ERDC/CHL TR-23-7

Coastal and Hydraulics Laboratory

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Regional Sediment Management

Geomorphic Assessment of the St. Francis River

Between Wappapello Lake and Lake City

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Abstract

The St. Francis River is a complex system that lies in the historic floodplain of the Mississippi and Ohio Rivers. The basin has undergone extensive anthropogenic modifications, including reservoir construction, large-scale channelization, and construction of leveed floodways. Several analyses of available gage data, lidar data, and historical research have provided a picture of geomorphic trends and an overall understanding of the river's stability. The types of analysis used to determine trends included yearly low stage plots, stage-duration curves, specific gage analysis, water surface slopes, and stream power changes. The results from these analyses were synthesized to develop an overall assessment of the reach. Channel cutoffs resulted in a significant decrease in channel length and sinuosity and triggered geomorphic change throughout the river. Immediately following channelization, dramatic decreasing trends in stage were observed for Fisk and Dekyn's Store, while St. Francis and Holly Island began to aggrade. Slopes and stream power were significantly increased for the upper portion of the study area and showed a decreasing trend for the lower reach.

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Preface

This study was conducted for the Regional Sediment Management program funded by the US Army Engineer Research and Development Center (ERDC), funding account code U4384647; AMSCO code 008303.

The work was performed by the Hydraulics and Hydrology branch of the US Army Corps of Engineers (USACE) Memphis District (MVM) and the River and Estuarine Engineering branch of ERDC's Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, COL Brian Sawser was the commander of MVM, and Mr. Michael Clay was the Hydraulics and Hydrology branch chief. Mr. David P. May was the River and Estuarine Engineering branch chief, and Dr. Cary A. Talbot was the division chief for the Flood and Storm Protection Division. The deputy director of ERDC-CHL was Mr. Keith Flowers, and Dr. Ty V. Wamsley was the director.

In addition to those who worked directly on this project, the authors would like to thank the additional Water Control office staff, Tim Belles and Seth Kuykendall, for their assistance in tirelessly working to locate, compile, and review data for the entire period of record used in the gage analyses in this report. Additionally, the MVM field staff's knowledge was invaluable for providing historical context and insight into how data were collected for the past 20 years and into current gage maintenance and discharge measurement collection.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

The Lower St. Francis Basin has been significantly altered by private landowners, local drainage districts, and the US Army Corps of Engineers (USACE) Memphis District (MVM). The lower portion of the basin extends from Wappapello Lake (managed by the St. Louis District) to the confluence with the Mississippi River. Since the Flood Control Act of 1928 was enacted (as a result of the Great Mississippi Flood of 1927), the lower portion of the basin has been altered to include a reservoir, a series of levees, channelization and cutoffs, and a floodway.

Each year, MVM spends millions of dollars conducting channel cleanouts, scour repairs, and clearing and snagging throughout the St. Francis Basin. One reach in particular, a 5.4 mi reach of the St. Francis below Arkansas Highway 90 (near Kennett, Missouri), requires a cleanout at least every five years at a cost between $2 million and $5 million.*

1.1 Background

The St. Francis Basin comprises approximately 9,703 sq mi of land in the Missouri bootheel and northeastern Arkansas. Geologically, the Greater St. Francis Basin is divided into the Upper St. Francis Basin within the Ozark Plateau (encompassing the sections labeled *Above Wappapello* and *Whitewater-Castor Diversion* in Figure 1) and the Lower St. Francis Basin (composed of all other basins). The St. Francis Basin is a low relief area within the ancient Mississippi River and Ohio River floodplain, as shown in Figure 1.

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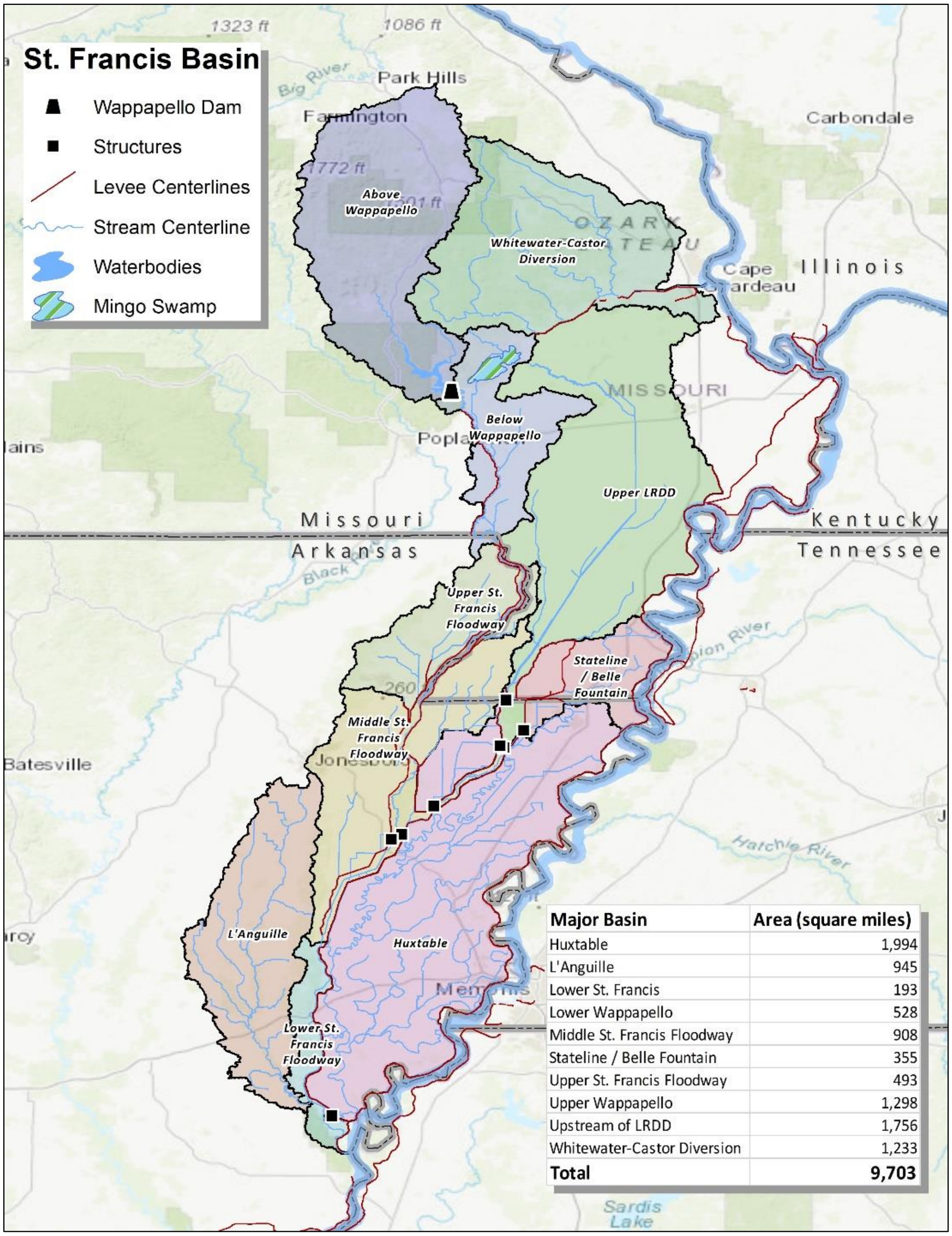
* For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 245–252, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 1. Major drainage basins and features within the St. Francis Basin.



Major Basin	Area (square miles)
Huxtable	1,994
L'Anguille	945
Lower St. Francis	193
Lower Wappapello	528
Middle St. Francis Floodway	908
Stateline / Belle Fountain	355
Upper St. Francis Floodway	493
Upper Wappapello	1,298
Upstream of LRDD	1,756
Whitewater-Castor Diversion	1,233
Total	**9,703**

1.2 Objectives

The goal of this study was to perform a geomorphic assessment of a 105 mi stretch of the St. Francis River to document the historical trends in the channel system and determine the current stability of the river channel.

Conclusions about each reach were based on a series of analyses supported by historical alterations to the basin.

1.3 Approach

A geomorphic analysis was conducted on a 105 mi reach of the St. Francis River, extending from Wappapello Lake to Lake City, Arkansas, to document long-term trends in river stability and establish the existing conditions. The analyses included specific gages, using period-of-record data for each gage; stage-duration plots; frequency analyses; sinuosity between reaches; stream-power; lidar-based slope analysis; and a review of historical aerial imagery. Ultimately, this study will help MVM understand where sediment sources originate and which specific reaches may contribute to the continual aggradation issues below Arkansas Highway 90. Data collected and analyses performed for this effort will inform future management decisions for the St. Francis River and its watershed.

2 History of the St. Francis Basin

Prior to flood control and drainage improvements made in the early 1900s, the Lower St. Francis Basin had a long history of frequent flooding due to backwater events from the Mississippi River and headwater events from the St. Francis, Mississippi, and Castor Rivers. These frequent floods and the flat terrain of the area created uninhabitable swampland throughout the majority of the Lower St. Francis Basin (USACE 1949).

Local drainage districts and logging companies developed a major drainage improvement plan at the turn of the 20th century. This plan included diverting 1,200 sq mi (i.e., the Whitewater and Castor Rivers) directly to the Mississippi River and creating hundreds of miles of new drainage channels and levees. These improvements were successful enough to allow logging activities, but they were largely inadequate in general because the levees still overtopped annually and crevassed often. To address flooding problems, Congress authorized USACE MVM to develop a comprehensive flood control plan in 1936 (USACE 1949).

Land use changes throughout the basin and the construction of flood control and drainage features resulted in a significantly altered discharge regime that, in turn, altered the sediment concentrations and transport capacity of the river. Since the flood control plan was developed in 1936, MVM has completed significant flood control improvements, including the construction of Wappapello Dam, the diversion of the Castor River, and the creation of levees, pump stations, the Wilhelmina Cutoff, and other channelizations.

Portions of the Lower St. Francis River within the leveed floodway are heavily aggradational, resulting in standing water that is unable to drain during low-flow conditions. Long periods of inundation have led to tree die-offs and debris jams in the river. To alleviate some of these problems, MVM most recently constructed a 5.4 mi drainage channel and two sediment traps below Arkansas Highway 90 to alleviate year-round ponded water on the floodway levees. The channel and sediment traps were designed to be cleaned out on a regular maintenance schedule every five years (West Consultants 1999); however, the construction schedule to clean out the channel typically takes two to three years, and by the end of the construction period, the channel has filled back in. Maintaining the channel has become an economic sink (i.e., approximately $5 million every five years) and a difficult construction task due to frequent high water and limited access in this reach. Other reaches within the basin are believed to be aggrading as well. Table 1 provides a historic timeline of construction activities that occurred within the St. Francis Basin and were performed by the MVM or the local drainage districts. Each major improvement lists a corresponding drainage basin in italics that can be referenced in Figure 1 for placement within the basin.

Table 1. Timeline of major events in the St. Francis River Basin. The basin in which the improvement took place is in parentheses at the end of each entry.

Year	Major Events
1915–1920	Little River Drainage District (LRDD) constructed the Little River Diversion Channel that diverted 1,233 sq mi from the St. Francis Basin to the Mississippi River (*Whitewater–Castor Diversion*).
1920	River gage installed at Wappapello, Missouri (between *Above and Below Wappapello*).
1936	Local interests constructed levees from the foothills near Wappapello, Missouri, to the Poinsette–Cross County line. This diverted flood flows from the natural channel above Marked Tree into a leveed floodway known as Oak Donnick to St. Francis Bay.
1938–1948	USACE MVM constructed levees.
1939	Marked Tree Siphon and navigation lock completed (*Huxtable*).
1941	Wappapello Dam construction is completed and forms a 625,000 ac-ft reservoir, which regulates 1,310 sq mi of Ozark Uplands (*Above Wappapello*).
1942	Clearing and snagging for logging navigation below Marked Tree, Arkansas (*Huxtable*).
1964–1973	Wappapello to Crowley's Ridge St. Francis River channelization and Wilhelmina Cutoff (*Below Wappapello*).
1967	Wilhelmina Cutoff construction completed (*Below Wappapello*).
1966	Ditch 12 enlargement and realignment (*Below Wappapello*).
1971	Dudley Ditch and Lick Creek scour repairs to four bridges—one at the confluence of the St. Francis River (*Below Wappapello*).
1971	St. Francis cleanout of main channel upstream and downstream of Highway 53 located between Fisk and St. Francis, Missouri (*Below Wappapello*).
1972	Crop losses and permanent damage to privately owned land due to sanding and increased flooding are first reported below Wilhelmina Cutoff (*Below Wappapello*).
1973	Dudley Ditch channel enlargement from 30 ft bottom width to 70 ft bottom width sections (*Below Wappapello*).
1974	Mingo Ditch channel enlargements (*Below Wappapello*).
1975	Removed sediment plug in Dudley Ditch at Pacific Railroad bridge crossing (*Below Wappapello*).
1976	St. Francis Lake Control Structure was constructed (*Middle St. Francis Floodway*).
1977	USACE and USGS partner to begin a sediment sampling program in the St. Francis Basin.

