for future hydroclimatechange. *Journal of Climate*, *22*(19), 5021-5045.

Speer, J. H. (2010). *Fundamentals of tree-ring research*. University of Arizona Press.

Stahle, D. W., & Cleaveland, M. K. (1992). Reconstruction and analysis of spring rainfall overthe southeastern US for the past 1000 years. *Bulletin of the American Meteorological Society*, *73*(12), 1947-1961.

Stahle, D. W., Burnette, D. J., Villanueva, J., Cerano, J., Fye, F. K., Griffin, R. D., ... & Wolff, K. P. (2012). Tree-ring analysis of ancient baldcypress trees and subfossilwood. *Quaternary Science Reviews*, *34*, 1-15.

Stahle, D. W., & Cleaveland, M. K. (1996). Large-scale climatic influences on baldcypress treegrowth across the southeastern United States. In *Climatic Variations and Forcing Mechanisms of the Last 2000 Years* (pp. 125-140). Springer, Berlin, Heidelberg.

Stokes, M. A. (1996). *An introduction to tree-ring dating*. University of Arizona Press.

Studhalter, R. A. (1956). Early history of crossdating.

Therrell, M. D., Elliott, E. A., Meko, M. D., Bregy, J. C., Tucker, C. S., Harley, G. L., ... & Tootle, G. A. (2020). Streamflow Variability Indicated by False Rings in Bald Cypress(Taxodium distichum (L.) Rich.). *Forests*, *11*(10), 1100.

Therrell, M. D., Kam, J., Tootle., Bearden. B., Elliot, E. *Increasing community resilience in coastal watersheds of Alabama by risk assessment of past, present and future trends in hydrologic and hydroclimatic extremes.* Environmental Protection Agency (EPA) Gulf ofMexico Program Cooperative Agreements 2017 EPA-GM-Cooperative Agreements- 2017-1.

Therrell, M. D., & Bialecki, M. B. (2015). A multi-century tree-ring record of spring flooding on the Mississippi River. *Journal of Hydrology*, *529*, 490-498.

Tootle, G.A., Harley, G., Maxwell, J., Elliot, E., Therrell, M.D., Kam, J. (2018). Paleo- perspectives of streamflow variability for Southeastern Interstate Rivers. *NationalScience Foundation (NSF) Collaborative Research*: NSF P2C2, 2018.

Tootle, G. A., Lakshmi, V., Therrell, M., Huffaker, R., & Elliott, E. A. (2017, December). Multi-decadal decline of Southeast United States streamflow. In *AGU Fall Meeting Abstracts* (Vol. 2017, pp. H21F-1547).

U.S. Geological Survey. National Water Information System Data Available on the World WideWeb (USGS Water Data for the Nation). 2016. Available online: http://waterdata.usgs.gov/nwis//inventory/?site_no=2428401 (accessed on 10 February 2021).

Vines, M., Tootle, G., Terry, L., Elliott, E., Corbin, J., Harley, G. L., ... & Therrell, M. (2021). A Paleo Perspective of Alabama and Florida (USA) Interstate Streamflow. *Water*, *13*(5), 657.

Wang, H., Kumar, A., Wang, W., & Jha, B. (2012). US summer precipitation and temperaturepatterns following the peak phase of El Niño. *Journal of Climate*, *25*(20), 7204-7215.

Woodhouse, C. A., Gray, S. T., & Meko, D. M. (2006). Updated streamflow reconstructions forthe Upper Colorado River basin. *Water Resources Research*, *42*(5).

Young, P. J., Megonigal, J. P., Sharitz, R. R., & Day, F. P. (1993). False ring formation in baldcypress (Taxodium distichum) saplings under two flooding regimes. *Wetlands*, *13*(4),293-298.