12-2023

Tree-Ring Reconstruction of Ouachita River Streamflow

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Tree-Ring Reconstruction of Ouachita River Streamflow

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Geology

by

Keaton Cade Jenkins-Joyce
University of Arkansas
Bachelor of Science in Geology, 2018

December 2023
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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Abstract

The Ouachita River drains the Ouachita Mountains and Upper Coastal Plain in Arkansas and Louisiana. The Ouachita River is used for navigation, power generation, recreation, water supply, and wastewater treatment. The river has been prone to low flows during drought and extreme flooding, which were principal justifications for the construction of three large multipurpose dams on the stream. It is likely that the use of the Ouachita River will be stressed by future population growth, economic expansion, and climate change. For this study, tree-ring chronologies from various locations in and near the Ouachita River drainage basin were used to reconstruct instrumental measurements of water year (October-September) and summer discharge (June-August) for the past 253- to 352-years, respectively. These reconstructions provide an extended long-term perspective on drought, periods of surplus water, and the potential modifications of Ouachita River streamflow due to reservoir management.

The construction of the Blakely Mountain Dam and the impoundment of Lake Ouachita may constitute the largest anthropogenic impact to the river. Dam construction began in 1947 and Lake Ouachita was completely filled by 1952. The reconstructions of June-August discharge, when compared with the instrumental measurements of summer low flows, suggests that the regulation of the Blakely Mountain Dam has not strongly impacted the summer high and low flow extremes recorded at the Camden streamflow gauge. Additionally, no major changes in water year extremes were detected that might be related to reservoir management. Water year and summer discharge have both increased in the late 20th and early 21st century, which may be part of a trend toward increased precipitation over the eastern United States recorded in instrumental observations and proxy precipitation reconstructions.
Keywords: Ouachita River, discharge, tree-ring chronology, streamflow reconstruction

Acknowledgement

I would like to thank all the people who have provided crucial support to me during this time of finishing up Graduate School along with my thesis. Without the support of my peers, my professors, along with my friends and family, my thesis would not have been completed. I would like to thank my committee members for being there for me during this time, offering support and help, and for providing their guidance to me. I would also like to give thanks to Ian Howard, Max Torbenson, and Dorian Brunette for their assistance and support on my thesis. Finally, I would like to especially thank Dr. Stahle for being as available as he could for me during COVID, along with believing in me when I did not and providing so much support to me, not only for my thesis, but to me personally as well.

I also need to extend my thanks to my friends and family for their support and faith in me completing my thesis. Their support and confidence in me was such a stable force that helped motivate me and push me to completion.

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Chapter 1: Introduction

1.1 The Question

The objective of this research project is to use proxy tree-ring data to reconstruct the history of the changing water levels in the Ouachita River, Arkansas. Existing tree-ring chronologies previously developed by the University of Arkansas Tree-Ring Laboratory will be used in this research to help accomplish that goal. The existing tree-ring data are expected to be well correlated with seasonal precipitation and evapotranspiration in the study area. These climate variables also influence water runoff into rivers. Therefore, the tree-ring data are expected to be correlated with water level variation in the river. In short, rainfall has a direct influence on both stream flow and tree growth, meaning that tree growth and streamflow are also correlated.

This research project has addressed two main questions:

1. Is it possible to develop skillful tree-ring reconstructions of water year to seasonal discharge for the Ouachita River stream gauge at Camden, Arkansas?
2. Has the construction of the Blakely Mountain Dam or other impoundments had a major impact on Ouachita River discharge?

1.2 Importance

The goal of this project is to provide a detailed history of changing discharge in the Ouachita River over the past 250- to 350-years. The extended streamflow reconstruction will be a useful contribution to water resource and wildlife management and may provide insights for reservoir management purposes. This project will document drought and wet episodes in the recent past and may also help determine whether river discharge has been impacted by reservoir development.

1.3 How We Did What We Did

This project has utilized existing tree-ring chronologies that were previously developed by the University of Arkansas Tree-Ring Laboratory for the Ouachita River basin study area. The instrumental record of the Ouachita River flow was obtained from the United States Geological Survey (USGS) stream gauge measurements at four stations along the river. The longest USGS record of monthly discharge has been recorded at Camden, Arkansas, and was used in this analysis. Utilizing the existing tree-ring chronologies along with the instrumental stream gauge data, statistical methods were then used to calculate estimates of water year and summer discharge for the Ouachita River for the past 250- to 350- years. The reconstructions provide a more detailed history of changes in water year to seasonal discharge in the Ouachita River. The reconstructions were also used to help determine if the Blakely Mountain Dam and other impoundments have had large impacts on the variability of seasonal to water year flow in the natural flow of the Ouachita River at Camden.

Chapter 2: Literature Review

2.1 Tree-Ring Reconstructions of Streamflow

Moisture variations can have a direct influence on both streamflow and tree growth, which means tree growth and streamflow are indirectly correlated. In developing moisture sensitive tree-ring chronologies, dendrochronologists are able to reconstruct certain hydrologic conditions for centuries prior to the instrumental era. With this information, dendrochronologists can then reconstruct the “dates for the occurrence of such hydrologic events as floods, droughts, and fluctuations of glaciers” (Stockton, 1975). Meko et al. (2007) were able to reconstruct droughts during the Medieval Climatic Anomaly in the Upper Colorado River Basin through the use of hydrologic data extracted from tree-rings. Dendrochronologists can also create “a paleoclimatic record that may be useful for extending hydrologic records or estimating trends and variability of precipitation and streamflow records” (Stockton, 1975). These paleoclimatic records or “reconstructions of streamflow”, “that are derived from moisture-sensitive trees extend, in both time and magnitude, the variability provided by relatively short gauge records” (Woodhouse et al., 2006).

The chronologies, that are created from moisture-sensitive trees and are used to make reconstructions of streamflow, are statistically calibrated with the instrumental discharge data. The reconstructions of streamflow are then compared with other instrumental or documentary observations of flow to confirm the accuracy of the reconstructed values. This “verification” process is necessary to demonstrate the correlation between the two sets of data to ensure that the hydrologic estimates from the tree-rings are an accurate reflection of the measured hydrologic data. Stockton and Jacoby (1976) reconstructed the annual runoff of the Colorado River at Lee Ferry with two different sets of gauging data along with two sets of semiarid tree-ring chronologies. They were able to calibrate 78% and 87% of the Colorado River's runoff variance with their semiarid tree-ring chronologies (Stockton et al., 1976). The two reconstructions were then averaged, and thus indicated that the relatively short gauging data did not accurately represent the long-term variations in the mean flow (Stockton et al., 1976). Woodhouse et al. (2006) created multi-century reconstructions of streamflow for the Upper Colorado River and the South Platte River located in Colorado. They concluded that their reconstructions were able to explain 63% to 76% of the variance in the stream gauge records (Woodhouse et al., 2006). They also found that the analyses of their reconstructions indicate that the 20th century gauge record does not fully represent the range of streamflow characteristics seen in the prior two to five centuries (Woodhouse et al., 2006). Cleaveland and Stahle (1989) reconstructed streamflow of the White River, Arkansas, from tree-ring chronologies in the drainage basin to analyze the history of surplus and deficit flows. They compared the tree-rings data with the data they retrieved to gauged measurements taken from the White River at Clarendon, both during the calibration period of 1930-1980 and the validation period of 1900-1929 (Cleaveland et al., 1989). Cleaveland and Stahle (1989) found that long periods without surplus flow occurred before the instrumental period. They were able to conclude that the gauge data were not fully representative of long-term hydrologic regimes of the White River at Clarendon, Arkansas (Cleaveland et al., 1989).

With a deeper understanding of what happened in the past, scientists are then able to monitor and predict what could happen in the future based on what has been observed through time. The management of water resources depends on the understanding of the natural variability in streamflow over numerous time scales, which is why the extension of the hydrologic record is so important. One of the driving factors behind Woodhouse et al.'s (2006) study for creating multi-century reconstructions of streamflow for the Upper Colorado River and the South Platte River in Colorado was for water resource planning. Recent severe drought conditions have motivated water resource managers in Colorado to use tree-ring reconstructions of streamflow in water resource planning. Woodhouse et al.'s (2006) reconstructions of streamflow were input into water system models to assess the reliability of Colorado's water supply systems under a much broader range of conditions that the gauge record could not provide. Harley et al. (2017) reconstructed the flow variability of the Suwannee River, Florida, from the use of tree-ring data and gauge records. The hydrologic records and results they produced were given to water resource managers, so that they could have a more comprehensive view of the flow history of the river to accurately model the water flow of the Suwannee River for the future (Harley et al., 2017).

Dendrochronologists are also able to discern anthropogenic impacts by comparing climate or streamflow during modern times with reconstructed climate during pre-settlement conditions. Stahle et al. (2001) observed how an anthropogenic impact, reservoir storage and the export of freshwater for human purposes, was changing the salinity levels in the water of San Francisco Bay through the use of tree-rings. Cleaveland (2000) was able to identify numerous instances of anthropogenic impacts on the White River's flow in his 963-year reconstruction of streamflow. He found that "the twentieth century is over-represented in short spans of consecutive above- and below-median summer flows", which "suggests that human modification of the watershed may be responsible for the anomalous twentieth-century low-flow hydrology of the White River" (Cleaveland, 2000). He then argued that these changes tend to reduce infiltration and speed up overland flow of runoff, increasing the frequency of small floods, which causes low flows to worsen by reducing the baseflow of the river (Cleaveland, 2000).

2.2 Climatic Variability

Natural and anthropogenic changes in climate may also impact streamflow reconstructions created from moisture sensitive tree-ring chronologies. This is why tree-ring data have been used to reconstruct long-term natural changes in climate and also anthropogenic impacts on climate change. It has been suggested that anthropogenic changes could impact the high-frequency characteristics of hydrologic time series, while climate tends to dominate the lower-frequency characteristics, such as extreme floods and presumably extreme low flows (Cleaveland, 2000). Stahle et al. (2020) found that there are significant 200- to 500-year trends toward increased precipitation over the eastern United States. These trends have been detected in both their cool and warm season reconstructions that were made from 439 tree-ring chronologies correlated with December through April totals and 547 different chronologies correlated with May through July totals (Stahle et al., 2020). Stahle et al. concluded that these seasonal precipitation changes appear to be part of the overall positive moisture trend for both the cool and warm season that has been recorded in other paleoclimate proxies (Stahle et al., 2020). They believe that the positive moisture trend is a result of not only natural forcing prior to the industrial revolution, but also a result of the recent enhancement by anthropogenic climate change (Stahle et al., 2020).

2.3 Dendro Tools Software

Historical Observations Tools (HOB Tools, Burnette and Stahle, 2013) and Dendro Tools (Burnette, 2021, personal communication) are collections of specialized computer programs that were created by Dr. Dorian J. Burnette for the processing and analysis of historical meteorological data and tree-ring data. The Dendro Tools software is available at the djburnette.com web site and is particularly valuable for reconstructing and analyzing past climate and streamflow from tree-rings. Dendro Tools software is written in a combination of Visual Basic.NET and R, with the main interface in Visual Basic.NET (Burnette, n.d.). Dendro Tools takes prewritten R script files, facilitates editing, runs R in the background, ingests the output from R, and displays it all in a user-friendly interface (Burnette, n.d.). Dendro Tools contains three main groups of tools that can be utilized by the user. The first group concerns dataset management and includes tools that check data for gaps and to estimate missing values for datasets. Dendro Tools can extract data from both the Global Historical Climatology Network and the United States Historical Climatology Network, transform monthly data available from various sources, compute averages and totals, and compute adjusted latewood chronologies using simple linear and robust regression (Burnette, n.d.). The second group of tools perform statistical analyses, from basic descriptive statistics to double mass analysis, contingency table analysis, linear regression, multiple linear regression, principal components analysis, and principal components regression modeling (Burnette, n.d.). Lastly, Dendro Tools can perform a selection of time series analyses, including tools that compute cublic smoothing splines and return time analysis (Burnette, n.d.). The Dendro Tools software was used to compute and analyze the tree-ring reconstructions for two different seasons of Ouachita River streamflow reported in this thesis.

2.4 Principal Components Analysis and Regression

Principal component analysis (PCA) is performed on the correlation (or co-variance) matrix computed on a set of variables such as several cross-correlated tree-ring chronologies from a given region (e.g., the Ouachita River basin) for a period of time in common to all chronologies. In this case, for example, PCA was computed on twelve tree-ring chronologies from the Ouachita River basin for the common time period of 1779-1980 as an initial step in the reconstruction of water year discharge. PCA is defined as “a mathematical algorithm that reduces the dimensionality of the data while retaining most of the variation in the data set” (Ringnér, 2008). By identifying directions, known as principal components, the modes of variation in the data are maximized to accomplish this reduction (Ringnér, 2008). By using just a few components, the large variation in the original variable set can be represented by fewer variables (Ringnér, 2008).

The data reduction power of PCA is valuable for regression modeling because it can simplify the models and reduce potential for spurious co-linearity among the predictor variables included in regression models. Enright (1984) noted the success of Peters, Jacoby, and Cook’s use of principal components analysis in their study and creation of a 225-year tree-ring chronology for the Yukon area (Peters et al., 1981; Jacoby et al., 1981). “Peters et al. (1981), found that using the principal components analysis for constructing the chronology resulted in similar results to using the standard tree-ring analytical methodology for constructing the same chronology”, along with the fact that using PCA produced not only a better summary of the ring width data, but also a better “climate correlation” (Enright, 1984). Enright (1984) also states that this comparison between the two different methods of principal components analysis and the standard tree-ring analytical methodology producing similar results was noted by both Fritts (1976) and Graybill (1979). The principal component scores, which are time series output from PCA for each component or mode of variability, can then be used as independent variables in a principal component regression for the reconstruction of climate or streamflow.

Fritts et al. (1971) were among the first to introduce principal components regression (PCR) to dendroclimatology in their study of “Multivariate techniques for specifying tree growth and climate relationships and for reconstructing anomalies in paleoclimate”. The idea of principal component regression is to replace the predictors, also known as the individual proxies or in this case the individual tree-ring chronologies, with fewer objectively determined variables that are linear combinations of the original proxies (National Research Council, 2007). The newly created variables are then designed to contain as much information as possible from the original proxies (National Research Council, 2007). By using uncorrelated variables, the principal components, problems that are due to variable intercorrelation (co-linearity) can thus be circumvented by this transformation of the predictor variable into a new set of variables (Fritts, 1976). In running a PCR analysis, the transformation ranks the new variable in order of their importance, which thus allows for the selection of the most significant variables (Fritts, 1976).

Chapter 3: Study Area

3.1 Geological Setting & Physical Geography

The Ouachita River begins in the Ouachita Mountains initially as a mountain stream, located just west of Eagleton, Arkansas in Polk County. The river then flows in a southeasterly direction through 11 counties in Arkansas and 6 parishes in Louisiana. The Ouachita River then empties into the Red River, which is located 35 miles above the confluence of both the Red River and the Mississippi River. In total the Ouachita River runs a length of 605 miles and drains in an area of about 24,790 square miles.

The Ouachita Mountains Region of Arkansas is comprised of folded and faulted Paleozoic age sedimentary rocks that were originally deposited, mostly, in deep marine environments. The southern Gulf Coastal Plains Region of Arkansas is dominated by both Tertiary marginal marine deposits and coastal plain continental deposits, along with a layer of both Quaternary terrace and alluvial deposits. The Ouachita River flows through the Ouachita Mountains Region's Paleozoic age sedimentary rocks, through the Gulf Coastal Plains Region's Quaternary age alluvium, and continues into Louisiana's Holocene aged alluvium.

3.2 Other Tributaries and Reservoirs in the Ouachita River Basin

The drainage basin of the Ouachita River, which is approximately 25,000 square miles, lies within the upper Coastal Plain of Arkansas and Louisiana. A few of the chief tributaries for the river include the Saline River from the north in Arkansas, the Boeuf River, Bayou Bartholomew River, and Tensas River that both enter from the east. Another chief tributary would include the Caddo River that is located near Arkadelphia, Arkansas, and Little Missouri River that joins the Ouachita River downstream. South of the Saline River, the Ouachita River flows into Lake Jack Lee, which is part of the Felsenthal National Wildlife Refuge (FNWR) in Felsenthal, Arkansas. Below the Felsenthal Dam the Ouachita River continues to flow into Louisiana. In Louisiana, as the Ouachita flows beyond the Tensas River, it is no longer referred to as the Ouachita River, but as the Black River. As the Black River, the Ouachita continues to flow through the Catahoula Parish and Concordia Parish, where the Ouachita then merges with the Red River.