Table 1 (cont.). Timeline of major events in the St. Francis River Basin. The basin in which the improvement took place is in parentheses at the end of each entry.

Year	Major Events
1977–1979	Wappapello to Crowley's Ridge channel cleanout, including Wilhelmina Cutoff (*Below Wappapello*).
1980	Scour repair at the mouth of Dudley Ditch (*Below Wappapello*).
1982	Legal determination made that Wilhelmina Cutoff had induced sanding and flooding damages to nine parcels of land (*Below Wappapello*).
1994	Dudley Ditch channel clearing (*Below Wappapello*).
2000	Cleanout of St. Francis River from Highway 90 to Missouri state line (*Upper St. Francis Floodway*).
2002	Dudley Ditch grade control structure built at Missouri County Road 642—approximately 4.8 mi upstream of St. Francis River (*Below Wappapello*).
~2003	Scour protection at the bridge over Mingo Ditch at SR 448 was constructed, acting as a grade control structure (*Below Wappapello*).
2003	Highway U Bridge scour repair between Fisk and St. Francis, Missouri, on St. Francis River with grade control (*Below Wappapello*).
2008	Cleanout of St. Francis River from Highway 90 to Missouri state line begins construction (*Upper St. Francis Floodway*).
2021	Cleanout of St. Francis River from Highway 90 to Missouri state line begins construction (*Upper St. Francis Floodway*).

An understanding of the history of the St. Francis Basin and the associated geomorphic changes is needed to develop a basin-wide comprehensive plan to address sedimentation. This construction history does not include local controls and construction activities, such as bridges, boat ramps, or other features, that may also act as grade control.

2.1 Pre-1800: Geologic History of the Basin

A large portion of the Lower St. Francis Basin (i.e., from below Crowley's Ridge to the present-day confluence with the Mississippi River near Helena, Arkansas) overlays the ancient, braided Ohio River and Mississippi River channels (Saucier 1964). Most of the St. Francis Basin is composed of a shallow layer of loess or silty clay underlain by a thick layer of fine sand. Because this area was the ancient path for the Ohio and Mississippi Rivers, the relief throughout the basin is minimal. Some portions of the St. Francis River have up to a 1 ft/mi slope, while most of the reach below Kennett, Missouri, has a 0.0–0.5 ft/mi slope. This area is commonly referred to as the *Sunken Lands* and is distinguished by dying timber and swampland. Many believe the Sunken Lands appeared during the 1811–1812 earthquakes. However, geologic evidence supports the theory that the Sunken Lands were a result of alluvial drowning as the Mississippi River formed new distributaries through the Left Hand Chute of the Little River. This addition of water to the Little River system increased discharge for the most southerly portion of the St. Francis River, creating a deeper channel with more pronounced natural levees that essentially cutoff the upper portion of the St. Francis River and created a sunken area disconnected from the primary flow coming from the Mississippi River (Saucier 1970).

2.2 1800–1910: Before Drainage and Flood Control Measures

The Lower St. Francis Basin was largely uninhabited until the mid- to late-1800s because most of the basin was swampland (USACE 1949). As part of the Swamp Land Act of 1850, the federal government turned over the St. Francis Basin to Missouri and Arkansas with the understanding that each state would improve drainage and convert the swampland to arable land (LRDD, n.d.). Timber companies purchased the majority of the land tracts within the St. Francis Basin for a very minimal price because the land was so undesirable to other investors. By the early 1900s, a large portion of the basin was cleared of its hardwood timber, and portions of the St. Francis River were considered navigable (USACE 1939). Timber resources within the basin were exhausted by the mid-1920s, so timber companies began devising a plan to drain and improve the lands to allow the nutrient-rich land to be farmed.

2.3 1910–1936: Early Drainage and Flood Control Measures

Timber activities continued to be a vital part of the economy through 1925. With the depletion of the bottomland hardwood forests, investors and local drainage entities began implementing flood control measures in an attempt to stabilize agricultural activities and prevent flood waters from the Mississippi River and St. Francis headwaters from destroying farms (USACE 1949). The first form of flood protection started with the construction of an embankment on the right descending bank of the Mississippi River from New Madrid, Missouri, to Helena, Arkansas. This levee is presently referred to as the St. Francis Levee.

Simultaneously, the Little River Drainage District (LRDD; n.d.) began the construction of significant drainage improvements, which included the Headwater Diversion and hundreds of miles of channel to drain the swampland. The Headwater Diversion (i.e., the Whitewater-Castor Diversion in Figure 1) diverts over 1,233 sq mi from the St. Francis Basin to the Mississippi River just below Cape Girardeau, Missouri. The LRDD also constructed hundreds of miles of drainage ditches and over 250 mi of levee to drain the Missouri bootheel to prevent flooding of the nearby farmland (Upper LRDD in Figure 1).

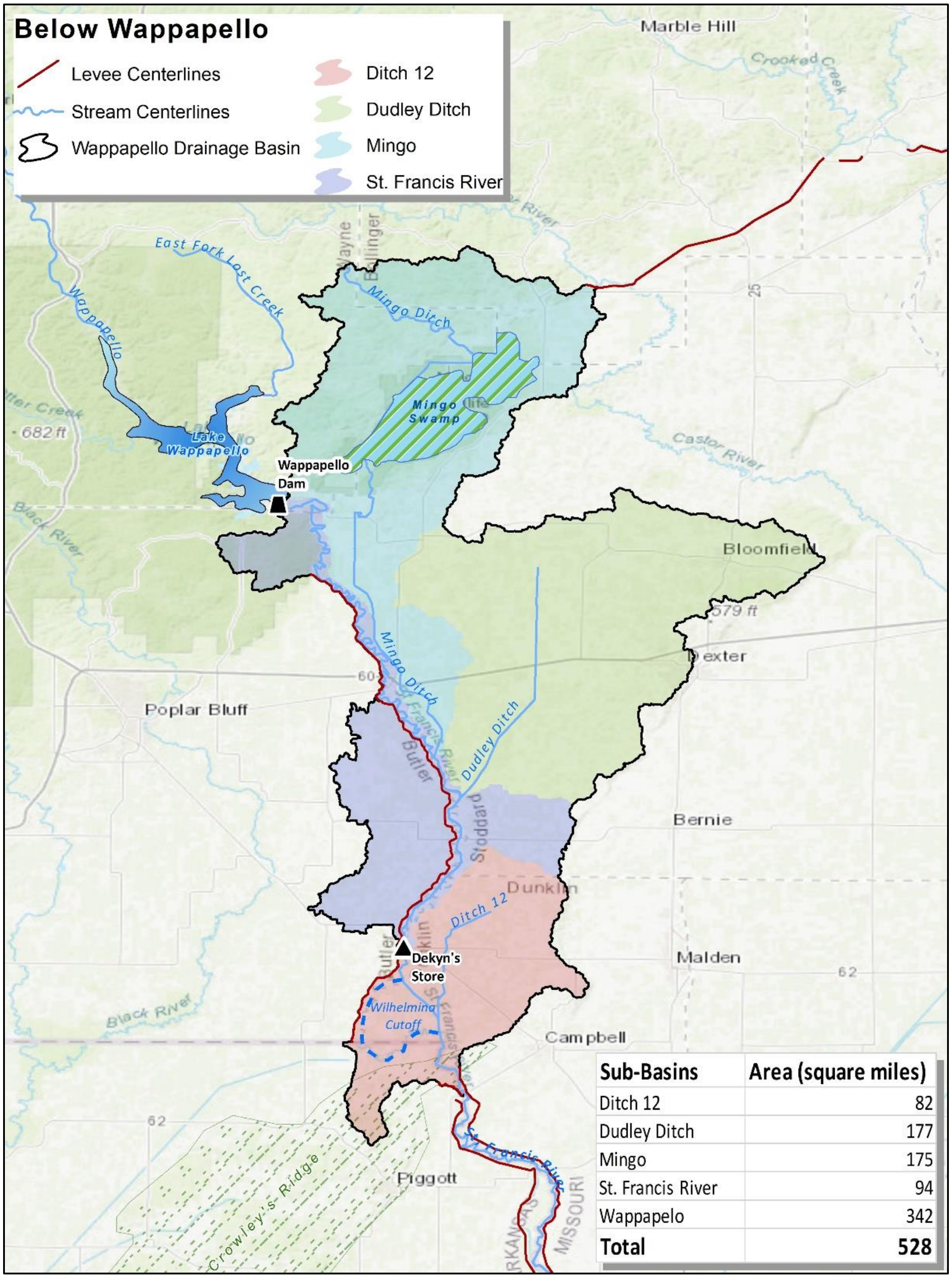
Near Wappapello, Missouri, farmers constructed earthen embankments on either side of the St. Francis River in an attempt to prevent floodwaters from the Ozarks from flooding their crops. The earthen embankments eventually turned into a floodway that extended south to Marked Tree, Arkansas, just south of where the Little River ditches tie back into the St. Francis River.

Many of the drainage improvements that were constructed by local entities were severely undersized. Levees crevassed frequently, and the improvements were unable to handle even annual flood flows. While USACE was authorized to assist locals with flood prevention through the Flood Control Act of 1928, the severity of the flood problem throughout the St. Francis Basin was not truly recognized until 1936, when Congress authorized USACE to develop a comprehensive flood control plan to be developed by the MVM (USACE 1949).

2.4 1936–1977: Federally Authorized Flood Control Plan

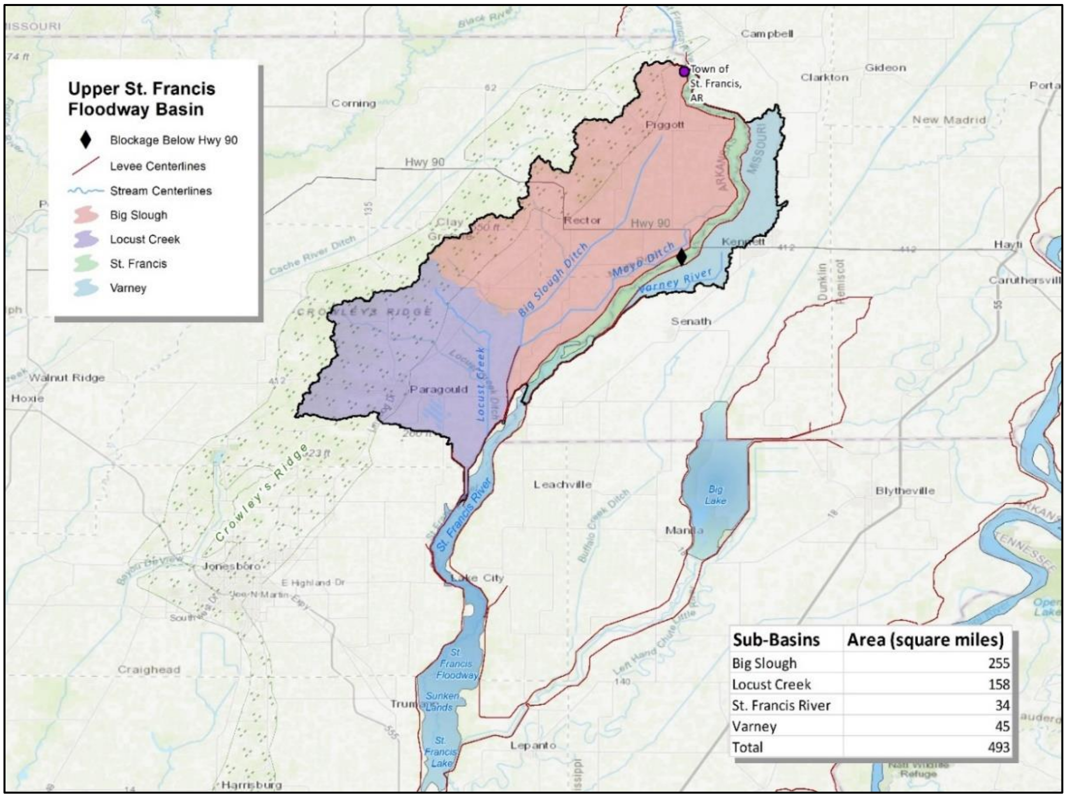
USACE MVM developed a flood control plan that included construction of a reservoir near Wappapello, Missouri; a channel cutoff near Wilhelmina, Missouri; miles of channel enlargement and straightening of the St. Francis River and several of its tributaries; improvement of the St. Francis Levee System (on the right descending bank of the Mississippi River); and leveed floodways throughout the majority of the Lower St. Francis Basin (USACE 1964). The first plan elements completed were the construction of Wappapello Dam, improvement of the St. Francis Levee System, and the leveed floodways that extended from St. Francis, Arkansas, to the confluence of the Mississippi River. The layout of the basin from below Wappapello Dam to the floodway is shown in Figures 2 and 3.