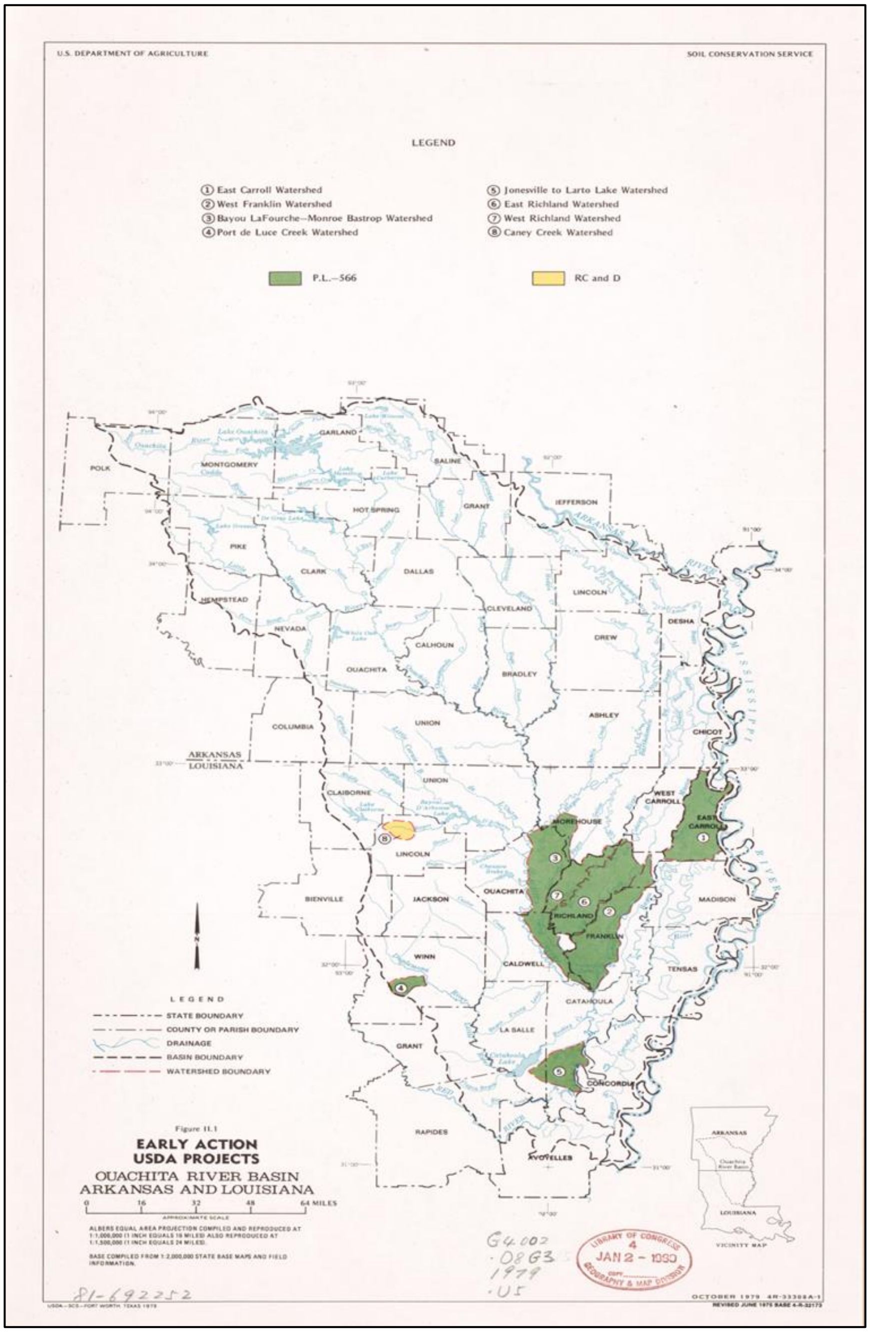


Figure 3.1: Image of the Ouachita River Basin (USDA-SCS, 1979). The green polygons represent areas that are under the Watershed Protection and Flood Prevention Act, while the yellow polygon represents an area that is under the Resource Conservation & Development Program.

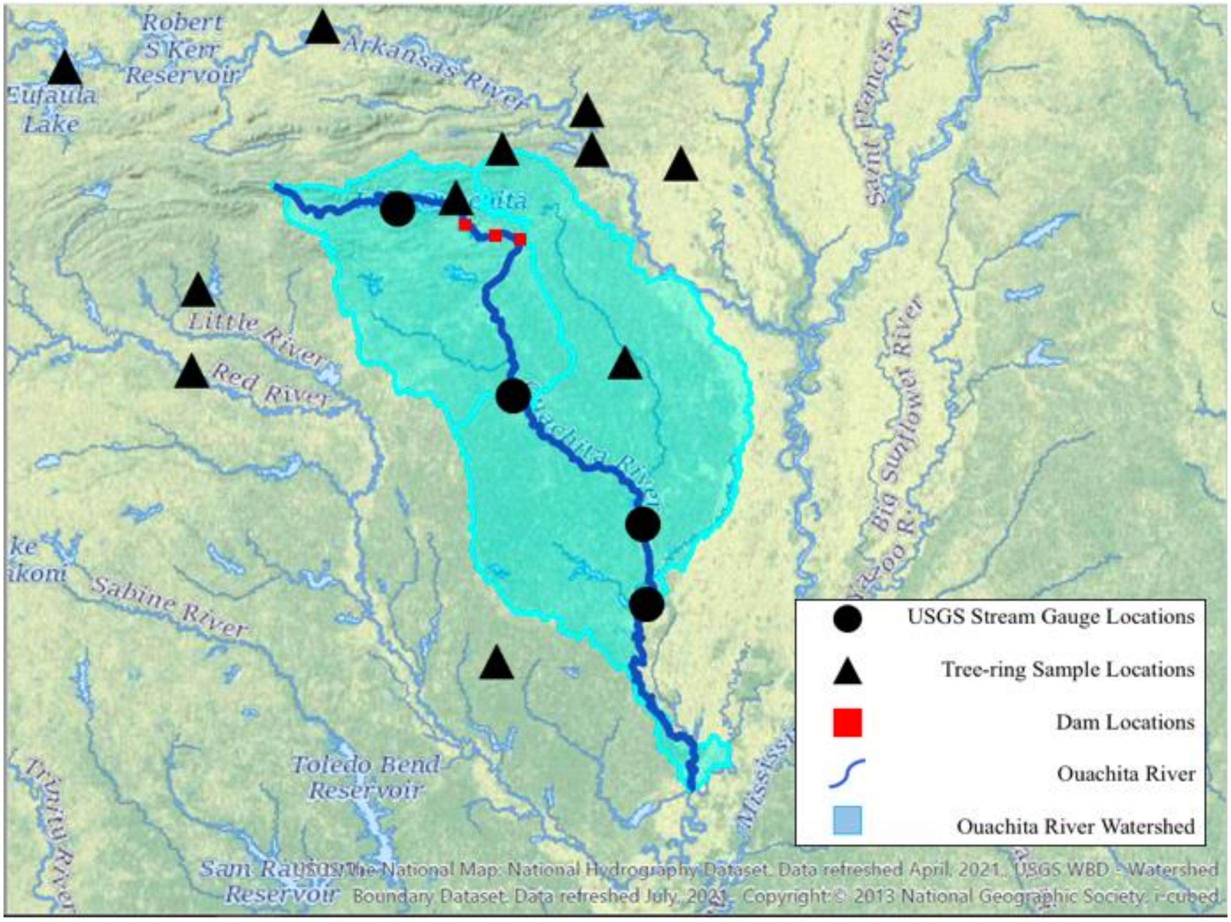


Figure 3.2: Image of the Ouachita River. The black circles represent areas where the USGS stream gauges are located, the black triangles represent areas where the tree-rings used in the study were sampled, while the red squares represent the areas where the three dams impound the Ouachita River. The light blue shaded area represents the Ouachita River watershed, while the dark blue line represents the Ouachita River.

3.3 History of the Ouachita River

The meaning of the word “Washita” (“Ouachita”) is “good hunting grounds”, which is why various Native American tribes lived along the river (USFS, 1937). Some of the Native American tribes that called the river home, were the Osage, the Quapaw, and the Caddo tribes

(Berry, 2003; Sloan, 1992). The earliest known historical accounts of the Ouachita River and the Native Americans that lived along it, came from the Hernando de Soto expedition of the 1530's (Sloan, 1992). The Hunter-Dunbar expedition was one of the first scientific explorations of the Ouachita River region. President Thomas Jefferson commissioned and sent George Hunter along with William Dunbar to explore the newly acquired Louisiana Purchase territory of 1803. The expedition began on October 6th, 1804, and concluded on January 27th, 1805 (Berry, 2003). The expedition covered a total of 450 miles from the mouth of the Ouachita River to Hot Springs, Arkansas (Berry, 2003). The expedition resulted in some of the earliest scientific studies conducted on the Ouachita River and offered an environmental description of both Arkansas and Louisiana. Hunter and Dunbar also provided observations of various plant and animal species found along the Ouachita, as well as various cultural groups (e.g., the Caddo, Quapaw, and Osage; Berry, 2003; Sloan, 1992). A French trader named LeFevre provided detailed accounts of the "place names, river sources, and adjacent regions, as well as European/Indian relations" in his journal (Berry, 2003). French traders had lived along the Ouachita River prior to the Louisiana Purchase and had already established various settlements along the river (Berry, 2003; Sloan, 1992). Those French settlements would later become cities in both Arkansas and Louisiana, like the Ecore a Fabri settlement which would become the city of Camden in Arkansas, and the Prairie de Canots settlement which would become the city of Monroe in Louisiana (Berry, 2003). With this population of French inhabitants, it resulted in the evolution of the word "Washita" into "Ouachita", as "Ouachita" comes from the French way of spelling the sound of the Native American word "Washita" (USFS, 1937).

3.4 Navigation

The Ouachita River has been a navigation route since the late 18th century (Britannica Academic, n.d.). In 1819 the steamboat traveled up the river, and this trend of steamboat travel played an integral part in the history of the Ouachita River (Gore, 2014). From 1819-1910, the Ouachita River was a great highway of commerce and transportation for the entire river valley in Arkansas, but the development of railroads led to the decline in river traffic (Gore, 2014). Moderate barge traffic continues today on the Ouachita River, carrying cargo like ammonia and crushed rocks (Gore, 2014).

There are a total of six lock and dams that were built on the Ouachita River prior to 1924 (U.S. Army Corps of Engineers, n.d.). In the later years after 1924, some of the locks were replaced and decommissioned. There are now currently four locks and dams on the Ouachita River (U.S. Army Corps of Engineers, n.d.; Figure 3.2 only shows 3). Each of the locks, have lock chambers that are 84 feet wide and 600 feet in length, and have from three to five tainter gates (U.S. Army Corps of Engineers, n.d.). The locks and dams also have a lift from 12 feet to 30 feet, a minimum depth of 9 feet, and a 100 foot wide navigation channel (U.S. Army Corps of Engineers, n.d.). This then allows for the accommodation of barge traffic from the Red River north to Camden, Arkansas (U.S. Army Corps of Engineers, n.d.).

Figure 3.3: Photo of Columbia Lock and Dam located in Columbia, Louisiana (Image from KNOE 8 News).

3.5: The Camden Gauge

The selected stream gauge site at Camden, Arkansas, is maintained, and currently operated, by the USGS Arkansas Water Science Center. On August 8, 1928, the Geological Survey established this gauging station by installing a chain gauge at the present site and datum (NAD83). The site was continued from September of 1929 to December of 1929. In December of 1929, the U.S. Army Corps of Engineers of the Vicksburg District, reestablished and maintained the gauging station until September 30th, 1979. The U.S. Army Corps of Engineers installed a wire-weight gauge, a staff gauge, continuous recording gauge, an auxiliary water-stage recorder, and a data collection platform with a rainfall recorder downstream of the present datum. On October 1st, 1979, the Geological Survey started maintaining the gauge, making discharge measurements, and computing daily discharge. The Geological Survey installed a new auxiliary gauge (water-stage recorder and wire-weight gauge) about 300 feet downstream from the old site, on the intake structure of Arkansas Electric Co-Op Corporation plant on the same bank at the present datum. The index velocity meter was removed in 2018 and the site transitioned to stage and discharge.

3.6 Large Dams on the Ouachita River

Arkansas has been impacted by floods throughout the state's history with some of the more damaging floods occurring in the years 1927 and 1937 (American National Red Cross, 1929; American National Red Cross et al., 1938). To combat flooding, Congress passed the Flood Control Act in 1917, later the Flood Control Act of 1923, and then the Flood Control Act of 1928 (Pearcy, 2000). As a result of the Flood Control Acts, various dams were constructed on rivers throughout Arkansas to mitigate this hazard. Some of those dams were constructed on the Ouachita River, which has a total of three multipurpose dams located in the upper portion of the river within the Ouachita Mountains area. The purposes of the three dams, other than flood control, include being used for hydroelectric power and as places that facilitate recreational activities such as fishing, boating, and other activities. Those three multipurpose dams that impound the Ouachita River are the Remmel Dam, the Carpenter Dam, and the Blakely Mountain Dam.

The company, Arkansas Power & Light (AP & L), now known as Entergy, was the first to construct a dam on the Ouachita River for hydroelectrical power production (Wilson, 1986). Construction of the dam started in May of 1923 and began operation in December of 1924 (Wilson, 1986). The Remmel Dam is located at Jones Mill, which is in Hot Springs County, Arkansas. The Remmel Dam impounds Lake Catherine, which produces hydroelectric power alongside the Entergy operated Remmel Dam (Wilson, 1986). Entergy retains a minimum flow of 200 to 400 CFS for Remmel Dam continuously under their FERC license (Entergy, n.d.).

FERC is the Federal Energy Regulatory Commission, which is a "federal agency that grants authority to private interests to dam public waterways and use those impoundments for hydroelectric generation" (Entergy, n.d.). The flow requirements for the Remmel Dam vary per month under Entergy's FERC license. The monthly flow requirement for January and February is 300 CFS, for March it is 400 CFS, for April it is 350 CFS, for May and December it is 250 CFS, and for June through November it is 200 CFS (Entergy, n.d.). The drainage area of the Ouachita River at the Remmel Dam is about 1,516 squared miles and the total storage capacity of Lake Catherine is only 35,370 acre feet. It is unlikely that Lake Catherine has a significant effect on peak flows at the Camden stream gauge, but power generation regulates normal flow.

Figure 3.4: Photo of the Remmel Dam located at Magnet Township, Arkansas (Image from the Arkansas Historic Preservation Program).

The Carpenter Dam is Entergy's second dam on the Ouachita River (Wilson, 1986). Construction began in February of 1929 and commenced operation in 1931 (Wilson, 1986). The Carpenter Dam is located closely to Hot Springs in Garland County in Arkansas. The dam also impounds Lake Hamilton, which is another Entergy lake that was created by the construction of the Carpenter Dam (Wilson, 1986). Entergy manages both the lake and the dam for hydroelectric power (Wilson, 1986). Since Entergy manages this dam, it also retains a certain minimum flow for the Carpenter Dam under their FERC license (Entergy, n.d.). The drainage area of the Ouachita River at the Carpenter Dam is about 1,441 squared miles. The total storage capacity of Lake Hamilton is only 190,100 acre feet. It is, again, unlikely that Lake Hamilton has a significant effect on peak flows at the Camden stream gauge.

Figure 3.5: Photo of the Carpenter Dam located near Hot Springs, Arkansas (Image from Entergy Arkansas, LLC.).

After the construction of both the Remmel Dam and the Carpenter Dam, Entergy planned to build a third dam at the site of the, now, Blakely Mountain Dam, but construction did not occur (Richter, 2005). Instead, the U.S. Army Corps of Engineers of the Vicksburg District were able to take over the project (Richter, 2005). The Corps of Engineers began construction of the dam after they were provided funding from the government in 1946 as a result of the Flood

Control Act of 1944. The dam portion of the project was completed in the summer of 1952, flood control operations began in the spring of 1953, and the power plant operation began in August of 1955 (Blytheville Courier News, 1952; U.S. Army Corps of Engineers, 1965). The Blakely Mountain Dam is located roughly 10 miles northwest of Hot Springs, Arkansas in Garland County. The dam also impounds Lake Ouachita, and the initial purpose of Lake Ouachita was to be utilized as a means of flood control and hydroelectric power. This was later amended by Section 4 of the Flood Control Act of 1944 to include public recreation (FCA, 1944). On July 4, 1956, the official dedication of the dam took place, and began the Blakely Mountain Dam's and Lake Ouachita's service of providing hydroelectric power, flood control, and benefits to recreation, agriculture, forestry, and fish and wildlife conservation (Hope Star, 1956; Arkansas State Archives, 1949). The U.S. Army Corps of Engineers of the Vicksburg District continues to operate the Blakely Mountain Dam to this day. In the past, the U.S. Army Corps of Engineers retained a maximum regulated outflow of 15,000 CFS out of the dam (U.S. Army Corps of Engineers, 1952). The drainage area of the Ouachita River at the Blakely Mountain Dam is about 1,105 squared miles, which is located upstream of Lake Catherine and Lake Hamilton. The total storage capacity of Lake Ouachita at flood pool elevation (592 feet) is only 2,768,000 acre feet.

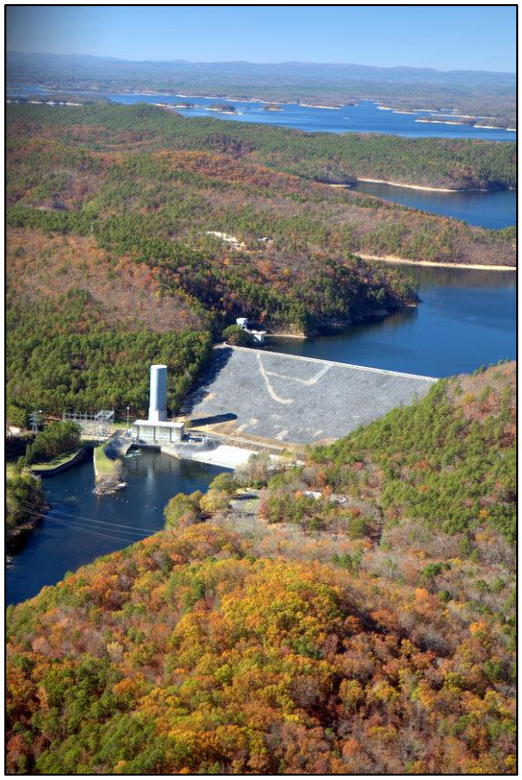


Figure 3.6: Photo of Blakely Mountain Dam located at Mountain Pine, Arkansas (Image from U.S. Army Corps of Engineers).

Chapter 4: Methodology

4.1 Stream Gauge Data

Monthly stream gauge data for the Ouachita River were obtained from the only four USGS's stream gauge stations located on the river in both Arkansas and Louisiana. These four recording stations are located at Mount Ida, Camden, and Felsenthal in Arkansas, and Monroe in Louisiana. The monthly stream gauge data obtained from USGS for all four of the stations were input into Microsoft Excel in order to parse and prepare the data to be utilized by the Dendro Tools software as well as to plot the data for initial analysis. Times series of the seasonal and annual discharge totals were constructed for each gauge station as well. The stream discharge data were then log transformed for the water year (WY; October-September) and the summer (JJA; June-August) period prior to regression modeling in the Dendro Tools software. Due to the short length of the discharge records at the Mount Ida, Felsenthal, and Monroe stations, the Camden station was chosen for reconstruction as it had the most extended discharge record out of the four.

Plots of the water year mean discharge (October-September) for each year (time series), as well as the mean discharge for December, January, and February (DJF), March, April, and May (MAM), June, July, August (JJA), and September, October, and November (SON) for each gauge station were constructed to get a better understanding of the discharge of the Ouachita River for each of the seasons. The summer discharge was chosen for focus of this study because it is the main tree growing season and thus better correlation will often be found between the discharge measurements and the tree-ring data. A hydrograph was also constructed for each gauge station, in order to illustrate the average stream level for each month of the year and the wet and dry seasons. With the Camden stream gauge data, plots were constructed that displayed the mean discharge for the following seasons for the full period of record that were created for October through September (WY), March, April, and May (MAM), and June, July, and August (JJA). Time series of the year-to-year streamflow data for those annual and seasonal averages were constructed as well. The time series were then inspected for drought and wet years, decadal regimes, and potential trends over time.

4.2 Tree-Ring Chronologies

A total of thirty-two tree-ring chronologies previously developed by the University of Arkansas Tree-Ring Laboratory, were correlated with both water year and summer discharge on the Ouachita River at Camden, Arkansas. The available tree-ring chronologies were collected near the vicinity of the Ouachita River drainage basin, which include locations in Arkansas, Louisiana, northeast Texas, and eastern Oklahoma. Correlation based screening was used to select the tree-ring chronologies that were significantly correlated with the water year or summer discharge. Eight tree-ring chronologies were significantly correlated with water year discharge at Camden. Those eight chronologies are listed in Table 4.1, along with the location, species, length, and additional details, and are not significantly correlated with summer discharge. Only those chronologies that were significantly correlated with June-August discharge, and were not well correlated with water year discharge, were used for the summer reconstruction. The four tree-ring chronologies for the reconstruction of summer discharge are listed in Table 4.1 as well. The two tree-ring reconstructions are based on separate tree-ring predictors.

Table 4.1: The tree-ring chronologies used to reconstruct water year (October-September) and summer (June-August) discharge for the Ouachita River at Camden, Arkansas, are listed along with the species, location (latitude/longitude in degrees and minutes), and the dating range of the chronology. The type of chronology used is also listed (EW = earlywood width; LW = latewood width; RW = total ring width). The species abbreviations are TADI (Taxodium distichum), PIEC (Pinus echinata), JUVI (Juniperus virginiana), and QUST (Quercus stellata).

WATER YEAR (WY) RECONSTRUCTION									
CODE	**SITE NAME**	**STATE**	**SPECIES**	**TYPE**	**LAT**		**LONG**		**DATING**
GLA	Grassy Lake	AR	TADI	RW	33	41	93	52	1766-1980
MDP	Mulberry River	AR	PIEC	LW	35	41	93	47	1669-2019
OUA	Lake Ouachita	AR	JUVI	RW	32	33	93	17	1480-1991
BIG	Big Cypress State Park	LA	TADI	EW	32	15	92	58	0997-1988
LEO	Lake Eufaula	OK	QUST	RW	35	6	95	38	1745-1980
MCW	McCurtain County	OK	QUST	RW	34	18	94	39	1624-1982
NIC	Nickle Preserve	OK	PIEC	LW	36	10	94	54	1581-2015
PEC	Pecan Bayou	TX	QUST	RW	33	45	95	5	1694-1982
SUMMER (JJA) RECONSTRUCTION									
CODE	**SITE NAME**	**STATE**	**SPECIES**	**TYPE**	**LAT**		**LONG**		**DATING**
BME	Bayou Meto	AR	TADI	RW	34	38N	91	45W	1522-1980
LAW	Lake Winona RNA	AR	PIEC	LW	34	48N	92	56W	1667-1980
MAU	Little Maumelle River	AR	TADI	RW	34	50N	92	30W	1532-1985
MOR	Moro Bayou	AR	TADI	RW	33	46N	92	20W	1262-1985

4.3 Principal Components Regression

To perform the principal components regression, the seasonal windows used in this study needed to be determined for reconstructing streamflow for the Ouachita River. For this study, the water year period (WY), which includes the entire annual flow average that begins in October and ends in September, and the summer period (JJA), which represents just June-August average flow were chosen. A correlation function analysis was conducted for individual streamflow months of the current growing season with the twelve total tree-ring chronologies previously developed and available from the University of Arkansas Tree-Ring Laboratory. Further correlation coefficients were computed in order to identify the relationships between streamflow and the various tree species' growth. The relationships being tested were between the tree-ring width indices from the twelve tree-ring chronologies and the monthly mean Ouachita River streamflow records for the Camden station for the WY and the JJA period. The autocorrelation often found in tree-ring and streamflow data were then investigated using autoregressive modeling (Stockton and Meko, 1983; Cook, 1985; Cook et al., 2013).

A principal components regression model was then used to reconstruct water year and summer discharge based on the period of time in common to all tree-ring chronologies used for each reconstruction (1767-1980 for the water year and 1671-1980 for the summer season). The regression models were then calibrated over the period 1929-1955 and used to reconstruct the predicted series over the full length of the different tree-ring data for the two periods. The principal components regression modeling and the spline computation for this study were both conducted in the Dendro Tools software.

4.4 Dendro Tools Reconstructions

For both the WY period and the JJA period, Dendro Tools' regression modeling was carried out with the log transformed instrumental data. Eight tree-ring chronologies were used as the predictor input data for the WY period, and four tree-ring chronologies were used as the predictor input data for the JJA period. There was no prewhitening of the predictor input data, (the respective tree-ring chronologies used), for either the WY and the JJA period. One lead and lag versions (+1 and –1) were entered into the forward stepwise regression as potential predictors for the WY and the JJA reconstructions. The predictand data used for both the WY and the JJA period were the log transformed stream discharge measurements for the respective periods of the Ouachita River at the Camden gauge station.

It is important to note that there was no record of flow for the year 2007 in the instrumental record of discharge measurements taken from the Camden gauge station. Autoregression in the predictor and predictand time series during the calibration period (1929-1955) was identified using the minimum Aikaike Information Criteria (AICc). The minimum AICc was used because it includes a penalty term for increasing the number of predictors in the model (Maxwell et al., 2011). The tree-ring chronologies for each period were calibrated with the instrumental log transformed discharge measurements for the Camden gauge station using PCR for the 27-year common period (1929-1955). The regression residuals of the calibration model were tested with the adjusted R-squared (R^2_{adj}; coefficient of determination adjusted downward for the loss of degrees of freedom), the standard error of the estimates (SE), and the Durbin-Watson statistic (DW; Draper and Smith, 1998). The independent log transformed discharge data available for the Camden gauge station for the verification period (1956-1980) were used to test the derived reconstructions for the WY and JJA period, and the Pearson correlation (*r*), reduction of error (RE), and coefficient of efficiency (CE) statistics were used to measure the degree of fit between the observed and reconstructed values (Cook et al., 1999). Ten-year smoothing splines were then fit to the instrumental data and to the back-transformed reconstructions of water year and summer discharge to highlight decadal variability.

Chapter 5: Results

5.1 WY Reconstruction & JJA Reconstruction

The observed and tree-ring reconstructed water year and summer discharge time series for the Ouachita River time series are illustrated in Figures 5.1, 5.2, and 5.3, panels a-d. The calibration and verification statistics are presented in Table 5.1. The eight tree-ring chronologies represent approximately 41.1% of the variance in the instrumental water year discharge data during the calibration period (1929-1955) and are significantly correlated with the instrumental data during the verification interval (1956-1980) with a Pearson correlation of $r = 0.417$. The four tree-ring chronologies explain 58.3% of the variance in the instrumental summer discharge data during the calibration period (1929-1955) and are also significantly correlated with the instrumental data during the verification interval (1956-1980) with a Pearson correlation of $r = 0.584$ (Table 5.1). Based on the calibration and verification statistics in Table 5.1, the tree-ring data appear to represent skillful proxies for both the water year and summer season mean flows during the calibration and verification periods, and by inference during the pre-instrumental period of reconstruction.

The water year discharge reconstruction from the eight tree-ring chronologies for the Ouachita River extends from 1767 to 2019, and the summer discharge reconstruction from the four tree-ring chronologies for the Ouachita River extends from 1668 to 2019 (Figure 5.3b,d). These two discharge reconstructions are not correlated with each other, and, in fact, estimate very different conditions during certain episodes over the recent past (250 to 350 years). The most notable difference would be the extreme summer low flow event that took place during the 1830's and 1840's. That event was more severe and sustained for the summer season discharge than is now estimated for the water year discharge based on the various tree-ring chronologies from in and near the Ouachita River drainage basin (Figure 5.3a,d). Other major differences between the water year and summer discharge reconstructions include (1) the extended duration of low flow in the late 1800's for the summer season, (2) the extended duration of low flow in the early 1900's to 1950's for the summer season, and (3) the surplus flow of the 1970's for the water year (Figure 5.3a-d). Decadal drought in the summer season is also estimated to have been more severe and sustained than for the water year during the 1930's and 1950's in the instrumental observations at Camden (Figures 5.1 & 5.2).

Periods of surplus flow for the water year at the Ouachita River include 1862-1880, 1940-1952, and 1971-1981 (Figure 5.3b). The periods of exceptional deficit flow for the water year include 1818-1832, 1850-1865, and 1950-1972 (Figure 5.3b). The periods of exceptional surplus flow for the summer include around 1740-1750, 1815-1824, 1845-1867, and 1902-1913 (Figure 5.3d). The periods of exceptional deficit flow for the summer include around 1707-1735, 1823-1848, 1868-1879, 1880-1891, and 1912-1957 (Figure 5.3d).

The instrumental and reconstructed summer discharge time series recorded low flow events after 1960 that were not as extreme as previously recorded in the reconstruction of summer season streamflow (Figure 5.3c,d). This period of decreased low flow events experienced in the Ouachita for the summer period after 1960 could be the result of either recovery from the 1930's and 1950's droughts or the regulation of discharge by the Blakely Mountain Dam. The most positive summer flows after 1960 do not appear to have equaled many of the summer flow extremes in the reconstruction (Figure 5.3d), which might be due to natural variability or perhaps to regulation or other anthropogenic modifications to Ouachita River flow during the summer. The positive trend in summer discharge during the last 90 years could be due to recovery from the 1930's and 1950's droughts or the regional wetting trend over the eastern United States (e.g., Stahle et al, 2020).

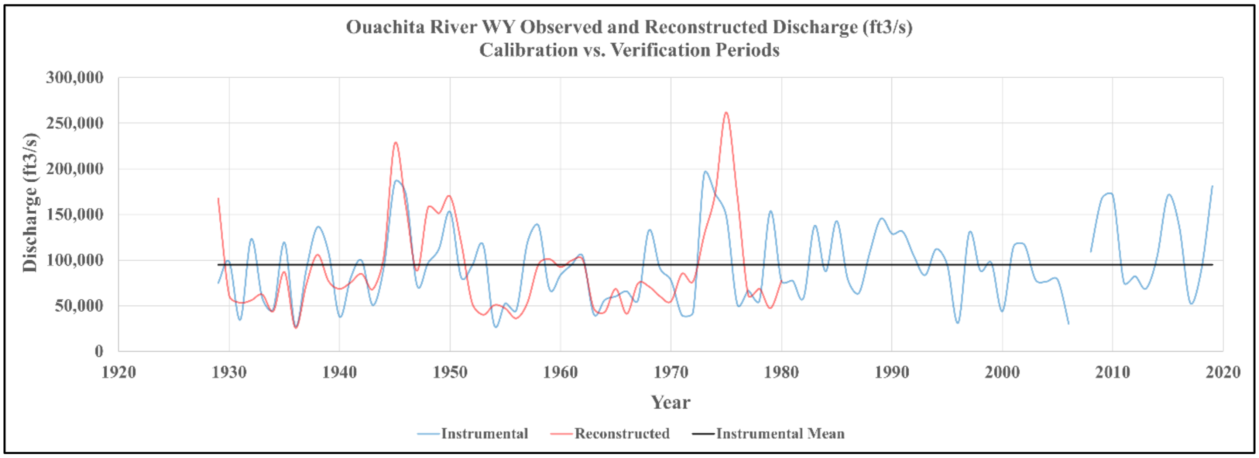


Figure 5.1: The instrumental (blue) and tree-ring reconstructed (red) water year discharge (CFS) are plotted for the Ouachita River at Camden, Arkansas from 1929-2019. The tree-ring data were calibrated with the instrumental water year data from 1929-1955 [R^2_{adj} and SE of the regression estimates (=0.583 and 0.402)] and were verified with instrumental log transformed water year discharge data used for calibration from 1929-1955. Note the drought events registered for the Ouachita River's water year discharge during the 1930's, 1950's, and 1960's. The statistics for the calibration and verification of the reconstructions for the water year are reported in Table 5.1. There are missing instrumental discharge data for the year 2007.

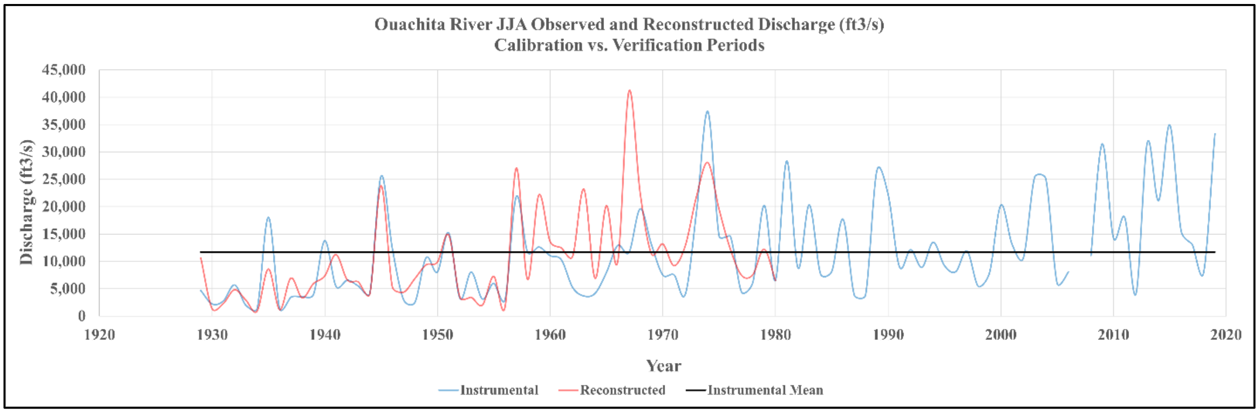
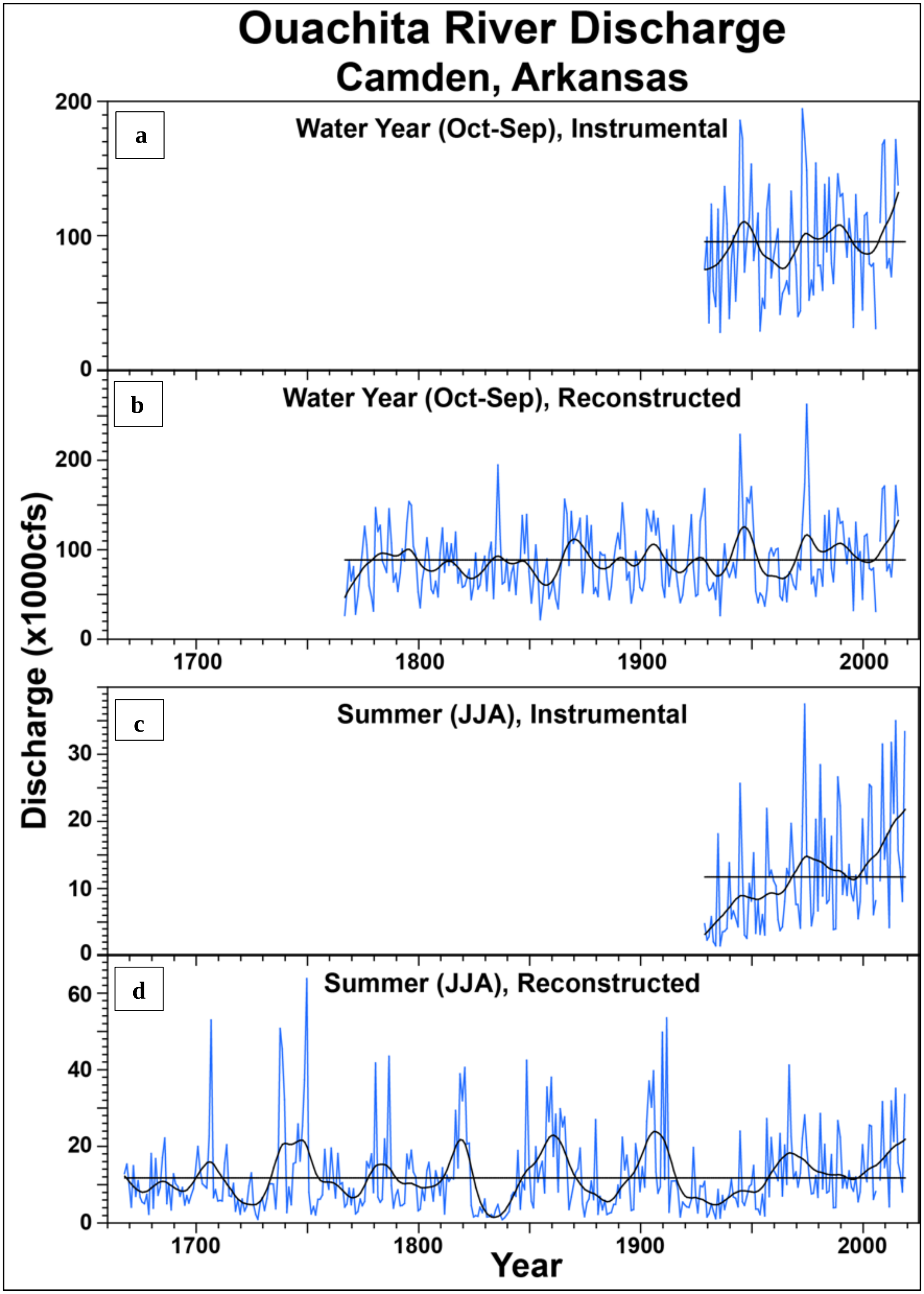


Figure 5.2: The instrumental (blue) and tree-ring reconstructed (red) summer discharge (CFS) are plotted for the Ouachita River at Camden, Arkansas from 1929-2019. The tree-ring data were calibrated with the instrumental summer data from 1929-1955 [R^2_{adj} and SE of the regression estimates (=0.411 and 0.496)] and were verified with instrumental log transformed summer discharge data used for calibration from 1929-1955. Note the drought events registered for the Ouachita River's summer discharge during the 1930's and 1950's. The low flow of discharge for the 1950's and could reflect the severe 1950's drought and potentially the impact of the Blakely Mountain Dam. The slight positive trend in the instrumental and reconstructed summer discharge since the mid-1950's reflects in part either the Ouachita River's recovery from the severe 1930's and 1950's drought or the regional wetting trend over the eastern United States. The statistics for the calibration and verification of the reconstructions for the summer period are reported in Table 5.1. There are missing instrumental discharge data for the year 2007.