Figure 2. Major features in the Below Wappapello Basin.



Sub-Basins	Area (square miles)
Ditch 12	82
Dudley Ditch	177
Mingo	175
St. Francis River	94
Wappapelo	342
Total	**528**

Figure 3. Major features in the Upper St. Francis Floodway Basin.



Sub-Basins	Area (square miles)
Big Slough	255
Locust Creek	158
St. Francis River	34
Varney	45
Total	493

Wappapello Dam was completed in 1941 and regulates approximately 1,298 sq mi of flow that runs off from the foothills of the Ozarks. Prior to completion of the dam, the contributing basin above Wappapello, Missouri, was flashy and produced flow extremes between 70 cfs and 82,500 cfs (USACE 1949). After dam construction, the maximum flow release was limited to 10,000 cfs (USACE 1964). From 1966 to 2013, the maximum flow release was limited to 7,000 cfs for a portion of the year, until the maximum flow release was again increased to 10,000 cfs in 2014 (USACE St. Louis District 2016).

Prior to the early 1960s, a leveed floodway was constructed, extending from St. Francis, Arkansas, just south of Crowley's Ridge to St. Francis Lake, which is the southern extent of the Sunken Lands. The floodway was designed with an authorized levee design flowline with 3 ft of freeboard because the majority of the floodway falls within the braided stream system that composes the Sunken Lands. The floodway was designed to pass 10,000 cfs from Wappapello and 12 in. of runoff in 30 days for all contributing drainage areas downstream. Design flows were adapted from the 1937 flood and range from 27,000 cfs at St. Francis, Arkansas, to 59,000 cfs at the Sunken Lands (USACE 1964). The braided channels do not have enough capacity to convey even the reduced flows coming from Wappapello Dam or the other tributaries upstream of Crowley's Ridge; therefore, the river typically flows levee to levee during high water events.

To further improve flood control features, the authorized flood control plan included significant channelization of the St. Francis River from Mingo Ditch to Wilhelmina, Missouri, where the channel was cut off. Construction of those improvements began in 1966 and was completed in 1975. The Wilhelmina Cutoff (Figure 2) was the most significant improvement and shortened the St. Francis River from 16 mi to 3.6 mi when it was completed in 1967 (USACE 1985). This significantly increased the gradient of the reach. The upstream end of the cutoff was blocked with an earthen plug, and the downstream end was constructed with a weir to allow fish habitat in what is now a backwater channel. In reference to the depth of channelization and the cutoffs, General Design Memorandum (GDM) 104 (USACE 1964, 10) stated, "To minimize maintenance, the depth of the cut will be held above the sand stratum. . . . The bottom widths will vary from 120 to 200 feet to give the required capacity at the depths available." The additional channelization was also completed upstream of the Wilhelmina Cutoff. In total, the St. Francis River was shortened by 29 mi, and the stream gradient was significantly increased. The slope of the river in the Wilhelmina area was increased from 0.5 ft/mi to 2.2 ft/mi (USACE 1985). Additional work, including additional channel work, increasing levee heights, and reducing levee heights in other areas, was completed throughout the Little River Ditches (USACE 1962).

Not long after the completion of the cutoffs and channelization, severe sanding and increased flooding began occurring downstream of the Wilhelmina Cutoff and extending to St. Francis, Arkansas. Crop losses and permanent damage to agricultural land due to sand deposition in the overbanks and more frequent flooding were reported as early as 1972. In addition, tributaries upstream of the channelization began incising, which was the impetus for a large scale sediment study throughout the entire St. Francis Basin (USACE 1985).

2.5 1977–Present: Ongoing Projects and Studies throughout the St. Francis Basin

In 1977, USACE MVM initiated a sediment collection effort to collect sediment samples at 27 locations throughout the St. Francis Basin, including many tributaries to the St. Francis River. Sample collection ultimately ended in 2001, though some sites were phased out much earlier. Induced flooding and sanding damages were reported in the late 1970s to early 1980s. This ultimately led to a legal determination that the federal government had induced flooding and sanding damages in the river reach between Dekyn's Store and Brown's Ferry with the construction of Wilhelmina Cutoff in 1982. Damages were also reported in the reach from Brown's Ferry to Holly Island. However, it was determined that there was no government liability for damages in this reach because the sand deposition near Holly Island was not related to the cutoffs (USACE 1985).

Hydraulic and sedimentation analyses completed by MVM concluded the Wilhelmina Cutoff created a localized imbalance in bankfull flow between the upstream channel improvement and the unimproved reach below St. Francis, Arkansas, which increased overbank flows and sedimentation (Table 2). In 1984, MVM acquired additional land to compensate for the increased damages (USACE 1985).

Table 2. Bankfull discharges in the St. Francis River determined from 1985 analysis (USACE 1985).

Location (Gage ID)	Bankfull Discharge (cfs)
Dekyn's Store (SF116)	10,000
Wilhelmina	10,000
St. Francis (SF117)	8,000
Brown's Ferry (SF118)	2,000
Holly Island (SF119)	4,000

Analysis of suspended sediment samples completed in 1985 indicated lower sand discharges at St. Francis when compared to the downstream sampling location at Brown's Ferry. MVM concluded that the sand deposited near Holly Island was due to localized sediment transport and erosion in the St. Francis to Brown's Ferry reach, rather than from the cutoffs (USACE 1985).

The MVM contracted with Neel-Schaffer Inc. to develop a hydraulic model (HEC-1) of the St. Francis Basin for the entire basin below Wappapello Dam. Neel-Schaffer Inc. completed the model in 1999 and then began work in 2000 on a sediment model (HEC-6T) for a comprehensive sediment study for the St. Francis Basin. The purpose of the sediment study was to evaluate the base condition in 1998 and to anticipate future water surface profiles based on reaches aggrading with sand and other reaches scouring to evaluate levee freeboard on the authorized project (Neel-Schaffer Inc. 2000).

The HEC-6T analysis split the basin into three zones: zone 1 extends from the mouth of the St. Francis River to the southern extent of St. Francis Lake, zone 2 extends from St. Francis Lake to the beginning of the floodway just below Crowley's Ridge, and zone 3 extends from the beginning of the floodway to Wappapello Dam. Zone 1 was predominantly erosional, with some areas having a tendency for deposition. Zone 2 was found to be largely depositional, and zone 3 was found to be largely erosional, with some areas expected to erode up to 5 ft within a 10-year period (Neel-Schaffer Inc. 2000).

Around the time the sediment model was being developed by Neel-Schaffer Inc., West Consultants (1999) began developing a sediment model specifically for the reach below Arkansas Highway 90. The goal was to evaluate various alternatives for improving drainage below Highway 90 to prevent year-round ponded water from saturating the levees north of Highway 90. West Consultants analyzed a 5.5 mi long drainage channel of various bottom widths and sediment trap configurations below Highway 90 to discover how to improve drainage with as little maintenance as possible. With MVM's input, they settled on a 40 ft bottom width channel with two sediment traps that were 100 ft wide and 500 ft long. The anticipated maintenance schedule was to clean out the sediment traps and channel every five years.

Construction of the drainage channel began in 2000 and was almost completed in 2001, when the newly constructed channel filled in with sand and had to immediately be cleaned out over the next few years. The channel was not cleaned out again until 2008. The cleanout effort took three years to complete, and much of the channel filled in with sand prior to completion of the cleanout. By 2015, the river was completely blocked with sediment and debris again. Another cleanout of the reach began construction in 2021. The cleanout will cost approximately \$2–\$3 million if MVM is able to spoil the material along the right descending bank, but that spoil area is now completely full, and the spoil material must be hauled out of the floodway with an anticipated cost of \$5 million. Sponsors have also encouraged MVM to continue to haul the material from the floodway for every cleanout instead of stockpiling the spoil within the floodway, where it is perceived to be reducing hydraulic capacity and increasing the water surface profile and potentially washing back into the channel.

3 Analyses

Prior to completing any analyses on the area of interest for this study, significant effort was dedicated to compiling period-of-record data in an electronic format. Previously, these data only existed in hard-copy records, and several individuals spent countless hours ensuring the period of record was complete for this geomorphic analysis. To verify the same trends were being observed between the analyses, several statistical analyses were conducted: frequency, stage-duration, and annual low-stage plots. Specific gages, sinuosity, stream power, and lidar-based slope were analyzed to determine the magnitude of change by reach. Aerial imagery of the study area was also reviewed to visually identify significant changes that had taken place.

3.1 Statistical Analyses

Analyses that relied on stage data were completed for 10 gage locations (Figure 4 and Table 3) between Wappapello Lake and Lake City, Arkansas. Table 3 summarizes the period of record for each gage. MD111 (i.e., Mingo Ditch at Fisk) is the only gage not on the mainstem of the St. Francis River. The gage is located approximately 10 mi upstream of the confluence of Mingo Ditch and the St. Francis River.

Analyses reliant on flow records were completed at just four primary gage locations:

1. SF114/07039500–St. Francis River Below Wappapello
2. SF115–St. Francis River at Fisk
3. SF117–St. Francis River at St. Francis
4. SF123–St. Francis River at Lake City

Table 3 shows the period of record available for each location.

Figure 4. Analyzed study reach gage locations for St. Francis River (SF) and Mingo Ditch (MD).