Ouachita River Discharge
Camden, Arkansas
a
Water Year (Oct-Sep), Instrumental
b
Water Year (Oct-Sep), Reconstructed
c
Summer (JJA), Instrumental
d
Summer (JJA), Reconstructed
Discharge (x1000cfs)
Year
0
100
200
10
20
30
40
60
1700
1800
1900
2000

Figure 5.3: Instrumental water year (October-September) discharge (CFS) is plotted from 1929-2019 for the Ouachita River at Camden, Arkansas (a). Tree-ring reconstructed water year (October-September) discharge (CFS) is plotted from 1767-2019 and the water year instrumental time series is appended from 1981-2019 for the Ouachita River at Camden, Arkansas (b). Instrumental summer (June-August) discharge (CFS) is plotted from 1929-2019 for the Ouachita River at Camden, Arkansas (c). Tree-ring reconstructed summer (June-August) discharge (CFS) is plotted from 1668-2019 and the summer instrumental time series is appended from 1981-2019 for the Ouachita River at Camden, Arkansas (d). The slight positive trend in the instrumental and reconstructed summer discharge since the mid-1950's reflects in part either the Ouachita River's recovery from the severe 1930's and 1950's drought or the regional wetting trend over the eastern United States. There are missing discharge data for the year 2007.

Table 5.1: Calibration and verification statistics computed for the reconstruction of the water year (October-September) and summer (June-August) discharge for the Ouachita River at Camden, Arkansas. The calibration interval is listed first (e.g., 1929-1955), followed by the verification interval (e.g., 1956-1980) for each reconstruction. The variance explained (R^2_{adj} = coefficient of determination adjusted downward for the loss of degrees of freedom), the standard error of the estimates (SE), and the Durbin-Watson statistic (DW) are listed for each reconstruction. The Pearson correlation coefficient comparing reconstructed with instrumental discharge data during the statistically independent verification periods are shown for the reconstructions, along with the reduction of error (RE) and coefficient of efficiency (CE) statistics calculated on observed and reconstructed data in the verification period. All tests indicate successful verification.

Time Period	R^2_{adj}	*SE*	*DW*	r	*RE*	*CE*
October-September						
1929-1955	0.411	0.402	2.673			
1956-1980				0.417	0.112	0.112
June-August						
1929-1955	0.583	0.496	2.2			
1956-1980				0.584	0.647	0.281

Chapter 6: Discussion

The various species of trees found in and near the Ouachita River drainage basin preserve a long tree-ring record of discharge that can be used to reconstruct the water year and summer flow for the Ouachita River at Camden, Arkansas for the past 253- and 352-years. The result of running principal component regression with the Dendro Tools software, which used eight tree-ring chronologies and the log transformed discharge data for the water year (October-September) and four tree-ring chronologies and the log transformed discharge data for the summer (June-August) period, resulted in successful reconstructions for both water year and summer discharge back to 1767 and 1668, respectively. The successful reconstructions are documented by the calibration and verification statistics in Table 5.1. Both the water year and summer reconstructions were back transformed to the original discharge units and identified historical drought events that occurred in the United States in the past 250- and 350-years.

The new reconstructions of water year and summer flow for the Ouachita River can be used with the instrumental time series for both periods to help document anomalies in the river's discharge record. The resulting graphs (Figure 5.3a-d) of the instrumental and reconstructed WY and JJA discharge for the Ouachita River at Camden are thus a significant product that can be utilized to study past surplus and deficit water year and summer flow. Reviewing Ouachita River water year and summer season discharge, certain periods of exceptional surplus and deficit flow of the river correlate to historical drought events that occurred in the past. Drought and wet regimes are also measured using the Palmer Drought Severity Index (PDSI). PDSI uses instrumental temperature and precipitation data to estimate the soil moisture balance of an area (Dai, 2019). The North American Drought Atlas (NADA) used hundreds of tree-ring chronologies to reconstruct the summer (June-August) PDSI on a 0.5-degree grid across North

America for the past several centuries (Cook et al 2007). Several periods of deficit water year flow on the Ouachita River correspond with pre-instrumental droughts identified in the NADA, including the Civil War era drought of the 1850's and 1860's (Figure 6.1). The droughts of the 1930's and 1950's which are identified in both the instrumental and reconstructed data for the Ouachita River (Figure 5.3a-d) also corresponded with widespread dryness over North America (Figures 6.2 & 6.3), based on composite mapping of the instrumental summer PDSI developed for the NADA and the mapping tools provided by Dr. Dorian Burnette, University of Memphis. Additionally, the droughts of the 1930's and 1950's which are identified in both the instrumental and reconstructed data for the Ouachita River (Figure 5.3a-d) also corresponded with low precipitation over South Central Arkansas, where a significant portion of the Ouachita River flows through, (Figures 6.4 & 6.5), based on plotting near real-time analysis of monthly precipitation developed for Climate at a Glance Divisional Time Series and the graphing tools provided by National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information.

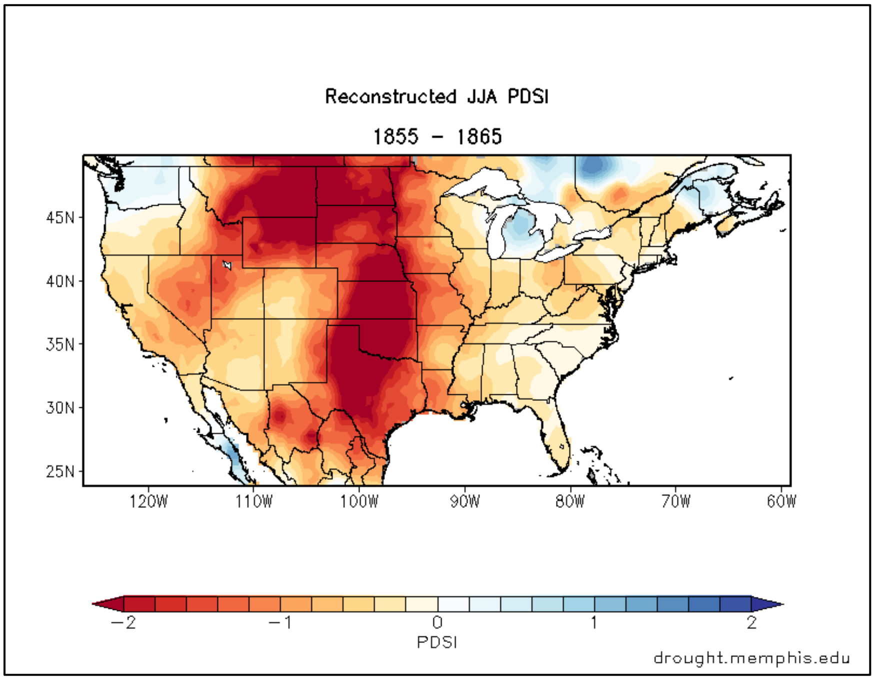


Figure 6.1: The average of reconstructed summer (JJA) PDSI is mapped for the Civil War Drought from 1855-1865 using the North American Drought Atlas (Cook et al., 2007). The NADA was derived from 1,845 tree-ring chronologies across North America (dry conditions are negative, wet estimates are positive). This figure was prepared using the mapping tools created by Dr. Dorian Burnette (drought.memphis.edu).

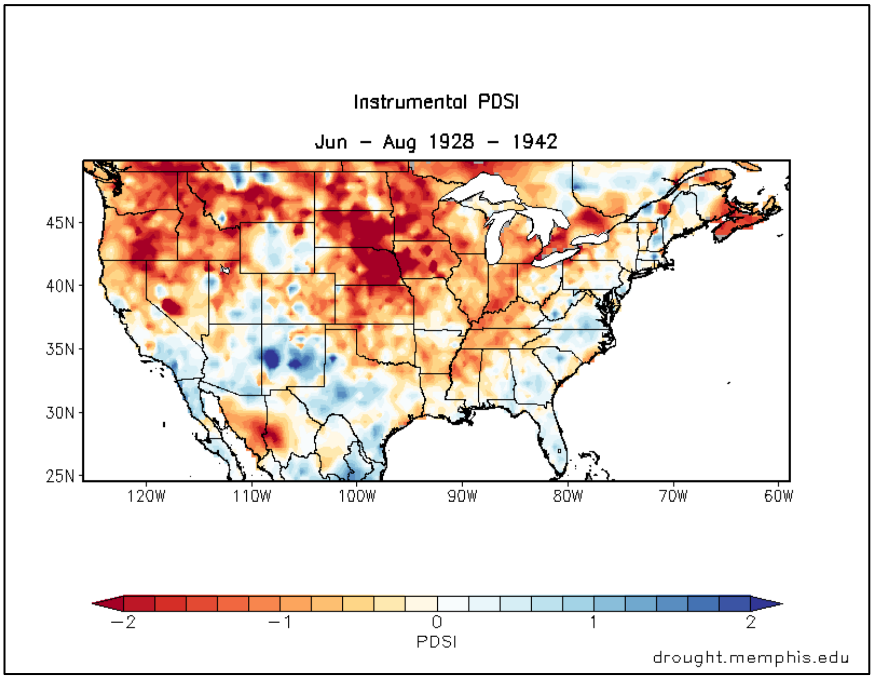


Figure 6.2: Instrumental summer PDSI is mapped for the Dust Bowl Drought (1928-1942) over the United States for the summer period (June-August; dry conditions are negative, wet estimates are positive). Figure created using the tools and data available at: drought.memphis.edu.

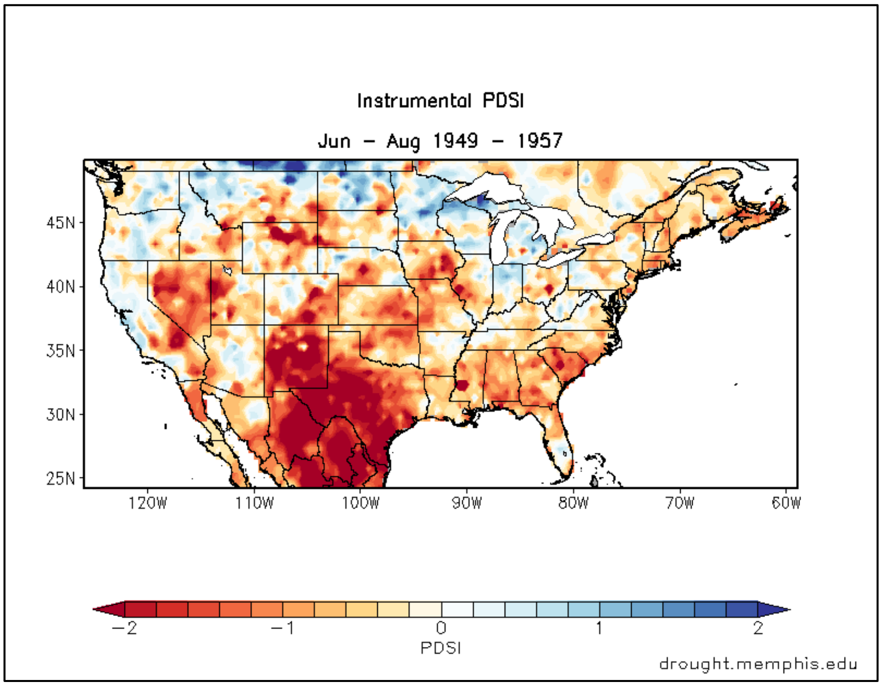


Figure 6.3: Instrumental summer PDSI is mapped for the 1950's Drought (1949-1957) over the United States for the summer period (June-August; dry conditions are negative, wet estimates are positive). Figure created using the tools and data available at: drought.memphis.edu.

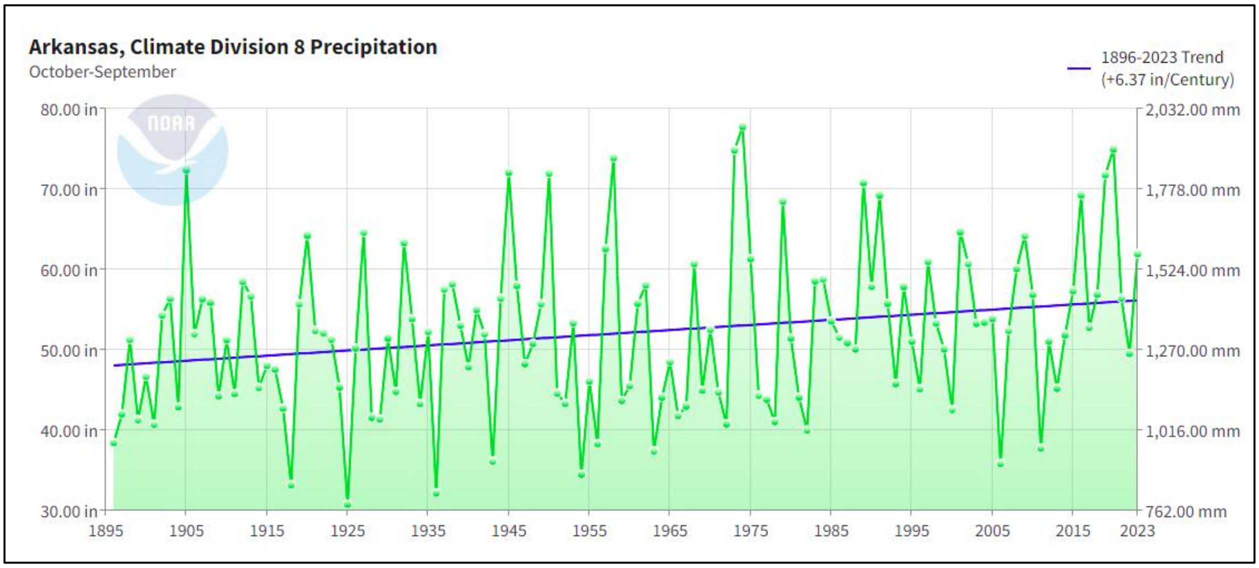


Figure 6.4: The precipitation (green) and century trend (blue) are plotted for the for Arkansas, Climate Division 8 (South Central Arkansas) from 1895-2023 for the water year (October-September). Note the decrease in precipitation registered in the 1930's, 1950's, and 1960's. Figure created using the tools and data available at: ncei.noaa.gov.

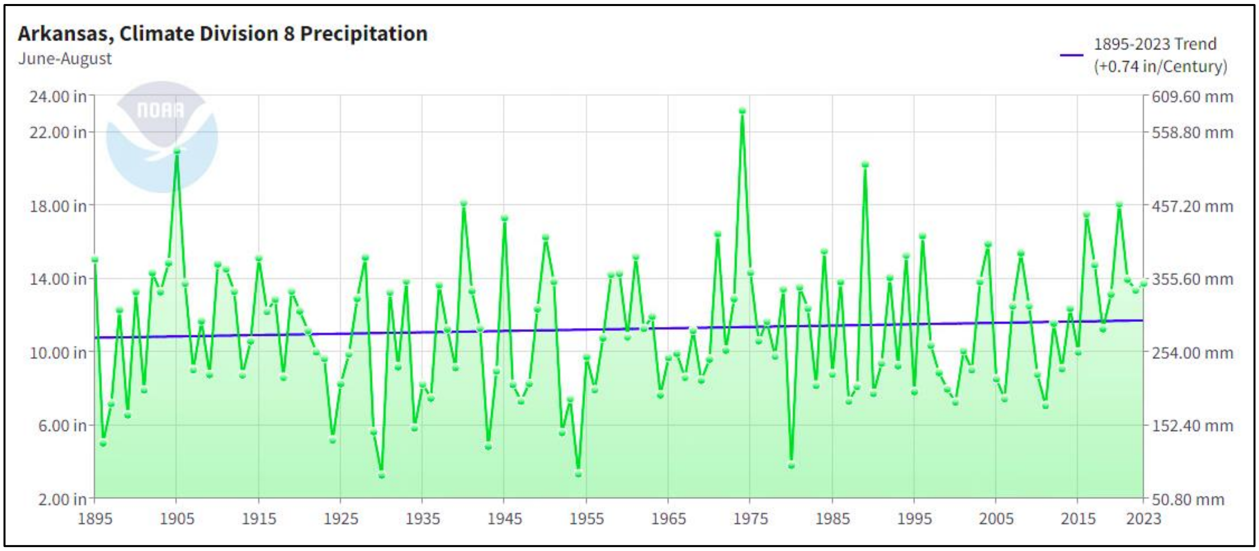


Figure 6.5: The precipitation (green) and century trend (blue) are plotted for the for Arkansas, Climate Division 8 (South Central Arkansas) from 1895-2023 for the summer period (June-August). Note the decrease in precipitation registered in the 1930’s and 1950’s. This figure was prepared using the tools created by the National Oceanic and Atmospheric Administration (ncei.noaa.gov).

Chapter 7: Conclusion & Implications

The Ouachita River is an important water and power resource to the states of Arkansas and Louisiana. This study used ring-width chronologies to reconstruct the flow history of the Ouachita River at Camden, Arkansas for both the full water year and summer season. This was done to better understand the natural flow history of the Ouachita River and what anthropogenic impacts could be affecting river flow. The resulting reconstructions will thus provide valuable information to water resource managers that will, hopefully, assist with the management of the river.

This study utilized the USGS stream gauge data at Camden, Arkansas, along with selected tree-ring chronologies that were well correlated with the flow data. To measure the changing flow of the Ouachita River two seasonal intervals were chosen for comparison with the tree-ring data. These intervals were the water year, which includes the mean annual flow that begins in October and ends in September, and the summer period, which includes the months of June, July, and August. After the data collection, statistical analyses were used to explore the relationships between the discharge measurements and the tree-ring chronologies. The software program Dendro Tools was used to develop the reconstructions of the flow history in the Ouachita River for both the water year and summer period. The tree-ring reconstructions recorded the effects of past droughts and pluvials on water year and summer streamflow. Many of these climate extremes identified in the water year and summer stream flow reconstructions also impacted very large areas of Arkansas and the southern United States during the past 250- to 350-years.

The water year and summer low flows exhibit a long-term trend from the relatively dry 1930's and 1950's into higher water year and summer flows in the late 20th and early 21st

centuries (Figures 5.1, 5.2, & 5.3a-d). Many instances when the water year and summer season discharge were below average correspond to known historical drought events, for example during the mid-1850's to mid-1860's (Civil War Drought), the 1930's (Dust Bowl Drought), the 1950's, and additionally, for the summer season, the historical drought events that occurred during the 1700's. After the 1960's, the instrumental and reconstructed summer low flow were not as low as previously recorded or reconstructed low flow events (Figure 5.3c,d). This period of decreased summer low flow events experienced on the Ouachita River after the 1960's may be due in part to recovery from the severe 1930's and 1950's droughts. However, the lack of low flows might also be due to flow regulation by the Blakely Mountain Dam. It is important to note that the instrumental JJA discharge data do not extend back before 1929, which means that the first three decades of the instrumental record were observed during the severe droughts that occurred in the 1930's and 1950's. Thus, we cannot conclude with certainty whether the summer season flow for the Ouachita River was impacted by the construction and operation of the Blakely Mountain Dam, due to the presence and effects of those severe and sustained droughts. Conversely, when looking at the instrumental precipitation data the water year has a strong decadal positive trend, while the summer period did not have as strong of a positive trend (Figures 6.4 & 6.5). From that information, there is a possibility that dam operation may have had some impact on trend for the summer period flow of the Ouachita River. Furthermore, the high summer flows after 1960 do not equal many of the positive extremes in the reconstruction (Figure 5.3d) and might also reflect some degree of artificial regulation of stream flow. Alternatively, the absence of extreme high summer flows during this interval after 1960 might simply be due to natural variability.

The positive trend in the summer discharge after the mid 1950's could be the result of the Ouachita River's recovery from the droughts the river has experienced in the early 20th century or a result of climate variability. This positive trend may correspond with the long-term wetting trend over the eastern United States. In the article, "Dynamics, Variability, and Change in Seasonal Precipitation Reconstructions for North America" Stahle et al. (2020) state that their seasonal reconstructions indicate a significant positive trend in both the cool and warm season precipitation that has impacted most of the eastern United States (Stahle et al., 2020). Additionally, the cool and warm season "may have been enhanced in recent decades by anthropogenic activity" and "the dynamics responsible for these moisture trends may involve a combination of factors related to anthropogenic warming" (Stahle et al., 2020). It is important to note that "the reconstructions indicate that cool- and warm-season precipitation trends began well before the industrial revolution and may also involve internal climate variability" (Stahle et al., 2020). The instrumental and reconstructed summer discharge data for the Ouachita River do indicate a positive trend since the early 20th century (Figure 5.3a-d) which may be related to the larger scale trends in precipitation over eastern North America.

References Cited

American National Red Cross. “The Mississippi Valley Flood Disaster of 1927: Official Report of the Relief Operations.” Washington, D.C.: The American National Red Cross, 1929.

American National Red Cross, and Norman H. Davis. “The Ohio Mississippi Valley Flood Disaster of 1937: Report of Relief Operations of the American Red Cross.” Washington, D. C, 1938.

Berry, Trey. “The Expedition of William Dunbar and George Hunter along the Ouachita River, 1804-1805.” The Arkansas Historical Quarterly, vol. 62, no. 4, 2003, p. 386. *DOI.org (Crossref),* doi:10.2307/40023081.

Blakely Mountain Lake, Map0297, Map collection, Arkansas State Archives, Little Rock, Arkansas. “Blakely Mountain Lake (Side 2).” Historic Maps Collection, Dec. 1949, https://digitalheritage.arkansas.gov/maps-collection/17.

Burnette, Dorian J., n.d., “Dendro Tools.” Dorian J. Burnette, http://www.djburnette.com/dendrotools/. Accessed 28 Feb. 2021.

Cleaveland, Malcolm K., and David W. Stahle. “Tree Ring Analysis of Surplus and Deficit Runoff in the White River, Arkansas.” Water Resources Research, vol. 25, no. 6, June 1989, pp. 1391–401. *DOI.org (Crossref),* doi:10.1029/WR025i006p01391.

Cleaveland, M. K. “A 963-Year Reconstruction of Summer (JJA) Stream Flow in the White River, Arkansas, USA, from Tree-Rings.” The Holocene, vol. 10, no. 1, Jan. 2000, pp. 33–41, doi:10.1191/095968300666157027.

Cook, Edward R. “A Time Series Analysis Approach to Tree Ring Standardization” (Dendrochronology, Forestry, Dendroclimatology, Autoregressive Process), ProQuest Dissertations Publishing, 1985.

Cook, Edward R., et al. "Drought Reconstructions for the Continental United States." Journal of Climate, vol. 12, no. 4, 1999, pp. 1145-1162.

Cook, Edward R., et al. “Five Centuries of Upper Indus River Flow from Tree Rings.” Journal of Hydrology, vol. 486, Apr. 2013, pp. 365–75. DOI.org (Crossref), doi:10.1016/j.jhydrol.2013.02.004.

Cui, Tong, et al. “Development of a Comprehensive Framework for Assessing the Impacts of Climate Change and Dam Construction on Flow Regimes.” Journal of Hydrology, vol. 590, Nov. 2020, p. 125358. DOI.org (Crossref), doi:10.1016/j.jhydrol.2020.125358.

Dai, Aiguo & National Center for Atmospheric Research Staff (Eds). Last modified 12 Dec 2019. "The Climate Data Guide: Palmer Drought Severity Index (PDSI)." Retrieved from https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi.

Draper, Norman R., and Harry Smith. Applied Regression Analysis. 1st ed., Wiley, 1998. DOI.org (Crossref), doi:10.1002/9781118625590.

"Encyclopedia of Arkansas." Encyclopedia of Arkansas, https://encyclopediaofarkansas.net/entries/ouachita-river-2392/. Accessed 28 Feb. 2021.

Enright, N. J. "Principal Components Analysis of Tree-Ring/Climate Relationships in White Spruce (Picea Glauca) from Schefferville, Canada." Journal of Biogeography, vol. 11, no. 4, July 1984, p. 353. DOI.org (Crossref), doi:10.2307/2845008.

FERC License | Entergy | We Power Life. https://www.entergy.com/operations_information/hydro/ferc/. Accessed 28 Feb. 2021.

Flood Control Act of 1944, Public Law 534, 78th Congress, Chapter 665, 2nd Session, H.R. 4485, sect. 7. Codified at 33 USCA §709.

Fritts, Harold C., Terence J. Blasing, Bruce P. Hayden, and John E. Kutzbach. "Multivariate Techniques for Specifying Tree-Growth and Climate Relationships and for Reconstructing Anomalies in Paleoclimate." Journal of Applied Meteorology and Climatology, vol. 10, no. 5, Oct. 1971, pp. 845-864. doi:10.1175/1520-0450(1971)010<0845:MTFSTG>2.0.CO;2>.

Fritts, H.C. *Tree Rings and Climate*. The Blackburn Press, 1976.

Graybill, D.A. "Revised Computer Programs for Tree-Ring Research." Tree-Ring Bulletin, vol. 39, 1976, pp. 77-82.

Groisman, P. Ya., R. W. Knight, T. R. Karl, D. R. Easterling, B. Sun, and J. H. Lawrimore, 2004: Contemporary changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations. J. Hydrometeor., 5, 64–85, https://doi.org/10.1175/1525-7541(2004)005,0064:CCOTHC.2.0.CO;2.

Jacoby, G. C., and E. R. Cook. "Past Temperature Variations Inferred from a 400-Year Tree-Ring Chronology from Yukon Territory, Canada." Arctic and Alpine Research, vol. 13, no. 4, Nov. 1981, p. 409. DOI.org (Crossref), doi:10.2307/1551051.

Maxwell, R. Stockton, et al. "A Multispecies Tree Ring Reconstruction of Potomac River Streamflow (950-2001): POTOMAC RIVER STREAMFLOW RECONSTRUCTION." Water Resources Research, vol. 47, no. 5, May 2011. DOI.org (Crossref), doi:10.1029/2010WR010019.

Meko, David M., et al. "Medieval Drought in the Upper Colorado River Basin." Geophysical Research Letters, vol. 34, no. 10, May 2007, p. L10705. DOI.org (Crossref), doi:10.1029/2007GL029988.

Mittal, Neha, et al. “Impact of Human Intervention and Climate Change on Natural Flow Regime.” Water Resources Management, vol. 30, no. 2, Jan. 2016, pp. 685–99. DOI.org (Crossref), doi:10.1007/s11269-015-1185-6.

National, Research Council, et al. “Surface Temperature Reconstructions for the Last 2,000 Years.” National Academies Press, 2007, doi:10.17226/11676.

O’Connor, Jim E., and John E. Costa. “Large Floods in the United States: Where They Happen and Why.” U.S. Geological Survey Circular 1245. Washington DC: U.S. Geological Survey, 2003.

Ouachita-Black River. https://www.mvk.usace.army.mil/Missions/Recreation/Ouachita-Black-River/. Accessed 28 Feb. 2021.

Ouachita National Forest. http://npshistory.com/publications/usfs/handbooks/ouachita/sec2.htm. Accessed 28 Feb. 2021.

“Ouachita River.” Britannica Academic, Encyclopædia Britannica, 1 Oct. 2008. academic-eb-com.eu1.proxy.openathens.net/levels/collegiate/article/Ouachita-River/57701.

“Ouachita Rover Power House Building to Begin.” Blytheville Courier News Newspaper, 18 Sept. 1952, p. 14. *Newspaperarchive*.

Pearcy. Matthew T. “A History of the Ransdell-Humphreys Flood Control Act of 1917.” Louisiana History: The Journal of the Louisiana Historical Association, vol. 41, no. 2, 2000, pp. 133–159. JSTOR, www.jstor.org/stable/4233654. Accessed 28 Feb. 2021.

Peters, K., G. C. Jacoby, and E. R. Cook. "Principal Components Analysis of Tree-Ring Sites." Tree-Ring Bulletin, vol. 41, 1981, pp. 1-19.

Richter, Wendy. “Swallowed Up in One Gulp: Lost Communities of the Upper Ouachita River Valley.” ProQuest Dissertations Publishing, 2005.

Ringnér, Markus. “What Is Principal Component Analysis?” Nature Biotechnology, vol. 26, no. 3, Mar. 2008, pp. 303–04. DOI.org (Crossref), doi:10.1038/nbt0308-303.

Sloan, David. "The Expedition of Hernando De Soto: A Post-Mortem Report Part II." The Arkansas Historical Quarterly, vol. 51, no. 4, 1992, pp. 297-327.

Stahle, David W., et al. "Ancient Blue Oaks Reveal Human Impact on San Francisco Bay Salinity." Eos (Washington, D.C.), vol. 82, no. 12, 2001, pp. 141-145, doi:10.1029/EO082i012p00141.

Stahle, David W., et al. “Dynamics, Variability, and Change in Seasonal Precipitation Reconstructions for North America.” Journal of Climate, vol. 33, no. 8, Apr. 2020, pp. 3173–95. DOI.org (Crossref), doi:10.1175/JCLI-D-19-0270.1.

Stockton, Charles W. *Long-Term Streamflow Records Reconstructed from Tree Rings*. University of Arizona Press, 1975.

Stockton, C. W. and Jacoby, G. C.: 1976, Long-Term Surface Water Supply and Streamflow Levels in the Upper Colorado River Basin, Lake Powell Research Project Bulletin No 18, Inst. of Geophysics and Planetary Physics, University of California, Los Angeles, 70 pp.

Stockton, C W. and D M. Meko. "Drought Recurrence in the Great Plains as Reconstructed from Long-Term Tree-Ring Records." Journal of Climate and Applied Meteorology, vol. 22., 1983, pp. 17-29, doi: 10.1175/1520-0450(1983)022<0017:DRITGP>2.0.CO;2

United States. Army. Corps of Engineers. “Flood-control outlet works for Blakely Mountain Dam, Ouachita River, Arkansas: Hydraulic model investigation.” U.S. Waterways Experiment Station, 1952.

United States. Army. Corps of Engineers. “[Arkansas 1965 Water Resources Development Report]; Water resources development in Arkansas.” Corps of Engineers, Lower Mississippi Valley, 1965.

United States. Army. Corps of Engineers. Southwestern Division. “[Arkansas 1975 Water Resources Development Report]; Water resources development in Arkansas.” Corps of Engineers, Southwestern Division, 1975.

Wilson, Stephen. *Harvey Couch: An Entrepreneur Brings Electricity to Arkansas*. Little Rock: August House, 1986.

Woodhouse, Connie A., and Jeffrey J. Lukas. “Multi-Century Tree-Ring Reconstructions of Colorado Streamflow for Water Resource Planning.” Climatic Change, vol. 78, no. 2–4, Sept. 2006, pp. 293–315. DOI.org (Crossref), doi:10.1007/s10584-006-9055-0.

“$31 Million Project is Dedicated.” Hope Star Newspaper, 5 July 1956, p. 2. *Newspaperarchive*.

Appendix

Table 4.1 – 1: The tree-ring chronologies used to reconstruct summer (June-August) and water year (October-September) discharge for the Ouachita River at Camden, Arkansas, are listed along with the species, location (latitude/longitude in degrees and minutes), and the dating range of the chronology. The type of chronology used is also listed (EW = earlywood width; LW = latewood width; RW = total ring width). The species abbreviations are TADI (*Taxodium distichum*), PIEC (*Pinus echinata*), JUVI (*Juniperus virginiana*), and QUST (*Quercus stellata*).