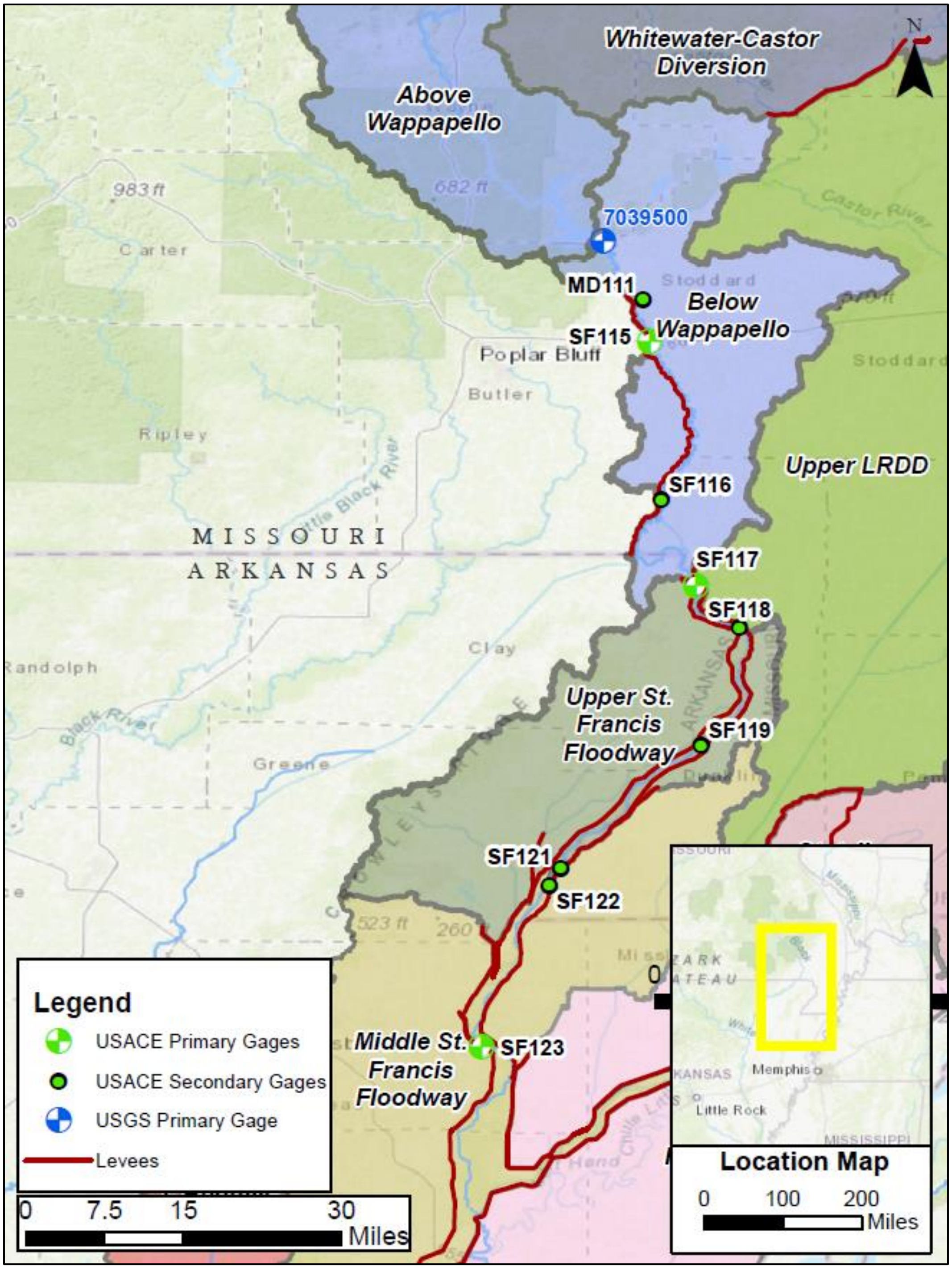


Table 3. List of gages used for statistical analyses.

Gage ID	Location	River Mile	Contributing Drainage Area (sq mi)	Stage Period of Record	Discharge Period of Record
SF114*/ 7039500[a]	St. Francis at Wappapello	211.9	1,311	1920–1994	1936–present
SF115*[b]	St. Francis at Fisk	202.1	1,370	1917–present	1935–present
SF116	St. Francis at Dekyn's Store	168.3	1,690	1933–Present	1969–1977
SF117*[b]	St. Francis at St. Francis	158.4	1,772	1892–Present	1917–present
SF118	St. Francis at Brown's Ferry	152.4	1,776	1916–present	N/A
SF119	St. Francis at Holly Island	139.6	1,787	1935–present	1933–1945
SF121	St. Francis at Hargrove	123.2	1,848	1916–1993	N/A
SF122	St. Francis at Hopkin's Bridge	121.0	1,850	1935–2002	N/A
SF123*	St. Francis at Lake City	104.1	2,374	1916–present	1917–present
MD111	Mingo Ditch at Fisk	N/A	N/A	1943–present	1943–1995

Note: * denotes primary gage locations that include both stage and discharge records.

[a] SF114/07039500 was maintained by MVM until 1983, when St. Louis District took ownership, and is currently maintained by the USGS.

[b] USGS collected discharge measurements at SF115 and SF117 from 1982 to 2011. These data were used to supplement USACE data collected during the same time period.

3.1.1 Frequency Analysis

A graphical flow frequency analysis was performed using annual peak flows derived from daily stage readings for SF114, SF115, SF117, and SF123. With the exception of SF115, the period of record analyzed for each gage location was 1942–2019, which represents stream conditions after construction of Wappapello Dam was completed. Calculated flow records did not exist for SF115 prior to 1984; therefore, the time period 1984–2019 was used in the analysis. Only observed discharge measurements were available for this location from 1935 to 1984.

3.1.2 Stage Duration

Stage-duration curves were completed for each gage listed in Table 3. Daily stages were broken down by decade after 1942, marking completion of construction of the Wappapello Dam. Changes in stage-duration curves may indicate changes in the channel, including channel aggradation or degradation. Daily stages were sorted and ranked from highest to lowest, and a probability was assigned based on that ranking. Stage data were then plotted against the exceedance probability and grouped by decade.

3.1.3 Yearly Low Stage

Yearly minimum stages were plotted for the entire period of record at all gages listed in Table 3 and were plotted over time to determine historical trends in low stages. Long-term trends may indicate changes in channel geometry, including degradation or aggradation. The Hydrologic Engineering Center's Data Storage System (HEC-DSS) was used to determine the minimum stage for each year.

3.2 Geomorphic Evaluation

Several analyses were completed to investigate changes in channel properties in response to morphological change. These analyses included an evaluation of historical imagery, sinuosity changes over time, specific gages, water surface slope, and stream power. Each of these analyses provided insight into the magnitude of stream changes and when those changes occurred.

3.2.1 Historical Aerial Imagery

Historical aerial imagery was available for portions of the project area for each of the following years: 1953, 1956, 1961, 1962, 1965, 1966, 1973, 1999, 2009, and 2011. The stream centerline for the St. Francis River was digitized for each year to determine stream lengths. These images were also used to determine when other features were constructed to help piece together the construction timeline for local improvements. River mileage below SF119–St. Francis at Holly Island could not be determined due to the complexity of the river system within the floodway below Highway 90. Through this reach, flow is split between multiple channels and distributaries and typically flows levee to levee within the floodway for flows greater than the two-year return interval.

3.2.2 Sinuosity

Sinuosity was determined from SF114–St. Francis at Wappapello to SF119–St. Francis at Holly Island. Sinuosity is used to describe the degree to which a stream meanders and is the ratio of river length to valley length (Schumm 1963). For this study, the extent was broken up into reaches between gages.

The stream length between gages was determined using the stream centerlines traced from the aerial imagery. Valley lengths were also determined using the aerial imagery. To calculate the sinuosity, Equation (1) was used.

$$Sinousity = \frac{Stream\ length}{Valley\ length}. \tag{1}$$

3.2.3 Specific Gage

Specific gage records were completed at primary gage locations (i.e., locations with both stage and discharge data) and secondary gage locations (i.e., locations with stage records only). USACE data were supplemented with USGS records at SF114, SF115, and SF117. Specific gage plots can be used to determine long-term trends in channel stability, but they may not be a good predictor of future trends and should be used carefully when attempting to infer future channel response.

The specific gage analysis produces a plot of stage and the corresponding discharge at a particular gage location through time. There are two different ways to perform specific gage analysis. The first way is referred to as the *rating curve method*, and the second is the *direct step method*. Both methods have advantages and disadvantages, and both are acceptable for this type of analysis. This study used the rating curve method due to the limited availability of observed measurements for the standard step method (Biedenharn et al. 2017). At many locations, there were not enough measurements in a single year to draw a rating curve covering the entire range of flows. Therefore, measurements from consecutive years were combined to generate the rating curve.

Specific gage analyses for this effort were generated from the Geomorphic Analysis Package tool developed by Engineer Research and Development Center (ERDC). At primary stations, the data were formatted and uploaded into the tool. For secondary stations, a time lag was applied to the discharge so it matched the corresponding stage value. The lag was determined by evaluating stage plots from primary and secondary locations. Peaks were noted at each location, and the corresponding lag was used to correlate the discharge to the appropriate stage value.

3.2.4 Water Surface Slope and Stream Power Records

The Geomorphic Analysis Package tool developed by ERDC was used to generate slope and stream power records for the period of record. Daily stages at consecutive gages were used to calculate daily water surface slopes. Slopes were determined between gages by subtracting the water surface elevation of the downstream gage from the water surface elevation of the upstream gage for each day then dividing by the length between the gages. Stream lengths were varied throughout the period of record based on the results from the aerial imagery analysis described in Section 4.4. An average water surface slope was calculated for each year. Slope and stream power were computed for the reaches given in Table 4.

Table 4. Reaches used for slope and stream power analyses.

Gage IDs	Reach
SF114–SF115	Wappapello to Fisk
SF115–SF116	Fisk to Dekyn's Store
SF116–SF117	Dekyn's Store to St. Francis
SF117–SF118	St. Francis to Brown's Ferry
SF118–SF119	Brown's Ferry to Holly Island

Stream power (Ω) represents the rate of potential energy to transport channel sediment per unit length of channel and is often used as a predictor of a stream's ability to transport sediment and alter its morphology through geomorphic work (Knighton 1999; Biedenharn et al. 2000). Stream power is derived by multiplying the specific weight of water by stream discharge and bed slope, as shown in Equation (2).

$$\Omega = \Upsilon Q S, \tag{2}$$

where

Ω = total stream power (Watts per meter),
Υ = specific weight of water (Newton per cubic meter),
Q = stream discharge (cubic meter per second), and
S = slope.

The specific weight of water is essentially constant; therefore, stream power is proportional to QS. Channel response to changes in flow or sediment discharges is often discussed qualitatively using Lane's (1955) balance, given by Equation (3):

$$QS \propto Q_s D_{50}, \tag{3}$$

where

Q = water discharge,
S = slope,
Q_s = bed material load, and
D_{50} = median size of bed material.

This relationship can be used to describe how changes in any one of the variables could influence the other variables as the stream adjusts. If QS increases, either Q_s, D_{50}, or both may increase in an attempt to reach a new equilibrium. The imbalance could ultimately lead to a decrease in slope as sediment eroded from the upstream reach could deposit downstream, thereby reducing the bed slope. Daily stream power values (QS) were calculated using daily calculated flows from SF114, SF115, and SF117 and the daily water surface slopes previously calculated. Yearly average values for QS were then calculated. Finally, cumulative or yearly total values were determined for each year.

4 Results and Discussion

4.1 Frequency Analysis

A graphical frequency analysis was completed at each primary gage location. Appendix A contains the graphical frequency plots. The low-flow discharge range at SF123 only includes one of several channels that flow through the floodway at this site due to limited access and the infeasibility of data collection. Flows below 3,000 cfs were disregarded due to this limitation in data collection at SF123. Table 5 gives the values at each gage location for various return periods and percent chance exceedance (PCE).

Table 5. Flows at St. Francis gages for various percent chance of exceedances (PCEs).

Percent Chance of Exceedance	Return Year	SF114 Flow (cfs)	SF115 Flow (cfs)	SF117 Flow (cfs)	SF123 Flow (cfs)
0.2	500	33,200	34,900	29,100	41,800
0.5	200	29,900	31,300	27,800	41,000
1	100	27,500	28,400	26,600	39,300
2	50	25,100	25,800	25,400	37,700
5	20	11,200	16,900	24,600	32,000
10	10	10,400	11,100	19,400	26,500
20	5	10,300	9,600	17,500	22,000
50	2	7,600	7,300	11,600	14,800
99	1	3,300	3,100	5,000	3,100

The leveed floodways of the Upper St. Francis River were designed to carry flows of 22,000 cfs at St. Francis, Arkansas (SF117), and up to 65,000 cfs just south of the St. Francis Lake area. Using the design flows established in GDM 104 (USACE 1964), the following relationships to PCE flows at SF114, SF117, and SF123 were determined. Normal planned releases from Wappapello Dam of 7,000 cfs have a 50% PCE at the SF114 gage. St. Francis, Arkansas (SF117), has a design flow of 22,000 cfs, which is between a 5% and 10% PCE. Lake City, Arkansas (SF123), has a design flow of 32,000 cfs, which is a 5% PCE.

4.2 Stage-Duration Plots

Stage-duration plots for SF114 (St. Francis River at Wappapello) to SF123 (St. Francis River at Lake City) are shown in Figures 5 through 14. An increase in PCE for a given stage over time could indicate aggradation, while a decrease in PCE could indicate degradation. Stage-duration curves also give an insight into flooding potential due to geomorphic change. A stage-duration curve was created for each decade for each gage. However, variations in rainfall and reservoir releases introduce uncertainty when comparing and interpreting the stage-duration plots. Table 6 shows the average flows for each decade for SF114, SF117, and SF123. Average flows for SF115 were not calculated because of large gaps in the discharge period of record. There are no major tributaries between SF114 and SF115.