WATER YEAR (WY) RECONSTRUCTION									
CODE	**SITE NAME**	**STATE**	**SPECIES**	**TYPE**	**LAT**		**LONG**		**DATING**
GLA	Grassy Lake	AR	TADI	RW	33	41	93	52	1766-1980
MDP	Mulberry River	AR	PIEC	LW	35	41	93	47	1669-2019
OUA	Lake Ouachita	AR	JUVI	RW	32	33	93	17	1480-1991
BIG	Big Cypress State Park	LA	TADI	EW	32	15	92	58	0997-1988
LEO	Lake Eufaula	OK	QUST	RW	35	6	95	38	1745-1980
MCW	McCurtain County	OK	QUST	RW	34	18	94	39	1624-1982
NIC	Nickle Preserve	OK	PIEC	LW	36	10	94	54	1581-2015
PEC	Pecan Bayou	TX	QUST	RW	33	45	95	5	1694-1982
SUMMER (JJA) RECONSTRUCTION									
CODE	**SITE NAME**	**STATE**	**SPECIES**	**TYPE**	**LAT**		**LONG**		**DATING**
BME	Bayou Meto	AR	TADI	RW	34	38N	91	45W	1522-1980
LAW	Lake Winona RNA	AR	PIEC	LW	34	48N	92	56W	1667-1980
MAU	Little Maumelle River	AR	TADI	RW	34	50N	92	30W	1532-1985
MOR	Moro Bayou	AR	TADI	RW	33	46N	92	20W	1262-1985

Table 5.1 – 2: Calibration and verification statistics computed for the reconstruction of the water year (October-September) and summer (June-August) discharge for the Ouachita River at Camden, Arkansas. The calibration interval is listed first (e.g. 1929-1955), followed by the verification interval (e.g. 1956–1980) for each reconstruction. The coefficients of the regression models, the variance explained (R^2_{adj} = coefficient of determination adjusted downward for the loss of degrees of freedom), the standard error of the estimates (SE), and the Durbin-Watson statistic (DW) are listed for each reconstruction. The Pearson correlation coefficient comparing reconstructed with instrumental discharge data during the statistically independent verification periods are shown for the reconstructions, along with the reduction of error (RE) and coefficient of efficiency (CE) statistics calculated on observed and reconstructed data in the verification period. All tests indicate successful verification.

Time Period	R^2_{adj}	*SE*	*DW*	r	*RE*	*CE*
October-September						
1929-1955	0.411	0.402	2.673			
1956-1980				0.417	0.112	0.112
June-August						
1929-1955	0.583	0.496	2.2			
1956-1980				0.584	0.647	0.281

Table 1 – 3: Camden stream gauge discharge data (CFS) for each month (January-December) from 1928-2019 with the mean monthly discharge for the Ouachita River at Camden, Arkansas.

Year	Jan	Feb	Mar	Apr	May	Jun
1928						
1929	16,420	11,210	13,120	5,387	8,338	3,576
1930	31,260	16,120	5,341	1,578	35,340	1,786
1931	1,565	5,189	7,572	3,906	2,332	727.3
1932	41,420	29,720	11,610	9,150	1,674	922.9
1933	18,810	7,377	7,913	8,425	10,740	882.9
1934	5,284	2,136	13,180	16,380	2,796	713.3
1935	22,500	10,320	13,910	13,560	32,280	16,120
1936	2,363	1,542	2,662	1,804	1,786	411
1937	46,610	9,518	11,450	4,779	7,281	2,306
1938	35,740	36,250	10,860	28,270	3,728	2,228
1939	8,747	34,050	17,820	32,560	4,516	2,348
1940	686.1	1,798	2,160	8,021	8,693	4,566
1941	6,959	12,110	12,730	12,110	13,520	3,020
1942	6,787	8,945	15,660	26,660	13,390	4,522
1943	5,841	3,359	13,620	11,370	4,605	4,013
1944	3,065	8,577	21,870	21,730	30,180	2,901
1945	19,500	12,630	45,110	48,110	17,930	21,890
1946	34,930	29,540	17,980	20,280	41,060	9,736
1947	7,605	3,037	8,601	7,827	17,140	1,924
1948	11,040	19,650	27,510	8,586	7,735	1,093
1949	33,500	20,770	22,380	9,940	7,942	7,855
1950	34,450	40,110	13,450	4,652	20,790	3,127
1951	14,450	21,730	6,765	10,340	4,523	3,658
1952	11,780	10,950	13,990	31,800	7,631	1,893
1953	9,378	11,090	13,790	14,460	45,760	3,016
1954	4,790	3,976	1,742	2,662	9,060	1,203
1955	3,697	6,955	13,690	9,284	4,230	2,964
1956	838.8	19,140	4,719	3,775	7,209	1,143
1957	2,593	12,630	9,140	32,550	32,970	16,840
1958	11,770	4,681	8,678	11,180	50,000	3,834
1959	4,705	14,970	9,141	7,453	1,945	8,122
1960	16,140	12,220	13,770	2,735	6,046	4,197
1961	7,231	10,230	13,440	24,540	9,793	2,223
1962	19,560	16,560	20,340	8,881	3,654	2,592

1963	3,232	2,330	10,680	2,658	2,970	668.1
1964	1,070	2,940	10,300	20,690	7,528	1,051
1965	6,860	17,650	9,095	5,012	2,174	2,406
1966	1,997	5,221	1,986	14,710	22,210	2,063
1967	3,989	2,234	3,835	6,007	19,430	4,243
1968	9,905	7,874	15,640	13,540	52,200	12,940
1969	8,727	32,850	10,790	5,007	4,431	5,577
1970	11,060	8,530	16,490	12,880	11,800	5,388
1971	6,135	5,371	5,757	1,590	1,897	899.5
1972	8,459	6,375	3,621	1,947	2,188	902.9
1973	19,170	17,750	31,350	41,950	13,550	9,138
1974	19,770	11,270	6,544	9,520	9,642	31,090
1975	13,220	19,760	16,540	14,060	18,660	8,509
1976	3,749	5,020	10,590	3,575	4,555	7,002
1977	4,690	6,749	12,680	20,370	2,808	1,949
1978	9,449	6,128	9,957	4,696	8,541	2,565
1979	16,470	14,690	19,630	34,720	27,970	13,840
1980	8,024	9,280	9,904	12,590	13,600	3,343
1981	2,349	5,234	6,372	4,662	9,678	18,180
1982	3,968	9,795	7,204	13,110	4,267	3,871
1983	13,990	14,050	8,795	8,234	20,770	5,532
1984	6,554	9,687	15,460	13,370	15,200	3,574
1985	10,310	12,830	20,660	22,110	10,820	2,205
1986	3,320	7,615	2,728	19,900	5,411	9,562
1987	5,655	7,940	14,980	4,594	4,003	1,648
1988	24,870	11,810	10,320	11,410	2,071	1,284
1989	11,220	31,030	19,180	18,030	10,330	9,041
1990	5,576	15,460	28,310	23,700	25,720	16,590
1991	25,920	12,810	8,830	22,470	26,240	4,060
1992	9,482	9,461	22,290	5,754	2,794	4,162
1993	13,730	8,561	13,160	10,400	11,780	3,558
1994	12,240	15,350	14,680	7,674	5,262	2,612
1995	15,750	6,847	11,220	11,250	10,280	3,698
1996	1,916	1,708	2,024	4,131	8,322	2,364
1997	9,284	17,250	27,380	18,270	10,010	6,593
1998	22,070	18,890	17,970	5,484	4,063	2,867
1999	17,660	15,120	14,450	17,220	5,168	2,081
2000	1,384	1,639	3,808	4,267	6,446	11,910
2001	20,260	25,330	23,690	6,758	5,220	6,886
2002	9,440	11,630	24,450	18,550	8,450	4,274

2003	8,217	13,500	9,922	2,153	5,873	17,350
2004	6,411	10,970	12,440	5,781	8,638	11,950
2005	20,030	10,660	4,985	4,580	1,407	2,051
2006	1,462	1,411	7,603	2,907	5,936	3,220
2007						
2008	955.3	9,869	21,820	33,270	4,857	3,358
2009	7,569	6,596	14,610	13,360	58,700	9,470
2010	13,300	28,240	5,388	3,191	5,753	7,358
2011	830.8	2,261	2,305	19,170	28,960	12,820
2012	8,166	13,790	23,890	8,499	1,731	1,299
2013	5,735	5,245	4,245	10,670	3,852	23,900
2014	10,130	11,370	9,724	15,240	10,290	11,240
2015	9,099	6,381	48,000	23,360	39,990	19,080
2016	23,740	9,109	22,240	14,560	19,060	4,864
2017		3,992	5,926	10,480	19,900	4,025
2018	2,372	22,340	32,330	17,680	2,171	1,631
2019	21,250	19,610	19,060	24,400	28,080	11,300
Mean of Monthly Discharge	11,700	12,200	13,500	13,000	12,900	5,930

Year	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1928				311.4	1,772	13,310
1929	860.3	217.4	426.6	341.8	2,122	3,714
1930	259.5	175.6	310.8	2,613	2,224	6,008
1931	1,216	807.4	534.7	320.4	1,014	22,120
1932	4,377	390.4	394.7	291.4	381.2	1,812
1933	382.3	701.8	578.9	803.9	1,232	2,969
1934	406.8	250.6	524.3	638.1	1,169	5,989
1935	1,361	581.6	974.7	1,738	5,437	8,262
1936	641.6	304.4	473.8	649.8	1,261	4,965
1937	638.2	504.5	983.2	1,322	7,882	8,194
1938	756.8	549.7	505.8	619.2	2,420	2,720
1939	801.1	790	880	632.4	720.2	739.5
1940	7,955	1,252	762.8	849	5,205	10,260
1941	1,888	522.4	1,407	3,667	4,163	7,293
1942	1,021	1,014	6,327	893.8	2,044	3,409
1943	872.8	574.1	154.4	370.4	445.7	1,089

1944	679.1	596.5	657.5	504.3	1,103	12,840
1945	2,287	1,397	2,123	4,646	6,330	4,451
1946	1,248	1,366	621.5	636.8	12,870	10,670
1947	504.8	536.9	1,318	867.5	6,638	12,080
1948	603.9	786.5	330.8	387.6	2,082	4,527
1949	1,974	846.8	568.7	5,850	2,570	9,716
1950	2,128	2,802	13,400	3,125	1,910	1,995
1951	10,140	1,416	1,128	943.3	5,723	7,498
1952	631.9	709.4	645.6	349.4	2,008	10,270
1953	3,254	1,775	1,206	878.1	708.5	1,099
1954	1,008	896	665.7	2,491	2,147	2,826
1955	1,742	1,295	1,481	2,620	1,591	1,263
1956	919.9	923.8	1,377	1,672	1,747	884.5
1957	2,185	2,817	3,275	5,947	18,960	10,170
1958	4,565	3,279	4,840	3,390	5,939	5,343
1959	1,974	2,532	2,713	2,521	2,446	13,630
1960	3,921	2,933	3,273	3,079	3,221	9,556
1961	4,590	3,479	3,689	3,675	6,526	15,300
1962	1,111	1,534	4,850	6,390	5,394	3,090
1963	2,191	803.6	629	793.9	2,901	2,908
1964	990.7	2,130	3,128	2,684	2,079	3,735
1965	2,451	3,116	3,130	1,421	1,196	1,344
1966	3,373	7,469	2,959	3,008	1,447	2,725
1967	4,291	3,098	1,650	1,480	2,645	7,344
1968	3,273	3,397	2,564	2,603	2,891	8,717
1969	3,888	3,575	2,162	1,550	2,691	4,014
1970	1,161	960.6	1,235	2,024	3,857	4,340
1971	2,608	4,010	937.5	1,000	1,458	11,170
1972	1,102	1,977	3,162	2,835	25,370	17,910
1973	6,151	3,941	5,058	7,109	18,790	33,030
1974	4,746	1,575	19,410	5,764	22,080	21,410
1975	2,102	4,025	2,151	1,655	2,552	2,861
1976	5,269	2,307	2,434	3,457	4,405	4,737
1977	1,312	1,089	2,295	1,451	3,206	4,192
1978	2,068	1,570	1,777	1,077	5,436	10,260
1979	2,687	3,715	3,138	2,625	4,618	8,255
1980	1,777	1,425	1,766	4,929	7,884	6,496
1981	6,248	3,922	1,654	3,600	4,023	2,643
1982	2,322	2,603	1,499	2,027	5,863	41,930
1983	13,030	1,768	1,676	1,796	2,439	13,680

1984	1,384	2,751	1,864	18,200	17,810	20,850
1985	3,182	2,786	1,110	1,670	5,097	13,760
1986	5,437	2,682	1,828	2,366	8,641	10,360
1987	1,287	866	1,589	1,077	10,570	31,320
1988	1,223	1,364	1,473	1,877	12,660	11,360
1989	13,640	3,885	3,223	2,548	2,274	1,154
1990	3,013	2,617	1,993	6,322	4,389	11,670
1991	1,800	3,175	3,230	2,837	13,710	21,940
1992	4,582	3,379	3,764	1,911	2,966	11,080
1993	3,165	2,179	1,044	3,881	8,785	27,500
1994	7,187	3,689	3,359	3,248	12,200	13,900
1995	3,094	2,422	1,216	875.1	1,410	1,160
1996	2,197	3,552	1,725	3,236	9,383	22,500
1997	3,503	1,781	1,023	1,271	5,169	6,063
1998	1,233	1,333	2,050	4,909	2,851	10,250
1999	3,188	2,654	1,474	1,031	1,317	2,411
2000	5,315	3,059	1,573	1,065	7,484	10,080
2001	3,694	2,551	1,555	4,229	1,658	26,270
2002	3,471	2,853	1,425	1,403	2,558	7,495
2003	4,616	3,437	1,971	747	1,806	2,441
2004	8,809	4,306	2,377	2,814	12,010	14,620
2005	2,454	1,494	1,597	963.3	1,274	726.1
2006	2,832	2,036				
2007					1,235	1,130
2008	3,015	4,709	25,150	9,385	4,149	7,340
2009	6,668	15,330	14,380	48,050	18,460	32,530
2010	3,801	3,140	1,525	646.4	1,223	687.8
2011	2,899	2,297	1,551	432.1	5,847	14,040
2012	1,250	1,533	2,008	1,284	1,481	1,591
2013	3,694	4,091	3,123	904.8	5,156	15,560
2014	4,532	5,330	4,066	3,144	1,838	2,807
2015	12,470	3,375	1,599	1,234	6,085	20,980
2016	2,728	8,001	4,913			
2017	4,679	4,351				
2018	2,262	4,077	3,907	3,796	10,050	19,560
2019	17,220	4,820	2,098			
Mean of Monthly Discharge	3,310	2,450	2,670	2,970	5,210	9,650

Table 2 – 4: Camden stream gauge discharge data in (CFS) and log transformed units for the water year (September-October) from 1929-2019 for the Ouachita River at Camden, Arkansas. There are missing instrumental discharge data for the year 2007.

Year	WY Instrumental Discharge (ft3/s)	WY Instrumental Discharge Log Transformed
1929	74956.1994	11.2246592
1930	98359.0449	11.4963798
1931	34695.2807	10.454359
1932	123112.552	11.7208543
1933	58297.8922	10.9733212
1934	46670.4885	10.7508673
1935	119390.3	11.6901532
1936	27425.3324	10.2192224
1937	90944.6229	11.4180061
1938	136281.217	11.8224758
1939	108277.328	11.5924511
1940	37985.3511	10.5449559
1941	80579.6352	11.2970012
1942	99456.0238	11.5074709
1943	50763.7876	10.8349385
1944	92168.8485	11.4313775
1945	185418.214	12.1303692
1946	172199.066	12.0564065
1947	72674.5825	11.193747
1948	96919.8356	11.4816395
1949	112766.837	11.6330776
1950	153050.95	11.9385262
1951	81177.1754	11.3043894
1952	94196.9022	11.4531426
1953	116354.72	11.6643987
1954	28688.5544	10.2642535
1955	52799.6751	10.8742603
1956	45520.9359	10.7259276
1957	119305.081	11.6894392
1958	137905.332	11.8343227
1959	68228.2281	11.1306137
1960	83842.1787	11.3366915
1961	95075.2688	11.4624242
1962	104582.582	11.5577323
1963	41034.7224	10.6221739
1964	56436.9861	10.94088
1965	60396.9275	11.0086935

1966	65954.5897	11.0967218
1967	55956.6349	10.9323323
1968	132799.374	11.7965948
1969	91221.1742	11.4210423
1970	77753.316	11.2612965
1971	39424.6734	10.5821471
1972	43365.5147	10.6774198
1973	194167.278	12.1764753
1974	172483.356	12.058056
1975	148284.94	11.906891
1976	51568.5591	10.8506675
1977	66547.7327	11.1056748
1978	55600.2422	10.9259428
1979	153626.552	11.94228
1980	77207.6126	11.2542533
1981	77604.2241	11.2593771
1982	58905.5421	10.9836905
1983	137668.856	11.8326065
1984	87760.4199	11.3823659
1985	142869.474	11.8696867
1986	79015.4462	11.2773986
1987	63929.3495	11.0655338
1988	108788.001	11.5971563
1989	145474.001	11.8877527
1990	128953.834	11.7672097
1991	130920.543	11.7823459
1992	104148.141	11.5535696
1993	83543.2995	11.3331203
1994	112213.893	11.6281621
1995	95117.7699	11.4628711
1996	31384.8243	10.3540798
1997	130209.126	11.7768971
1998	88455.8148	11.3902584
1999	97022.0507	11.4826936
2000	44160.691	10.6955903
2001	114562.38	11.6488748
2002	116703.511	11.6673919
2003	78494.3267	11.2707816
2004	76676.0277	11.2473444
2005	78704.3272	11.2734534
2006	30370.5327	10.3212281
2007	-99	-99
2008	109365.275	11.6024487
2009	167555.373	12.0290692
2010	170734.118	12.0478628
2011	75655.3985	11.2339441

2012	82493.9579	11.3204803
2013	68902.2333	11.1404439
2014	103545.232	11.5477638
2015	171144.415	12.050263
2016	137519.067	11.8315179
2017	53360.8072	10.8848318
2018	88765.267	11.3937507
2019	181235.48	12.1075525

Table 2 – 5: Camden stream gauge discharge data in (CFS) and log transformed units for the summer months (June-August) from 1928-2019 for the Ouachita River at Camden, Arkansas. There are missing instrumental discharge data for the year 2007.

Year	JJA Instrumental Discharge (ft3/s)	JJA Instrumental Discharge Log Transformed
1929	4653.31183	8.44533447
1930	2220.99462	7.7057104
1931	2750.46022	7.91952353
1932	5690.4172	8.64653885
1933	1966.96452	7.58424678
1934	1370.75269	7.22311528
1935	18057.914	9.80133932
1936	1356.96774	7.21300789
1937	3448.74194	8.14576479
1938	3534.45161	8.17031344
1939	3939.46237	8.27879954
1940	13772.1183	9.53040141
1941	5430.31183	8.59975184
1942	6556.63441	8.7882327
1943	5460.30108	8.60525921
1944	4176.27957	8.33717607
1945	25572.6129	10.1492773
1946	12350.5807	9.42145836
1947	2965.64194	7.99484879
1948	2482.98925	7.81721846
1949	10675.6559	9.27572128
1950	8057.32258	8.99433659
1951	15211.9387	9.62983584
1952	3234.65591	8.08167784
1953	8045.03226	8.99281007
1954	3106.7957	8.04134715
1955	6000.76344	8.69964198

1956	2986.94194	8.00200538
1957	21837.4624	9.99138223
1958	11678.5269	9.36550713
1959	12628.5914	9.44371868
1960	11051.1936	9.31029372
1961	10291.6989	9.23909292
1962	5237.06559	8.56351662
1963	3662.84301	8.2059949
1964	4172.00968	8.33615314
1965	7973.13011	8.98383243
1966	12905.6237	9.46541844
1967	11632.3441	9.36154478
1968	19609.7742	9.8837834
1969	13039.8065	9.47576199
1970	7509.26344	8.92389266
1971	7517.85484	8.92503612
1972	3981.09247	8.28931155
1973	19229.9355	9.86422348
1974	37408.8925	10.5296637
1975	14636.2903	9.59125936
1976	14577.957	9.58726587
1977	4349.73226	8.37786957
1978	6203.66022	8.73289475
1979	20237.2581	9.91528064
1980	6544.67742	8.78640739
1981	28346.6667	10.2522647
1982	8796.22581	9.08207802
1983	20328.6452	9.91978626
1984	7708.4086	8.95006704
1985	8172.35484	9.00851238
1986	17681.0323	9.78024772
1987	3801.30108	8.24309868
1988	3871.29893	8.26134537
1989	26561.9785	10.1872361
1990	22220.0108	10.0087486
1991	9035.62366	9.10893023
1992	12122.957	9.40285621
1993	8902.52688	9.09409044
1994	13488.1183	9.50956445
1995	9213.7957	9.12845717
1996	8113.34409	9.0012654
1997	11876.871	9.38234817
1998	5433.33333	8.6003081
1999	7922.92473	8.9775157
2000	20282.8817	9.91753254
2001	13129.8602	9.48264432

2002	10598.2043	9.26843986
2003	25399.5591	10.1424871
2004	25066.172	10.1292745
2005	5998.41936	8.69925127
2006	8087.74194	8.99810485
2007	-99	-99
2008	11081.8817	9.31306678
2009	31465.172	10.3566366
2010	14298.6559	9.56792082
2011	18020.1075	9.7992435
2012	4082.09893	8.31436658
2013	31681.4946	10.363488
2014	21103.6237	9.95720004
2015	34922.8925	10.4608978
2016	15592.7097	9.65455876
2017	13054.6667	9.47690095
2018	7970.97742	8.9835624
2019	33338.8925	10.4144799

Table 5 – 6: Instrumental Camden stream gauge discharge data in (CFS) and log transformed units for the water year (October-September) from 1929-2019 for the Ouachita River at Camden, Arkansas. There are missing instrumental discharge data for the year 2007. Reconstructed Camden stream gauge discharge data in (CFS) and log transformed units for the water year (October-September) from 1767-2019 for the Ouachita River at Camden, Arkansas. There are missing reconstructed discharge data for the year 2007.

Year	**WY Instrumental Discharge (ft3/s)**	**WY Instrumental Discharge Log Transformed**	**WY Reconstructed Discharge (ft3/s)**	**WY Reconstructed Discharge Log Transformed**
1766	-99	-99	-99	-99
1767	-99	-99	25874.1583	10.161
1768	-99	-99	51688.9859	10.853
1769	-99	-99	87553.0347	11.38
1770	-99	-99	64344.0664	11.072
1771	-99	-99	80177.6438	11.292
1772	-99	-99	27364.4499	10.217
1773	-99	-99	46957.5838	10.757
1774	-99	-99	75432.9906	11.231
1775	-99	-99	96374.7966	11.476

1776	-99	-99	125492.34	11.74
1777	-99	-99	104715.246	11.559
1778	-99	-99	58806.0488	10.982
1779	-99	-99	46676.6818	10.751
1780	-99	-99	30791.6861	10.335
1781	-99	-99	146093.192	11.892
1782	-99	-99	119730.66	11.693
1783	-99	-99	126626.869	11.749
1784	-99	-99	87029.2893	11.374
1785	-99	-99	80418.5379	11.295
1786	-99	-99	73939.3174	11.211
1787	-99	-99	145074.111	11.885
1788	-99	-99	106830.634	11.579
1789	-99	-99	63069.9685	11.052
1790	-99	-99	72765.7022	11.195
1791	-99	-99	52470.1649	10.868
1792	-99	-99	73203.6089	11.201
1793	-99	-99	100107.511	11.514
1794	-99	-99	86595.2289	11.369
1795	-99	-99	129702.676	11.773
1796	-99	-99	153276.69	11.94
1797	-99	-99	148746.679	11.91
1798	-99	-99	103259.447	11.545
1799	-99	-99	93433.0111	11.445
1800	-99	-99	51948.0781	10.858
1801	-99	-99	34578.9364	10.451
1802	-99	-99	65120.8465	11.084
1803	-99	-99	81145.5715	11.304
1804	-99	-99	112645.388	11.632
1805	-99	-99	91308.5765	11.422
1806	-99	-99	55105.235	10.917
1807	-99	-99	50513.7068	10.83
1808	-99	-99	64215.5068	11.07
1809	-99	-99	46630.0285	10.75
1810	-99	-99	95034.9502	11.462
1811	-99	-99	123747.688	11.726
1812	-99	-99	74533.2043	11.219
1813	-99	-99	106937.518	11.58
1814	-99	-99	81879.1779	11.313
1815	-99	-99	105979.398	11.571
1816	-99	-99	82289.599	11.318
1817	-99	-99	119014.427	11.687
1818	-99	-99	62006.8412	11.035
1819	-99	-99	77497.4259	11.258
1820	-99	-99	57239.5287	10.955
1821	-99	-99	59100.8154	10.987

1822	-99	-99	66836.1914	11.11
1823	-99	-99	77419.9672	11.257
1824	-99	-99	43608.1788	10.683
1825	-99	-99	59100.8154	10.987
1826	-99	-99	95606.874	11.468
1827	-99	-99	55160.3678	10.918
1828	-99	-99	59994.0098	11.002
1829	-99	-99	80017.4488	11.29
1830	-99	-99	92041.9748	11.43
1831	-99	-99	53369.7828	10.885
1832	-99	-99	95894.1253	11.471
1833	-99	-99	107473.545	11.585
1834	-99	-99	44622.7903	10.706
1835	-99	-99	100408.285	11.517
1836	-99	-99	193881.03	12.175
1837	-99	-99	110968.316	11.617
1838	-99	-99	61083.6796	11.02
1839	-99	-99	63133.07	11.053
1840	-99	-99	88876.2294	11.395
1841	-99	-99	53690.9641	10.891
1842	-99	-99	73423.5494	11.204
1843	-99	-99	81633.9085	11.31
1844	-99	-99	49217.277	10.804
1845	-99	-99	83533.2471	11.333
1846	-99	-99	87816.0882	11.383
1847	-99	-99	137585.387	11.832
1848	-99	-99	95415.8513	11.466
1849	-99	-99	138829.244	11.841
1850	-99	-99	74757.1396	11.222
1851	-99	-99	39934.6641	10.595
1852	-99	-99	64537.3884	11.075
1853	-99	-99	104610.583	11.558
1854	-99	-99	74087.344	11.213
1855	-99	-99	21354.1205	9.969
1856	-99	-99	40416.7669	10.607
1857	-99	-99	71324.8448	11.175
1858	-99	-99	89054.1597	11.397
1859	-99	-99	44801.6389	10.71
1860	-99	-99	54014.0783	10.897
1861	-99	-99	65907.0042	11.096
1862	-99	-99	44489.1225	10.703
1863	-99	-99	33523.4341	10.42
1864	-99	-99	71182.3377	11.173
1865	-99	-99	97343.3794	11.486
1866	-99	-99	155904.668	11.957
1867	-99	-99	139804.458	11.848

1868	-99	-99	82043.1002	11.315
1869	-99	-99	142059.321	11.864
1870	-99	-99	106617.186	11.577
1871	-99	-99	114347.805	11.647
1872	-99	-99	122271.59	11.714
1873	-99	-99	134726.22	11.811
1874	-99	-99	51277.1237	10.845
1875	-99	-99	74161.4684	11.214
1876	-99	-99	137173.249	11.829
1877	-99	-99	95320.4832	11.465
1878	-99	-99	126373.868	11.747
1879	-99	-99	50362.3928	10.827
1880	-99	-99	57125.1641	10.953
1881	-99	-99	47051.5929	10.759
1882	-99	-99	96761.0678	11.48
1883	-99	-99	93153.1321	11.442
1884	-99	-99	93433.0111	11.445
1885	-99	-99	66903.061	11.111
1886	-99	-99	43826.7658	10.688
1887	-99	-99	57930.5408	10.967
1888	-99	-99	86768.5927	11.371
1889	-99	-99	103569.69	11.548
1890	-99	-99	117830.214	11.677
1891	-99	-99	100408.285	11.517
1892	-99	-99	151448.362	11.928
1893	-99	-99	116657.783	11.667
1894	-99	-99	65512.7461	11.09
1895	-99	-99	74384.2868	11.217
1896	-99	-99	39974.6187	10.596
1897	-99	-99	54775.5935	10.911
1898	-99	-99	97246.0846	11.485
1899	-99	-99	80177.6438	11.292
1900	-99	-99	57296.7969	10.956
1901	-99	-99	53690.9641	10.891
1902	-99	-99	66502.8445	11.105
1903	-99	-99	144494.973	11.881
1904	-99	-99	133119.167	11.799
1905	-99	-99	120090.391	11.696
1906	-99	-99	142343.724	11.866
1907	-99	-99	115959.932	11.661
1908	-99	-99	134188.392	11.807
1909	-99	-99	101620.443	11.529
1910	-99	-99	59694.7885	10.997
1911	-99	-99	46119.9089	10.739
1912	-99	-99	99409.2056	11.507
1913	-99	-99	58395.8439	10.975

1914	-99	-99	79777.7562	11.287
1915	-99	-99	126247.557	11.746
1916	-99	-99	77265.282	11.255
1917	-99	-99	58279.1689	10.973
1918	-99	-99	40174.9923	10.601
1919	-99	-99	48581.5933	10.791
1920	-99	-99	69842.6407	11.154
1921	-99	-99	75357.5954	11.23
1922	-99	-99	104297.221	11.555
1923	-99	-99	138275.037	11.837
1924	-99	-99	80017.4488	11.29
1925	-99	-99	47476.9686	10.768
1926	-99	-99	49315.8101	10.806
1927	-99	-99	131662.881	11.788
1928	-99	-99	144929.109	11.884
1929	74956.1984	11.2246592	167711.413	12.03
1930	98359.0463	11.4963798	61389.8628	11.025
1931	34695.2823	10.454359	53423.1793	10.886
1932	123112.555	11.7208543	56050.032	10.934
1933	58297.8912	10.9733212	62317.6518	11.04
1934	46670.4882	10.7508673	44134.6294	10.695
1935	119390.296	11.6901532	87029.2893	11.374
1936	27425.3323	10.2192224	25822.4617	10.159
1937	90944.6265	11.4180061	73939.3174	11.211
1938	136281.217	11.8224758	105873.472	11.57
1939	108277.332	11.5924511	76956.8381	11.251
1940	37985.3524	10.5449559	68665.3511	11.137
1941	80579.6327	11.2970012	75584.0076	11.233
1942	99456.0284	11.5074709	84965.4515	11.35
1943	50763.7857	10.8349385	68118.2197	11.129
1944	92168.85	11.4313775	103777.037	11.55
1945	185418.22	12.1303692	228205.085	12.338
1946	172199.075	12.0564065	158577.704	11.974
1947	72674.5839	11.193747	88344.5686	11.389
1948	96919.8377	11.4816395	157471.536	11.967
1949	112766.84	11.6330776	151448.362	11.928
1950	153050.957	11.9385262	169736.073	12.042
1951	81177.1758	11.3043894	119372.006	11.69
1952	94196.9046	11.4531426	52891.6098	10.876
1953	116354.716	11.6643987	40174.9923	10.601
1954	28688.5538	10.2642535	50766.9078	10.835
1955	52799.6742	10.8742603	47098.668	10.76
1956	45520.9346	10.7259276	36388.2064	10.502
1957	119305.081	11.6894392	53369.7828	10.885
1958	137905.328	11.8343227	95320.4832	11.465
1959	68228.2308	11.1306137	101113.608	11.524

1960	83842.1799	11.3366915	92503.3371	11.435
1961	95075.2726	11.4624242	99608.223	11.509
1962	104582.582	11.5577323	100810.722	11.521
1963	41034.7234	10.6221739	47334.7511	10.765
1964	56436.9858	10.94088	43088.008	10.671
1965	60396.9267	11.0086935	68528.1576	11.135
1966	65954.593	11.0967218	41274.4936	10.628
1967	55956.6353	10.9323323	74384.2868	11.217
1968	132799.374	11.7965948	71182.3377	11.173
1969	91221.1722	11.4210423	60415.4412	11.009
1970	77753.3177	11.2612965	54995.1347	10.915
1971	39424.6723	10.5821471	85220.7306	11.353
1972	43365.5142	10.6774198	76803.0783	11.249
1973	194167.273	12.1764753	127388.914	11.755
1974	172483.352	12.058056	172818.986	12.06
1975	148284.944	11.906891	261973.858	12.476
1976	51568.5619	10.8506675	170757.551	12.048
1977	66547.7358	11.1056748	61574.3089	11.028
1978	55600.2402	10.9259428	68871.6564	11.14
1979	153626.56	11.94228	47476.9686	10.768
1980	77207.6095	11.2542533	77207.6095	11.2542533
1981	77604.2211	11.2593771	77604.2211	11.2593771
1982	58905.5445	10.9836905	58905.5445	10.9836905
1983	137668.858	11.8326065	137668.858	11.8326065
1984	87760.4217	11.3823659	87760.4217	11.3823659
1985	142869.471	11.8696867	142869.471	11.8696867
1986	79015.4435	11.2773986	79015.4435	11.2773986
1987	63929.347	11.0655338	63929.347	11.0655338
1988	108787.999	11.5971563	108787.999	11.5971563
1989	145474.006	11.8877527	145474.006	11.8877527
1990	128953.828	11.7672097	128953.828	11.7672097
1991	130920.546	11.7823459	130920.546	11.7823459
1992	104148.141	11.5535696	104148.141	11.5535696
1993	83543.2967	11.3331203	83543.2967	11.3331203
1994	112213.894	11.6281621	112213.894	11.6281621
1995	95117.7712	11.4628711	95117.7712	11.4628711
1996	31384.8258	10.3540798	31384.8258	10.3540798
1997	130209.126	11.7768971	130209.126	11.7768971
1998	88455.8114	11.3902584	88455.8114	11.3902584
1999	97022.0547	11.4826936	97022.0547	11.4826936
2000	44160.6897	10.6955903	44160.6897	10.6955903
2001	114562.385	11.6488748	114562.385	11.6488748
2002	116703.511	11.6673919	116703.511	11.6673919
2003	78494.3244	11.2707816	78494.3244	11.2707816
2004	76676.0283	11.2473444	76676.0283	11.2473444
2005	78704.3259	11.2734534	78704.3259	11.2734534

2006	30370.5328	10.3212281	30370.5328	10.3212281
2007	-99	-99	-99	-99
2008	109365.274	11.6024487	109365.274	11.6024487
2009	167555.38	12.0290692	167555.38	12.0290692
2010	170734.125	12.0478628	170734.125	12.0478628
2011	75655.4001	11.2339441	75655.4001	11.2339441
2012	82493.9553	11.3204803	82493.9553	11.3204803
2013	68902.2354	11.1404439	68902.2354	11.1404439
2014	103545.23	11.5477638	103545.23	11.5477638
2015	171144.413	12.050263	171144.413	12.050263
2016	137519.073	11.8315179	137519.073	11.8315179
2017	53360.8068	10.8848318	53360.8068	10.8848318
2018	88765.2657	11.3937507	88765.2657	11.3937507
2019	181235.487	12.1075525	181235.487	12.1075525

Table 5 – 7: Instrumental Camden stream gauge discharge data in (CFS) and log transformed units for the summer (June-August) from 1929-2019 for the Ouachita River at Camden, Arkansas. There are missing instrumental discharge data for the year 2007. Reconstructed Camden stream gauge discharge data in (CFS) and log transformed units for the summer (June-August) from 1668-2019 for the Ouachita River at Camden, Arkansas. There are missing reconstructed discharge data for the year 2007.