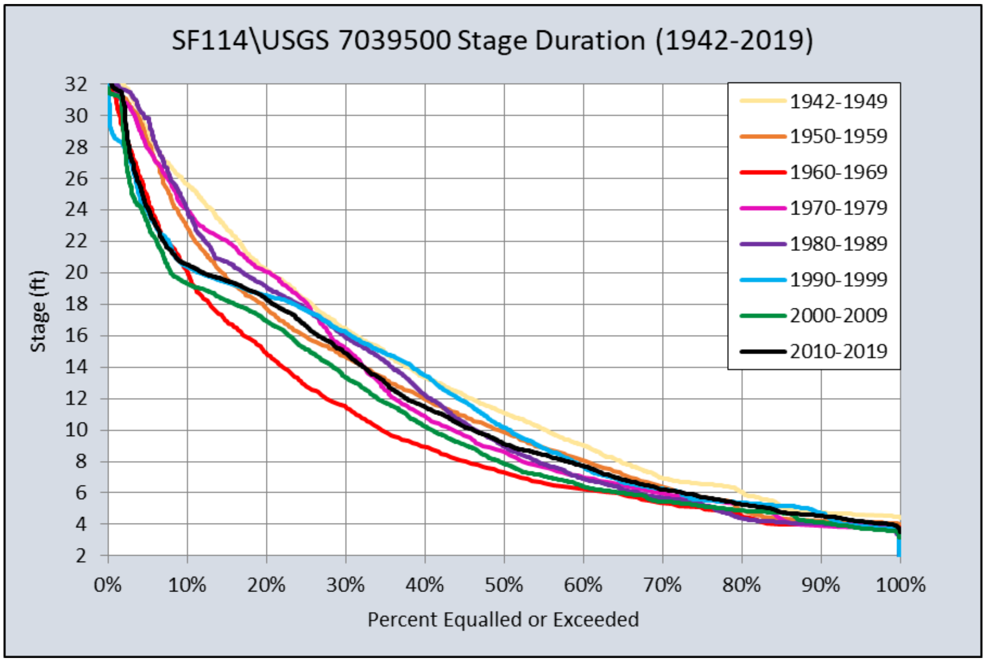
For SF114, the average flows per decade are within 10% of the overall average for most decades. The average flow for the 1960s is approximately 25% lower than the period-of-record average, and the 1940s is approximately 12% higher than the overall average. A similar difference for the 1960s was calculated for SF117. Average flows at SF123 show a generally increasing trend over the period of record.

Table 6. Average flow for each primary gage by decade.

Time Period	Average Flow (cfs)		
	SF114	SF117	SF123
1942–1949	1,843	2,306	1,157
1950–1959	1,599	2,279	2,380
1960–1969	1,220	1,765	2,537
1970–1979	1,680	2,386	3,337
1980–1989	1,655	2,238	3,140
1990–1999	1,756	2,495	3,211
2000–2009	1,600	2,159	2,904
2010–2019	1,800	2,659	3,463
1942–2019	1,639	2,285	2,724

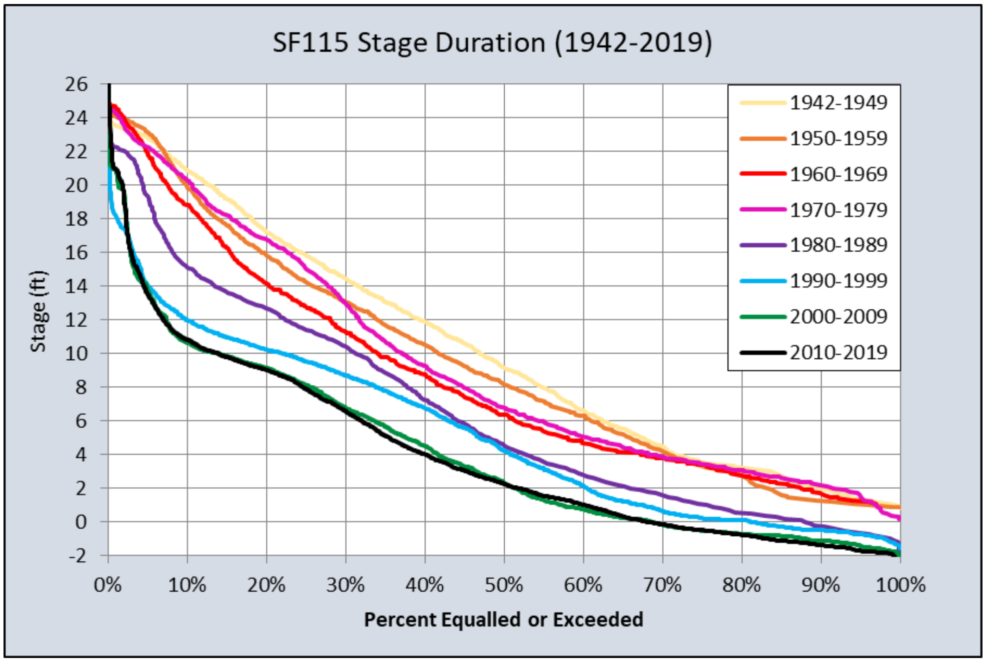
For SF114, just below Wappapello Dam, the stage-duration curves show no clear indication of whether stages are consistently becoming more or less exceeded from decade to decade (Figure 5). There is little variation in the PCE at stages below 6 ft. This could be an indication that the river has been relatively stable in this reach since construction of Wappapello Dam.

Figure 5. Stage-duration plot at SF114–St. Francis River at Wappapello.



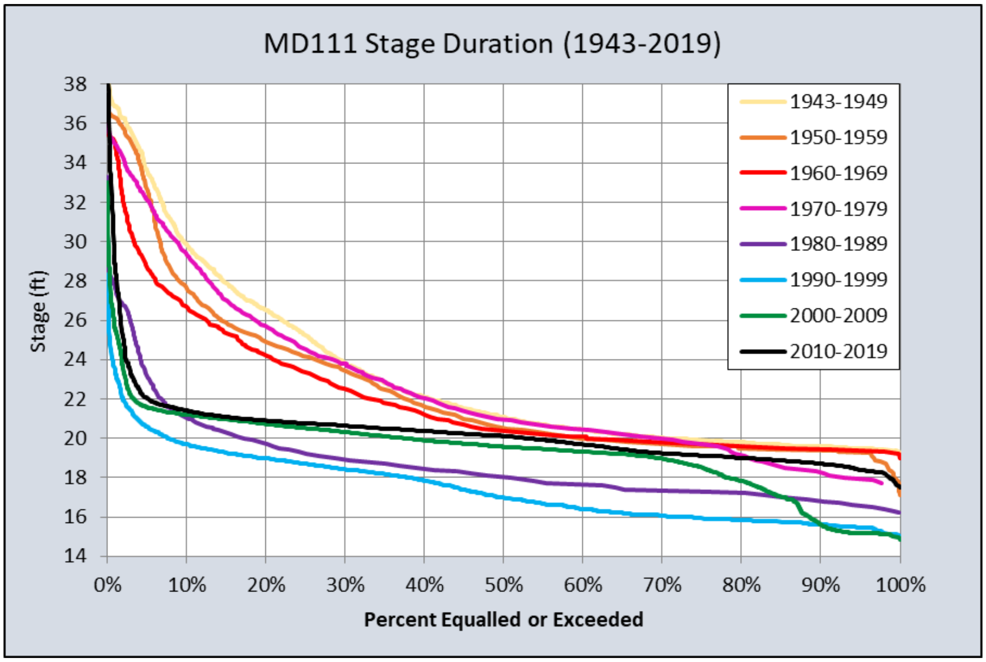
SF115 (St. Francis at Fisk, Missouri) shows a decrease in PCE for all stages from 1942 to 2019 (Figure 6). The stage-duration curves are relatively consistent from 1942 to 1979, indicating the channel was in relative equilibrium during this period. The curves for the 1980s through the 2000s show a steady decrease in PCE, which is likely due to degradation in this reach. The plot shows little change in stage duration for the past two decades.

Figure 6. Stage-duration plot for SF115–St. Francis River at Fisk.



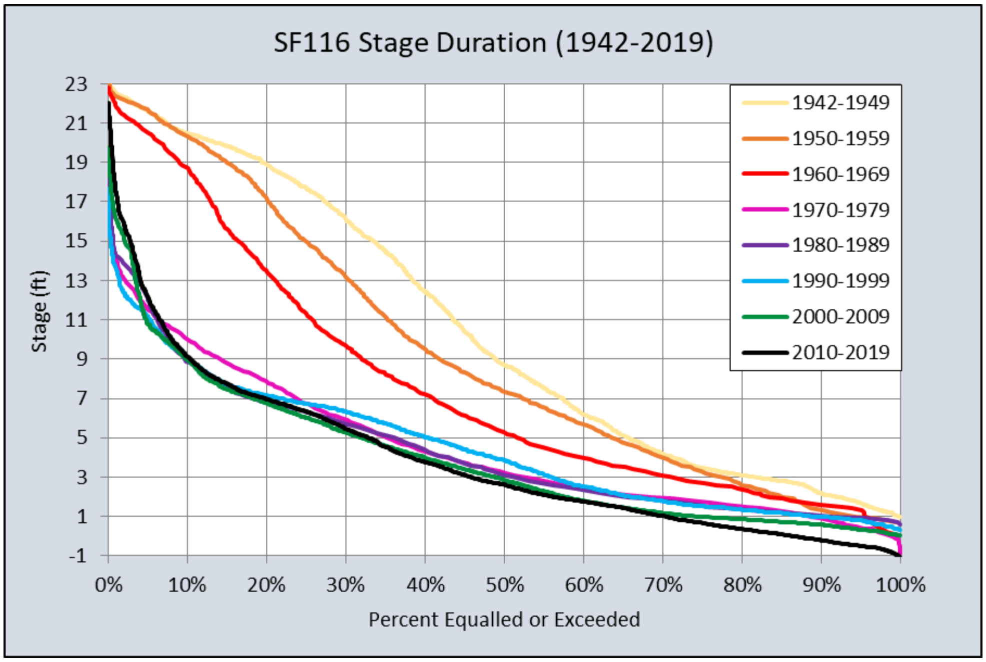
MD111 is located approximately 10 mi upstream of the confluence of Mingo Ditch and the St. Francis River. The confluence is located between SF115 and SF116. The stage duration plot for MD111, Mingo Ditch at Fisk, shows the curves were relatively constant for 1943–1979 (Figure 7). Between the 1970s and 1990s, PCEs dropped significantly for all stages, indicating possible channel degradation during this time period. PCEs at stages below 22 ft increased after the 1990s, potentially due to the construction of a grade control structure at the bridge between 1996 and 2003 (observed in aerial imagery).

Figure 7. Stage-duration plot for MD111–Mingo Ditch at Fisk.



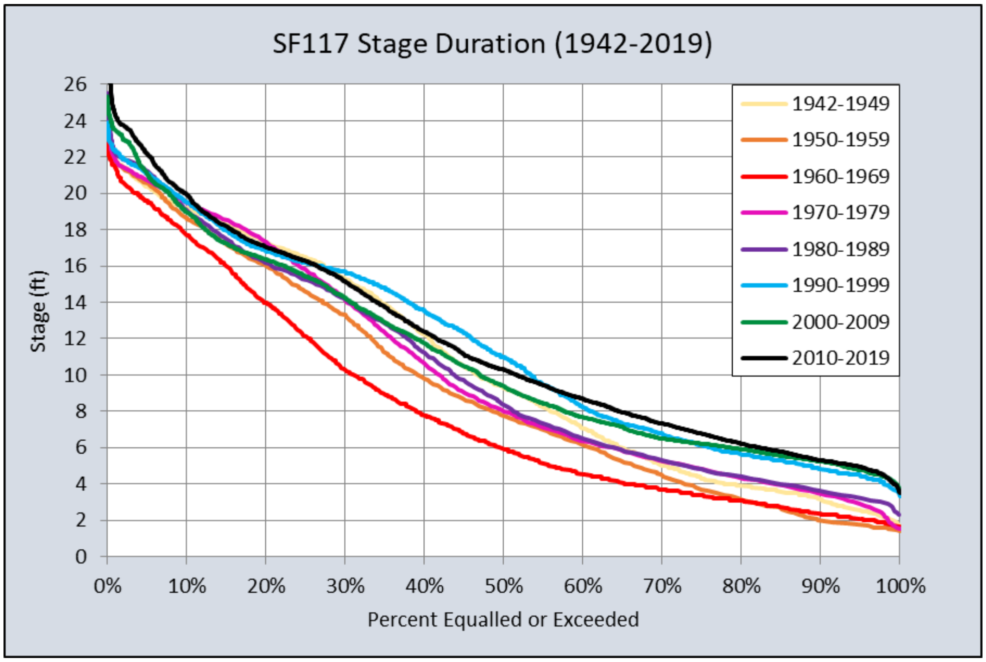
SF116 (St. Francis at Dekyn's Store) shows that stages are decreasingly exceeded from the 1940s to the 1970s, with stark contrasts easily visible between the 1960s and 1970s (Figure 8). After the 1970s, the curves show essentially no change between decades. This is likely due to channel degradation in the 1960s and 1970s as a response to the channel cutoffs.

Figure 8. Stage-duration plot for SF116–St. Francis River at Dekyn's Store.



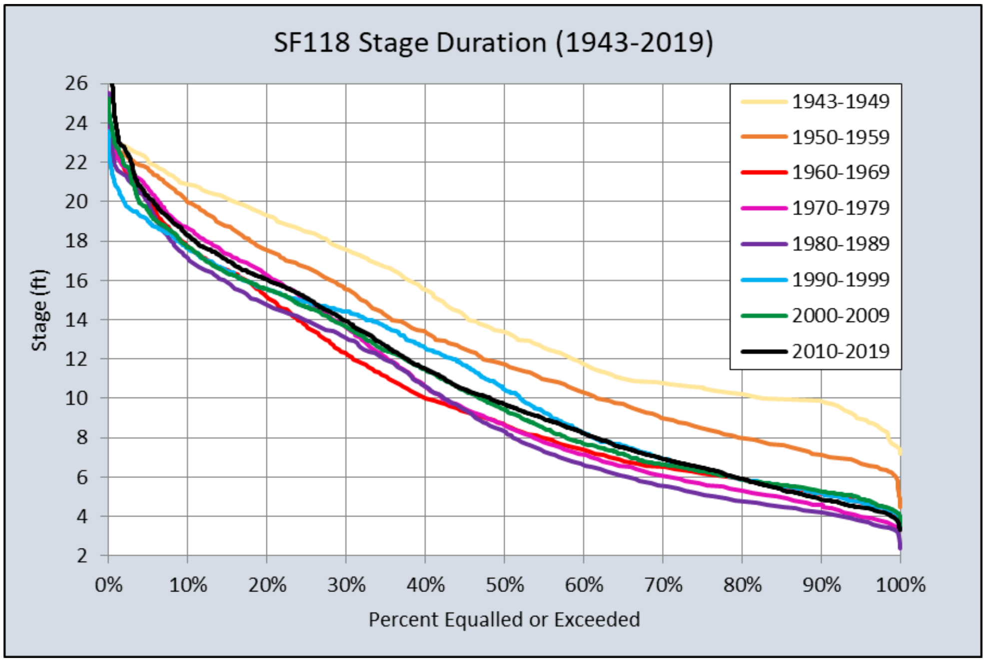
SF117 (St. Francis River at St. Francis) shows a decreasing trend from the 1940s through the 1960s (Figure 9). For example, the PCE for a stage of 10 ft dropped from approximately 50% to approximately 40% during this time period (i.e., between the 1940s and 1950s). The 1960s curve shows a further decrease in PCE (approximately 30%), but this may be attributed to the decrease in average flow during that time frame. The stage exceedance increased through the 1970s and 1980s, back to approximately 55%. This indicates some degradation through the 1950s, aggradation from the 1970s to the 2000s, then a relatively stable trend since the 2000s. The increase in PCE is apparent at low stages. A stage of 4 ft was equaled or exceeded 65% of the time in the 1950s, and it is currently exceeded nearly 100% of the time.

Figure 9. Stage-duration plot for SF117–St. Francis River at St. Francis.



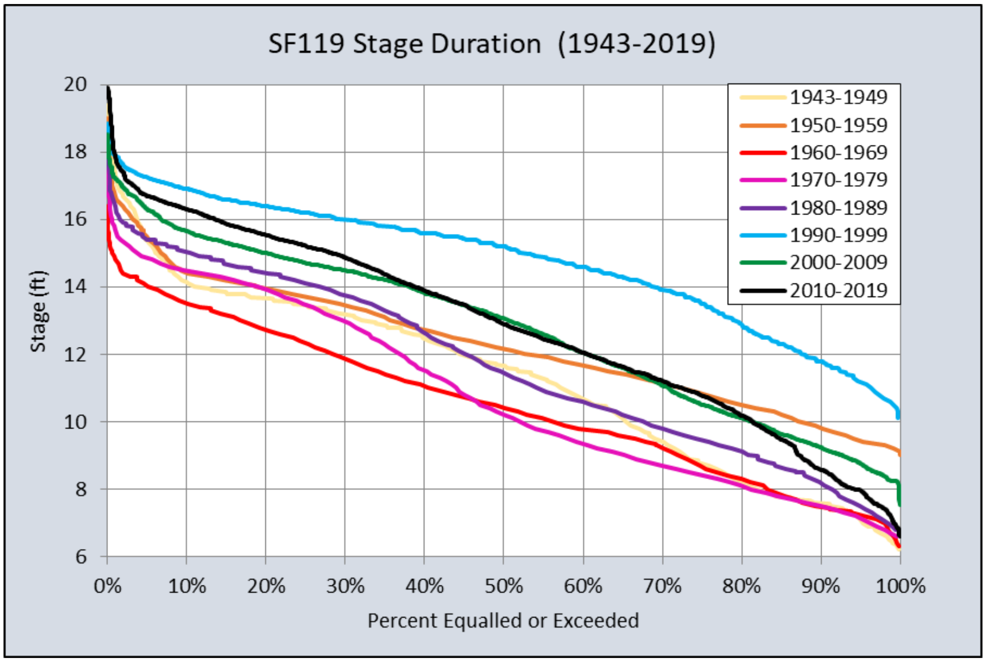
At SF118 (Brown's Ferry), a decreasing trend in PCE showed a decreasing trend for all stages from the 1940s through the 1970s, indicating there was degradation during this time period (Figure 10). Since the 1970s, the curves appear to be relatively constant, indicating the channel may have reached equilibrium.

Figure 10. Stage-duration plot for SF118–St. Francis River at Brown's Ferry.



SF119 is located on the bridge at Arkansas Highway 90, which is approximately 1 mi upstream of the blockage described in Section 2.5. A decrease in PCE between the 1950s and 1960s was observed for all stages, indicating degradation (Figure 11). A clear increase from the 1970s to the 1990s was observed, indicating significant aggradation during this time period. The PCE for a stage of 14 ft increased from 5% to 70% from the 1960s to the 1990s. In 2000, the channel was realigned by MVM below Highway 90 to improve drainage in this reach. This drainage improvement reduced the PCE of a stage of 14 ft to approximately 40% of the time. No significant change is shown from the 2000s to 2010s. At this location in the floodway, water flows levee to levee during high stages. Increased seepage gradients and higher stages for longer periods of time due to channel aggradation have direct implications for levee safety in this reach.

Figure 11. Stage-duration plot for SF119–St. Francis River at Holly Island.



Gages at SF121 (St. Francis River at Hargrove) and SF122 (St. Francis River at Hopkin's Bridge) are no longer in operation and have a relatively short period of record. The stage-duration curves show a slight increase in PCE at SF121 from the 1960s to the 1990s (Figure 12). However, this may be attributed to lower than average flows during the 1960s. No trend was observed at SF122 (Figure 13).

Figure 12. Stage-duration plot for SF121–St. Francis River at Hargrove.

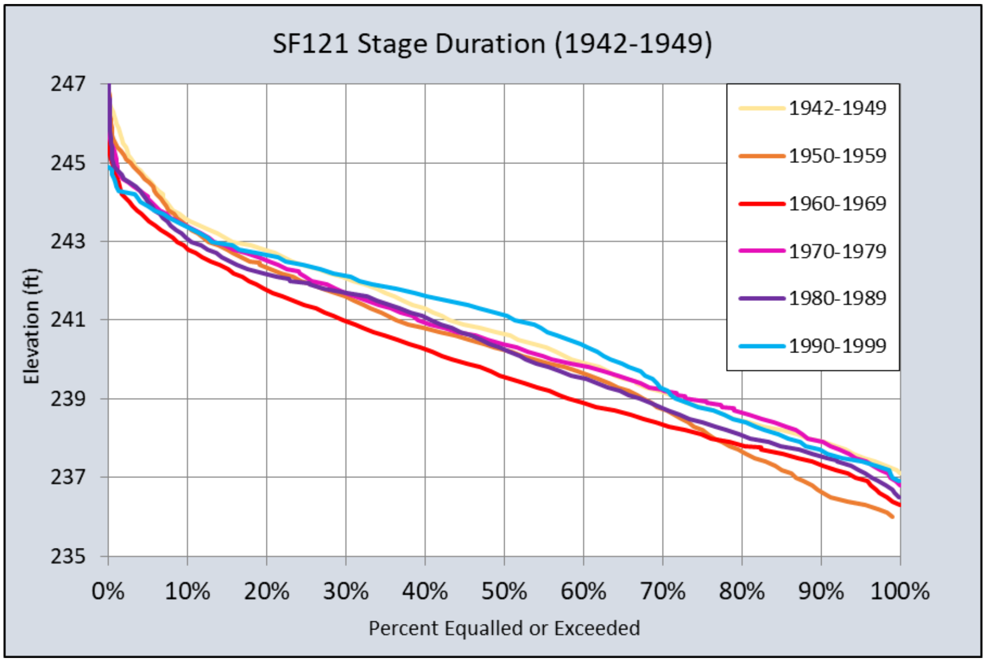
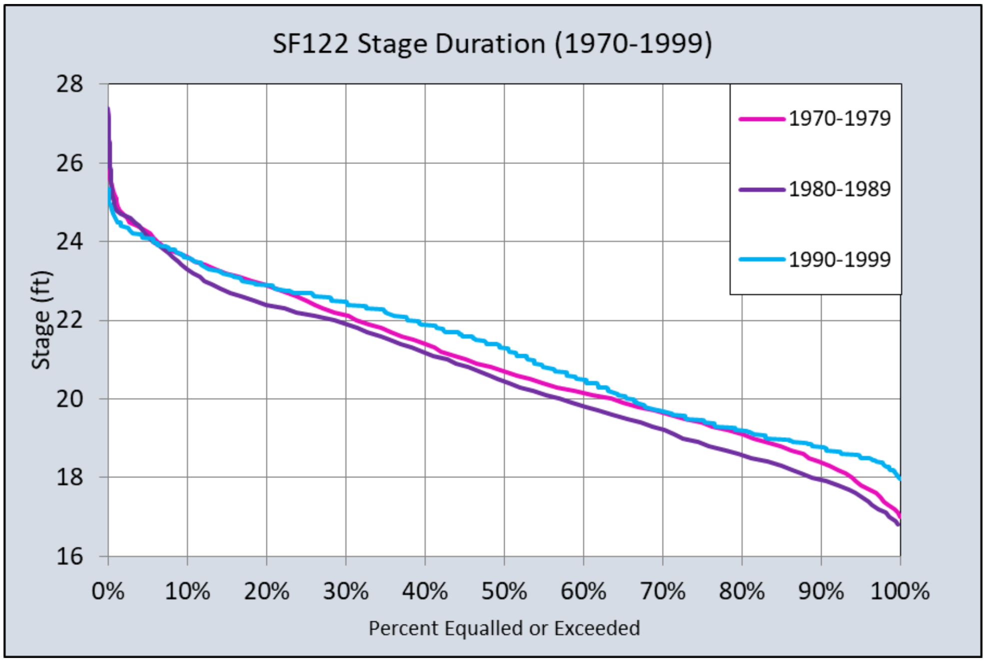


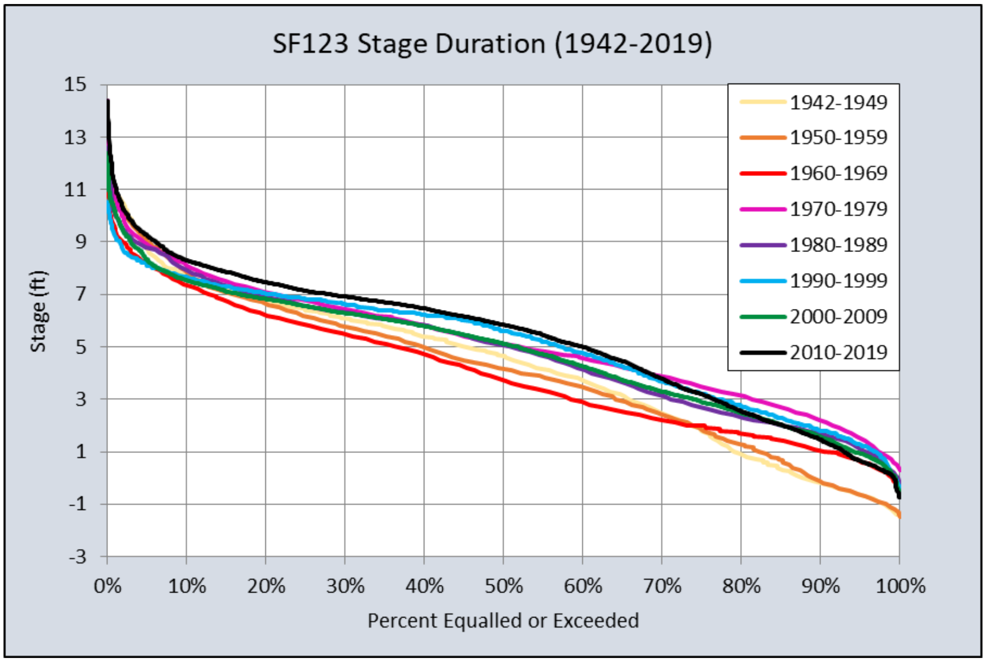
Figure 13. Stage-duration plot for SF122–St. Francis River at Hopkin's Bridge.