Year	**JJA Instrumental Discharge (ft3/s)**	**JJA Instrumental Discharge Log Transformed**	**JJA Reconstructed Discharge (ft3/s)**	**JJA Reconstructed Discharge Log Transformed**
1667	-99	-99	-99	-99
1668	-99	-99	12733.60703	9.452
1669	-99	-99	15229.65815	9.631
1670	-99	-99	10331.98807	9.243
1671	-99	-99	4011.818866	8.297
1672	-99	-99	14779.55373	9.601
1673	-99	-99	6768.264625	8.82
1674	-99	-99	10916.16503	9.298
1675	-99	-99	6528.940774	8.784
1676	-99	-99	5281.682599	8.572
1677	-99	-99	4831.923947	8.483
1678	-99	-99	7339.30918	8.901
1679	-99	-99	2149.520343	7.673

1680	-99	-99	17961.75403	9.796
1681	-99	-99	3759.344928	8.232
1682	-99	-99	16680.57254	9.722
1683	-99	-99	7065.647925	8.863
1684	-99	-99	9063.403584	9.112
1685	-99	-99	16915.7429	9.736
1686	-99	-99	22048.50328	10.001
1687	-99	-99	4831.923947	8.483
1688	-99	-99	10198.54151	9.23
1689	-99	-99	3245.419836	8.085
1690	-99	-99	12657.43413	9.446
1691	-99	-99	10137.53347	9.224
1692	-99	-99	9302.142231	9.138
1693	-99	-99	6788.599907	8.823
1694	-99	-99	9099.729802	9.116
1695	-99	-99	4555.087413	8.424
1696	-99	-99	7023.380965	8.857
1697	-99	-99	5054.327065	8.528
1698	-99	-99	7065.647925	8.863
1699	-99	-99	8883.936169	9.092
1700	-99	-99	13426.69274	9.505
1701	-99	-99	19791.345	9.893
1702	-99	-99	14030.657	9.549
1703	-99	-99	10107.16644	9.221
1704	-99	-99	9442.726107	9.153
1705	-99	-99	8955.292703	9.1
1706	-99	-99	22448.96972	10.019
1707	-99	-99	52838.74461	10.875
1708	-99	-99	6444.613857	8.771
1709	-99	-99	8569.802793	9.056
1710	-99	-99	5591.483972	8.629
1711	-99	-99	5756.011121	8.658
1712	-99	-99	5563.59633	8.624
1713	-99	-99	15444.37286	9.645
1714	-99	-99	20272.08306	9.917
1715	-99	-99	7037.441783	8.859
1716	-99	-99	6687.530821	8.808
1717	-99	-99	10208.74515	9.231
1718	-99	-99	2963.125789	7.994
1719	-99	-99	5872.290258	8.678
1720	-99	-99	2096.448497	7.648
1721	-99	-99	6081.459527	8.713
1722	-99	-99	2942.456336	7.987
1723	-99	-99	4183.903745	8.339
1724	-99	-99	9537.627082	9.163
1725	-99	-99	12951.92882	9.469

1726	-99	-99	4675.072736	8.45
1727	-99	-99	2022.318693	7.612
1728	-99	-99	769.6993623	6.646
1729	-99	-99	4969.129734	8.511
1730	-99	-99	6418.88689	8.767
1731	-99	-99	3118.165104	8.045
1732	-99	-99	6167.198735	8.727
1733	-99	-99	9887.236877	9.199
1734	-99	-99	10137.53347	9.224
1735	-99	-99	10026.63168	9.213
1736	-99	-99	3579.577301	8.183
1737	-99	-99	14271.21713	9.566
1738	-99	-99	50614.8353	10.832
1739	-99	-99	45297.17738	10.721
1740	-99	-99	32016.28633	10.374
1741	-99	-99	2517.445561	7.831
1742	-99	-99	9172.81961	9.124
1743	-99	-99	4619.307126	8.438
1744	-99	-99	15305.99713	9.636
1745	-99	-99	15693.47029	9.661
1746	-99	-99	25693.67162	10.154
1747	-99	-99	15994.49693	9.68
1748	-99	-99	25134.58336	10.132
1749	-99	-99	37197.61778	10.524
1750	-99	-99	63576.55187	11.06
1751	-99	-99	7895.119005	8.974
1752	-99	-99	2230.542258	7.71
1753	-99	-99	4171.370843	8.336
1754	-99	-99	1893.154946	7.546
1755	-99	-99	5984.930467	8.697
1756	-99	-99	6051.128121	8.708
1757	-99	-99	7208.383481	8.883
1758	-99	-99	19034.34009	9.854
1759	-99	-99	11036.9057	9.309
1760	-99	-99	8647.279139	9.065
1761	-99	-99	19399.45011	9.873
1762	-99	-99	11316.3063	9.334
1763	-99	-99	6342.320564	8.755
1764	-99	-99	17943.80125	9.795
1765	-99	-99	9887.236877	9.199
1766	-99	-99	10363.03058	9.246
1767	-99	-99	4019.850533	8.299
1768	-99	-99	4764.748338	8.469
1769	-99	-99	8919.54308	9.096
1770	-99	-99	4596.268235	8.433
1771	-99	-99	8751.67159	9.077

1772	-99	-99	2206.140748	7.699
1773	-99	-99	2815.795236	7.943
1774	-99	-99	6161.034619	8.726
1775	-99	-99	4328.602411	8.373
1776	-99	-99	5519.26512	8.616
1777	-99	-99	15882.9264	9.673
1778	-99	-99	14242.70322	9.564
1779	-99	-99	17872.1694	9.791
1780	-99	-99	7808.748604	8.963
1781	-99	-99	41606.01387	10.636
1782	-99	-99	6594.55772	8.794
1783	-99	-99	5239.597702	8.564
1784	-99	-99	6002.912217	8.7
1785	-99	-99	21785.5024	9.989
1786	-99	-99	11801.71336	9.376
1787	-99	-99	43303.98751	10.676
1788	-99	-99	9623.853161	9.172
1789	-99	-99	3692.282096	8.214
1790	-99	-99	7051.530751	8.861
1791	-99	-99	8527.060723	9.051
1792	-99	-99	4359.008926	8.38
1793	-99	-99	4385.241599	8.386
1794	-99	-99	4904.949126	8.498
1795	-99	-99	17765.25744	9.785
1796	-99	-99	14058.74639	9.551
1797	-99	-99	18844.94524	9.844
1798	-99	-99	13240.02874	9.491
1799	-99	-99	11884.61517	9.383
1800	-99	-99	3019.963427	8.013
1801	-99	-99	3442.661007	8.144
1802	-99	-99	8655.930743	9.066
1803	-99	-99	5756.011121	8.658
1804	-99	-99	13561.63324	9.515
1805	-99	-99	15677.78467	9.66
1806	-99	-99	9585.434637	9.168
1807	-99	-99	5591.483972	8.629
1808	-99	-99	13413.27276	9.504
1809	-99	-99	10796.74523	9.287
1810	-99	-99	7108.169249	8.869
1811	-99	-99	14228.46764	9.563
1812	-99	-99	2261.989467	7.724
1813	-99	-99	12295.63991	9.417
1814	-99	-99	10689.31582	9.277
1815	-99	-99	11660.93914	9.364
1816	-99	-99	11327.62827	9.335
1817	-99	-99	29143.87355	10.28

1818	-99	-99	14285.49549	9.567
1819	-99	-99	38715.68136	10.564
1820	-99	-99	31761.17783	10.366
1821	-99	-99	40376.37033	10.606
1822	-99	-99	20475.82089	9.927
1823	-99	-99	20743.74429	9.94
1824	-99	-99	4380.858549	8.385
1825	-99	-99	1423.679505	7.261
1826	-99	-99	1766.932021	7.477
1827	-99	-99	1579.715427	7.365
1828	-99	-99	3991.809836	8.292
1829	-99	-99	2588.93015	7.859
1830	-99	-99	6136.439703	8.722
1831	-99	-99	1446.641584	7.277
1832	-99	-99	1543.796621	7.342
1833	-99	-99	2016.260828	7.609
1834	-99	-99	1318.170409	7.184
1835	-99	-99	3222.781224	8.078
1836	-99	-99	4707.913052	8.457
1837	-99	-99	1974.360841	7.588
1838	-99	-99	750.6954173	6.621
1839	-99	-99	1243.891437	7.126
1840	-99	-99	2004.199484	7.603
1841	-99	-99	2815.795236	7.943
1842	-99	-99	6967.418067	8.849
1843	-99	-99	7887.227832	8.973
1844	-99	-99	6754.741624	8.818
1845	-99	-99	18750.95569	9.839
1846	-99	-99	3477.260326	8.154
1847	-99	-99	10561.81059	9.265
1848	-99	-99	8561.237274	9.055
1849	-99	-99	42277.06418	10.652
1850	-99	-99	15244.89543	9.632
1851	-99	-99	5502.732137	8.613
1852	-99	-99	3804.728826	8.244
1853	-99	-99	19712.33774	9.889
1854	-99	-99	10488.13608	9.258
1855	-99	-99	14200.03914	9.561
1856	-99	-99	15898.81727	9.674
1857	-99	-99	7715.603608	8.951
1858	-99	-99	35277.47721	10.471
1859	-99	-99	26344.11001	10.179
1860	-99	-99	37835.38293	10.541
1861	-99	-99	17274.72967	9.757
1862	-99	-99	28197.82144	10.247
1863	-99	-99	7942.632116	8.98

1864	-99	-99	29643.55466	10.297
1865	-99	-99	24959.25564	10.125
1866	-99	-99	27501.61475	10.222
1867	-99	-99	14559.51484	9.586
1868	-99	-99	3350.952792	8.117
1869	-99	-99	6654.176622	8.803
1870	-99	-99	9509.057078	9.16
1871	-99	-99	12977.8586	9.471
1872	-99	-99	14086.89202	9.553
1873	-99	-99	19380.06036	9.872
1874	-99	-99	4856.144066	8.488
1875	-99	-99	1533.02778	7.335
1876	-99	-99	5089.831475	8.535
1877	-99	-99	6124.179088	8.72
1878	-99	-99	10850.86414	9.292
1879	-99	-99	5907.629913	8.684
1880	-99	-99	26795.78827	10.196
1881	-99	-99	2175.469974	7.685
1882	-99	-99	6761.499744	8.819
1883	-99	-99	3245.419836	8.085
1884	-99	-99	5779.081275	8.662
1885	-99	-99	2046.732709	7.624
1886	-99	-99	2430.859069	7.796
1887	-99	-99	2588.93015	7.859
1888	-99	-99	4717.3383	8.459
1889	-99	-99	4679.750147	8.451
1890	-99	-99	9749.780004	9.185
1891	-99	-99	6380.488878	8.761
1892	-99	-99	22203.38425	10.008
1893	-99	-99	13684.23884	9.524
1894	-99	-99	17553.34835	9.773
1895	-99	-99	11248.61175	9.328
1896	-99	-99	3071.741673	8.03
1897	-99	-99	3367.749513	8.122
1898	-99	-99	20578.45636	9.932
1899	-99	-99	15914.72404	9.675
1900	-99	-99	8046.560403	8.993
1901	-99	-99	14472.4193	9.58
1902	-99	-99	9181.997018	9.125
1903	-99	-99	26396.85095	10.181
1904	-99	-99	36901.22399	10.516
1905	-99	-99	30031.43664	10.31
1906	-99	-99	39537.30755	10.585
1907	-99	-99	13226.79533	9.49
1908	-99	-99	7600.733236	8.936
1909	-99	-99	9302.142231	9.138

1910	-99	-99	49612.59441	10.812
1911	-99	-99	11248.61175	9.328
1912	-99	-99	53316.43971	10.884
1913	-99	-99	2617.565588	7.87
1914	-99	-99	10785.95388	9.286
1915	-99	-99	10764.40353	9.284
1916	-99	-99	10883.46561	9.295
1917	-99	-99	8664.591003	9.067
1918	-99	-99	1427.956957	7.264
1919	-99	-99	5329.432294	8.581
1920	-99	-99	4651.755713	8.445
1921	-99	-99	4092.862983	8.317
1922	-99	-99	3924.52263	8.275
1923	-99	-99	6039.037959	8.706
1924	-99	-99	19516.1967	9.879
1925	-99	-99	6502.877173	8.78
1926	-99	-99	2443.0438	7.801
1927	-99	-99	9556.721425	9.165
1928	-99	-99	9330.090559	9.141
1929	4653.3118	8.4453345	10657.29593	9.274
1930	2220.9946	7.7057104	1385.754451	7.234
1931	2750.4602	7.9195235	2326.220206	7.752
1932	5690.4172	8.6465389	4831.923947	8.483
1933	1966.9645	7.5842468	2933.642195	7.984
1934	1370.7527	7.2231153	935.4240913	6.841
1935	18057.914	9.8013393	8621.376175	9.062
1936	1356.9677	7.2130079	1190.346833	7.082
1937	3448.7419	8.1457648	6960.454132	8.848
1938	3534.4516	8.1703134	3350.952792	8.117
1939	3939.4624	8.2787995	5949.128398	8.691
1940	13772.118	9.5304014	7354.002487	8.903
1941	5430.3118	8.5997518	11248.61175	9.328
1942	6556.6344	8.7882327	6640.881569	8.801
1943	5460.3011	8.6052592	6247.895712	8.74
1944	4176.2796	8.3371761	4052.138316	8.307
1945	25572.613	10.149277	23813.31126	10.078
1946	12350.581	9.4214584	5388.379665	8.592
1947	2965.6419	7.9948488	4380.858549	8.385
1948	2482.9893	7.8172185	6863.686726	8.834
1949	10675.656	9.2757213	9376.857832	9.146
1950	8057.3226	8.9943366	9877.354582	9.198
1951	15211.939	9.6298358	14838.79034	9.605
1952	3234.6559	8.0816778	3442.661007	8.144
1953	8045.0323	8.9928101	3439.220067	8.143
1954	3106.7957	8.0413472	2050.83027	7.626
1955	6000.7634	8.699642	7295.405169	8.895

1956	2986.9419	8.0020054	1644.184836	7.405
1957	21837.462	9.9913822	27038.03886	10.205
1958	11678.527	9.3655071	6714.334516	8.812
1959	12628.591	9.4437187	22114.7481	10.004
1960	11051.194	9.3102937	13656.89771	9.522
1961	10291.699	9.2390929	12481.46471	9.432
1962	5237.0656	8.5635166	10916.16503	9.298
1963	3662.843	8.2059949	23202.14476	10.052
1964	4172.0097	8.3361531	6918.816445	8.842
1965	7973.1301	8.9838324	20170.97563	9.912
1966	12905.624	9.4654184	9916.943124	9.202
1967	11632.344	9.3615448	41068.63621	10.623
1968	19609.774	9.8837834	22471.42992	10.02
1969	13039.807	9.475762	11384.40824	9.34
1970	7509.2634	8.9238927	13200.36817	9.488
1971	7517.8548	8.9250361	9228.021969	9.13
1972	3981.0925	8.2893116	12861.58191	9.462
1973	19229.936	9.8642235	21916.60834	9.995
1974	37408.893	10.529664	28057.18422	10.242
1975	14636.29	9.5912594	19535.72266	9.88
1976	14577.957	9.5872659	12246.55559	9.413
1977	4349.7323	8.3778696	7457.682589	8.917
1978	6203.6602	8.7328948	7593.136302	8.935
1979	20237.258	9.9152806	12234.31515	9.412
1980	6544.6774	8.7864074	6544.677416	8.78640739
1981	28346.667	10.252265	28346.66598	10.2522647
1982	8796.2258	9.082078	8796.225781	9.08207802
1983	20328.645	9.9197863	20328.64512	9.91978626
1984	7708.4086	8.950067	7708.408616	8.95006704
1985	8172.3548	9.0085124	8172.354869	9.00851238
1986	17681.032	9.7802477	17681.03226	9.78024772
1987	3801.3011	8.2430987	3801.301093	8.24309868
1988	3871.2989	8.2613454	3871.298928	8.26134537
1989	26561.979	10.187236	26561.9787	10.1872361
1990	22220.011	10.008749	22220.01193	10.0087486
1991	9035.6237	9.1089302	9035.62368	9.10893023
1992	12122.957	9.4028562	12122.95704	9.40285621
1993	8902.5269	9.0940904	8902.526929	9.09409044
1994	13488.118	9.5095645	13488.11829	9.50956445
1995	9213.7957	9.1284572	9213.795677	9.12845717
1996	8113.3441	9.0012654	8113.34406	9.0012654
1997	11876.871	9.3823482	11876.87095	9.38234817
1998	5433.3333	8.6003081	5433.333344	8.6003081
1999	7922.9247	8.9775157	7922.924724	8.9775157
2000	20282.882	9.9175325	20282.88163	9.91753254
2001	13129.86	9.4826443	13129.8602	9.48264432

2002	10598.204	9.2684399	10598.2043	9.26843986
2003	25399.559	10.142487	25399.55924	10.1424871
2004	25066.172	10.129275	25066.17233	10.1292745
2005	5998.4194	8.6992513	5998.419339	8.69925127
2006	8087.7419	8.9981049	8087.74191	8.99810485
2007	-99	-99	-99	-99
2008	11081.882	9.3130668	11081.88176	9.31306678
2009	31465.172	10.356637	31465.17319	10.3566366
2010	14298.656	9.5679208	14298.65592	9.56792082
2011	18020.108	9.7992435	18020.10756	9.7992435
2012	4082.0989	8.3143666	4082.098935	8.31436658
2013	31681.495	10.363488	31681.49388	10.363488
2014	21103.624	9.9572	21103.62361	9.95720004
2015	34922.893	10.460898	34922.89115	10.4608978
2016	15592.71	9.6545588	15592.70975	9.65455876
2017	13054.667	9.476901	13054.6667	9.47690095
2018	7970.9774	8.9835624	7970.977407	8.9835624
2019	33338.893	10.41448	33338.89125	10.4144799