SF123 (St. Francis at Lake City) is located just upstream of St. Francis Lake. Stage-duration curves were similar for the decades from the 1940s to 1960s (Figure 14). An increase in PCE between the 1960s and 1970s indicates possible aggradation during this period. However, the St. Francis Lake Control Structure was constructed in 1976 to impound more water in the lake. In addition, average flows at SF123 increased from the 1940s to

the 1980s and may account for the increasing trend observed in the stage-duration curve. The curves are fairly similar between the 1970s and the present day.

Figure 14. Stage-duration plot for SF123–St. Francis River at Lake City.

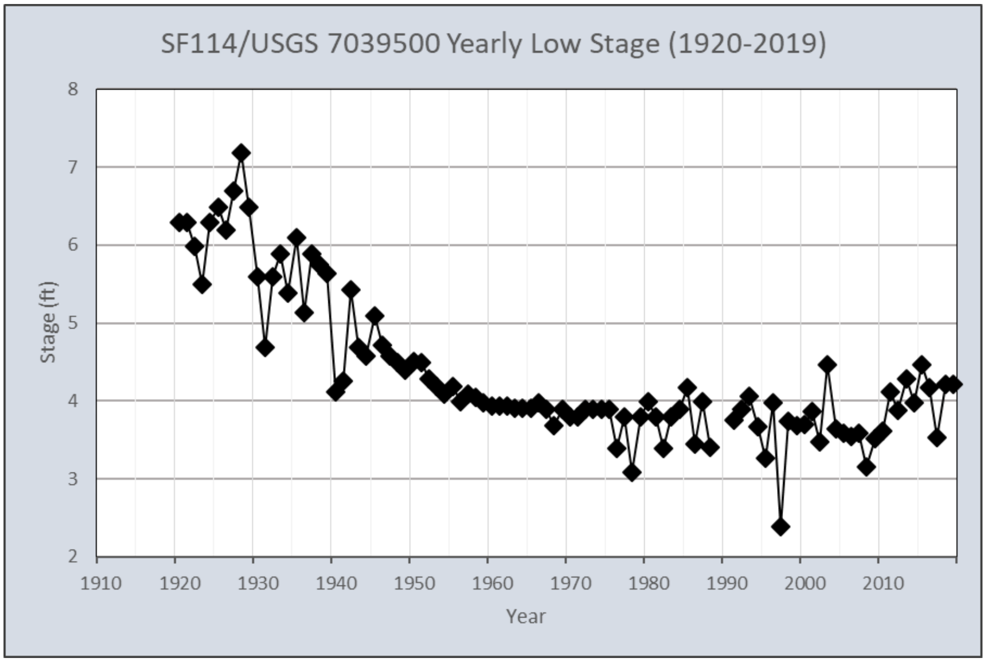


4.3 Yearly Low Stage

Yearly low-stage plots for each gage downstream of Wappapello to Lake City are included from upstream to downstream in Figures 15 through 20 and Figures 22 through 25. Some variation in yearly low stage from year to year is expected due to the natural variability in rainfall between years. However, trends over multiple years or decades can show a geomorphic change in the river. A downward trend in yearly low stage over multiple years could suggest degradation of the channel, while an upward trend would likely suggest aggradation.

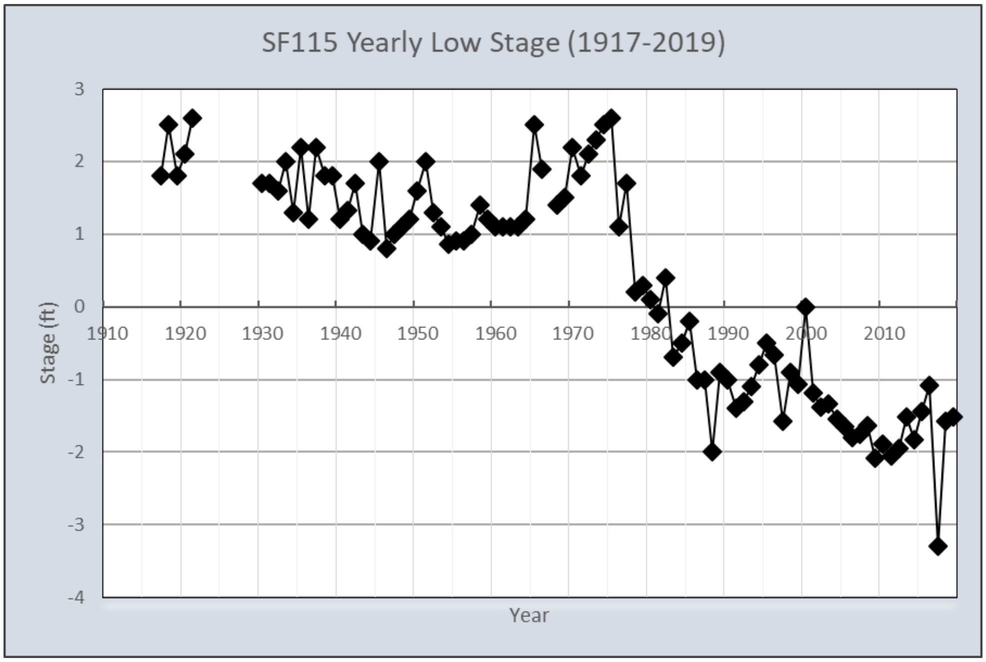
SF114–St. Francis River at Wappapello (just downstream of Wappapello Dam) shows a steady decline in annual stage from 1920 to 1960, before stages begin to oscillate approximately 1 ft from year to year after 1960 (Figure 15). Yearly low stages have remained fairly constant since the mid-1950s, indicating the channel has likely been stable in the last six decades.

Figure 15. Yearly low-stage plot for SF114/USGS 7039500–St. Francis River at Wappapello Dam.



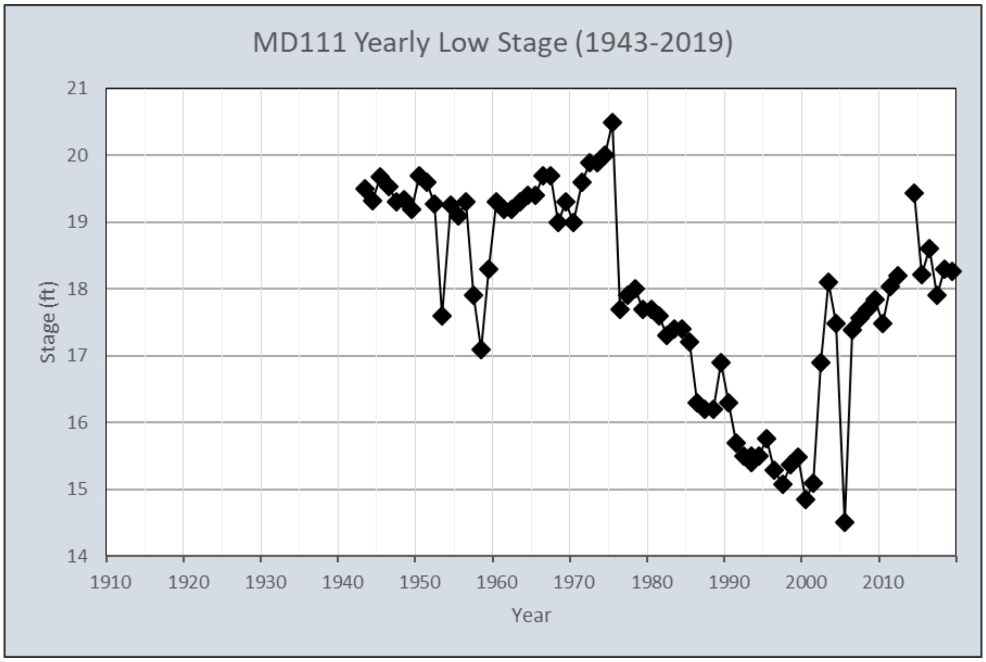
Stages at SF115 (St. Francis River at Fisk, Missouri) show a dramatic drop in yearly low stages starting in 1975 and continuing through 2010 (Figure 16). During this time period, yearly low stages dropped approximately 4 ft. This may have been due to channel degradation. This corresponds to the trend witnessed in the stage-duration plot for SF115 (Figure 6).

Figure 16. Yearly low-stage plot for SF115–St. Francis River at Fisk.



The MD111 gage is located on the bridge on County Road 448 near Fisk, Missouri. The yearly low stage for MD111 was relatively constant prior to 1975 (Figure 17). Between 1975 and 1976, there was an approximately 3 ft drop in yearly low stage. This could have been in response to the channel enlargement that began construction in 1974. Mingo Ditch was enlarged from an approximately 20 ft bottom width to a 40 ft bottom width in the vicinity of the gage. Yearly low stages continued to drop steadily from 1976 to the early 2000s, likely indicating channel degradation during this time period. In addition, the confluence of Mingo Ditch with the St. Francis River is located between SF115 and SF116. Both SF115 and SF116 show decreasing trends in stages during the same time period. This drop in low stages may also be attributed to a channel response due to the lowering of the St. Francis River at the confluence. Low stages jumped up 3 ft between 2000 and 2003. Aerial imagery showed the bridge where the gage is located was significantly reinforced between 1996 and 2003. This scour protection created a grade control structure and a constriction in the stream, which is reflected in the low-stage plot.

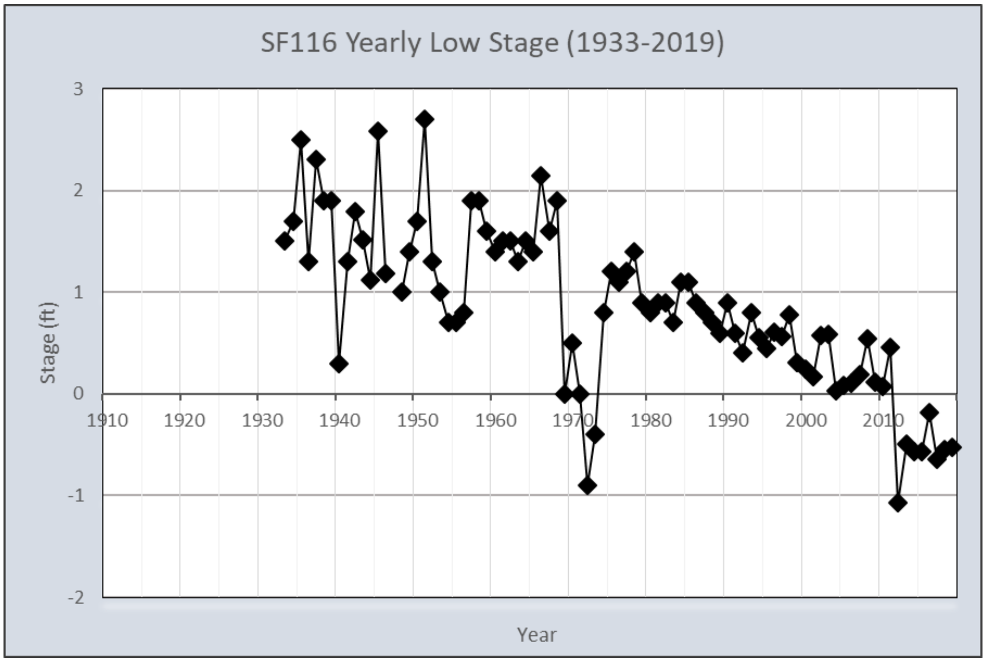
Figure 17. Yearly low-stage plot for MD111–Mingo Ditch at Fisk.



SF116 (St. Francis River at Dekyn's Store, Missouri, which is just 2 mi upstream of the Wilhelmina Cutoff), shows relatively stable stages until 1969, when a steep drop occurred (Figure 18). The cause of this steep drop is unclear. After a jump in 1975, yearly low stages steadily decreased in this reach, indicating potential channel degradation as a response to the

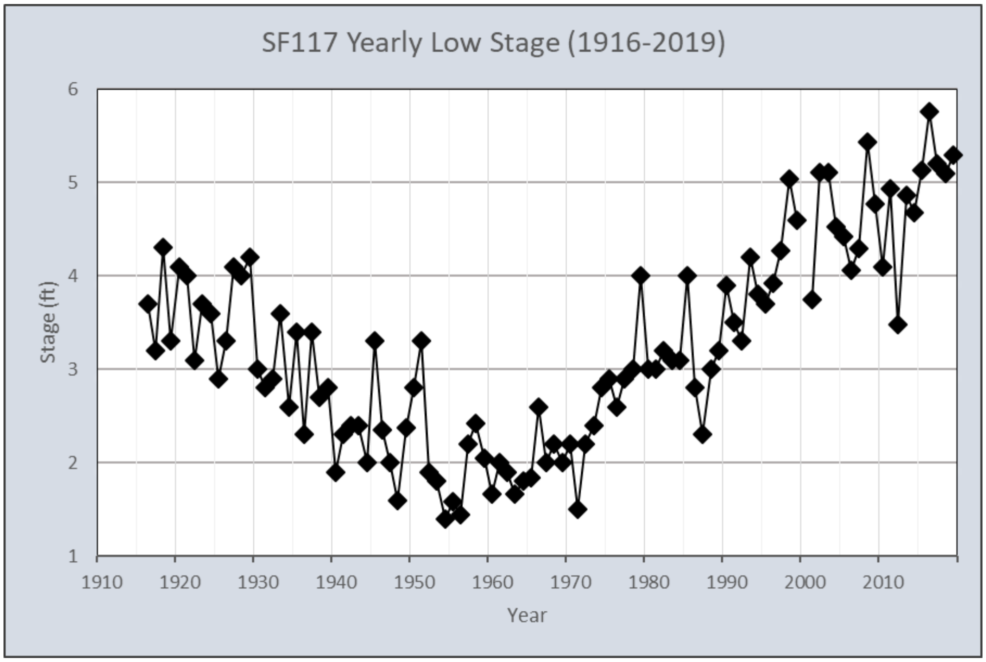
channelization. This is consistent with the stage-duration plot for this location (Figure 8), in which a drop in PCE is shown for most stages between the 1960s and 1970s.

Figure 18. Yearly low-stage plot for SF116–St. Francis River at Dekyn's Store.



At SF117 (St. Francis at St. Francis, Missouri), a decreasing trend is observed from 1916 through the mid-1950s (Figure 19). The trend flips and low stages begin to climb in 1964. Yearly low stages increased approximately 3 ft from 1964 to 2019, potentially indicating aggradation. This is consistent with the stage-duration curve for this location (Figure 9).

Figure 19. Yearly low-stage plot for SF117–St. Francis River at St. Francis.



Annual low stages for SF118 (St. Francis at Brown's Ferry) steadily decreased from 1920 to the early 1970s (Figure 20). An approximately 10 ft drop in low stage was observed during this time period. An investigation of aerial imagery from 1953 and 1966 indicates this may be attributed to channel enlargements and tree clearing in this reach (Figure 21). Historical topographic maps indicate that the primary channel of the St. Francis River flowed to the east of Sevenmile Island. Currently, the main channel of the river flows around Sevenmile Island to the west. No documents detailing the time of this change were found. A similar trend was shown in the stage-duration plot for SF118 (Figure 10). After a slight increase in the 1980s and 1990s, low stages remained relatively constant. In the 1980s to 1990s, the yearly low stage increased approximately 2.5 ft, which could indicate some aggradation.

Figure 20. Yearly low-stage plot for SF118–St. Francis River at Brown's Ferry.

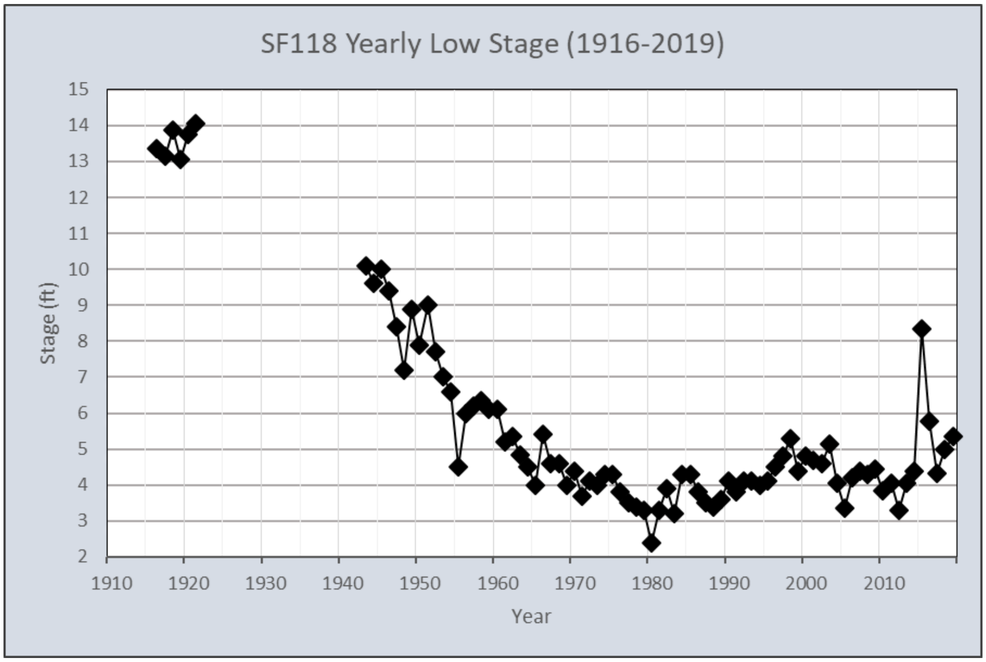


Figure 21. Aerial imagery of SF118 and Sevenmile Island from 1953 (*left*) and 1966 (*right*).

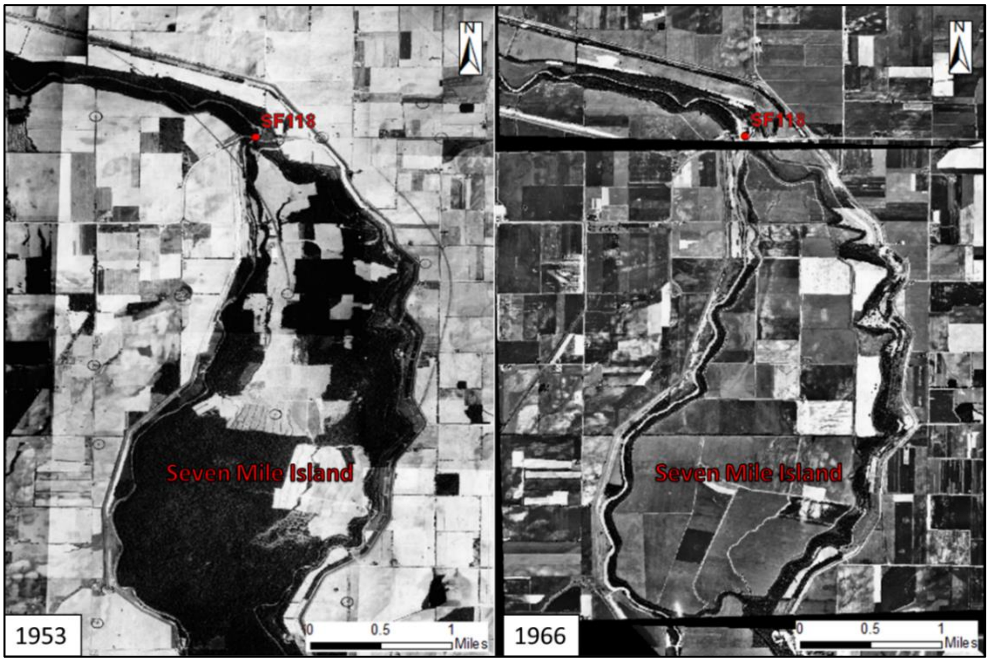
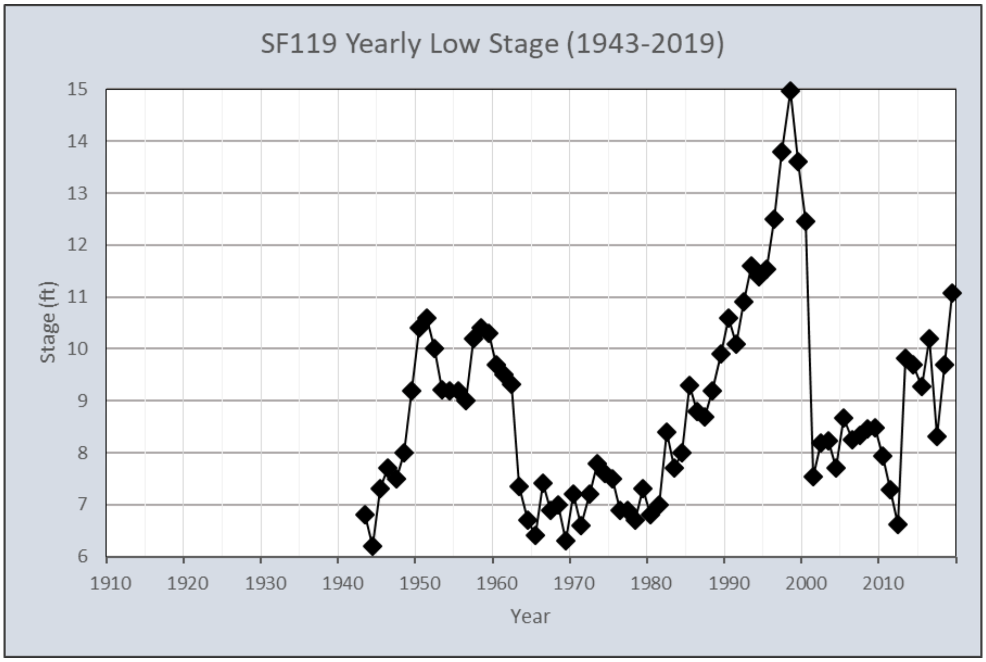


Figure 22 shows an approximately 4 ft increase in yearly low stage for SF119 at Highway 90 from 1943 to 1952 and then a drop again in the early 1960s. Little is known about the river engineering activities in the reach below Highway 90 during this time period. Low stages were relatively constant from the mid-1960s until 1980, when low stages began to steadily increase. Over the next two decades, yearly low stages increased 8 ft, indicating significant aggradation in this reach. The drainage channel constructed in 2000 dramatically decreased the low stages. These trends were also observed in the stage-duration plot. However, since the construction, the yearly low stages have steadily increased, indicating significant aggradation is continuing below Highway 90.

Figure 22. Yearly low-stage plot for SF119–St. Francis River at Holly Island.



Yearly low stages for SF121 and SF122 (Figures 23 and 24, respectively) remained relatively constant over the period of record, with a slight increase over time. This could indicate some aggradation in this reach.

Figure 23. Yearly low-stage plot for SF121–St. Francis River at Hargrove.

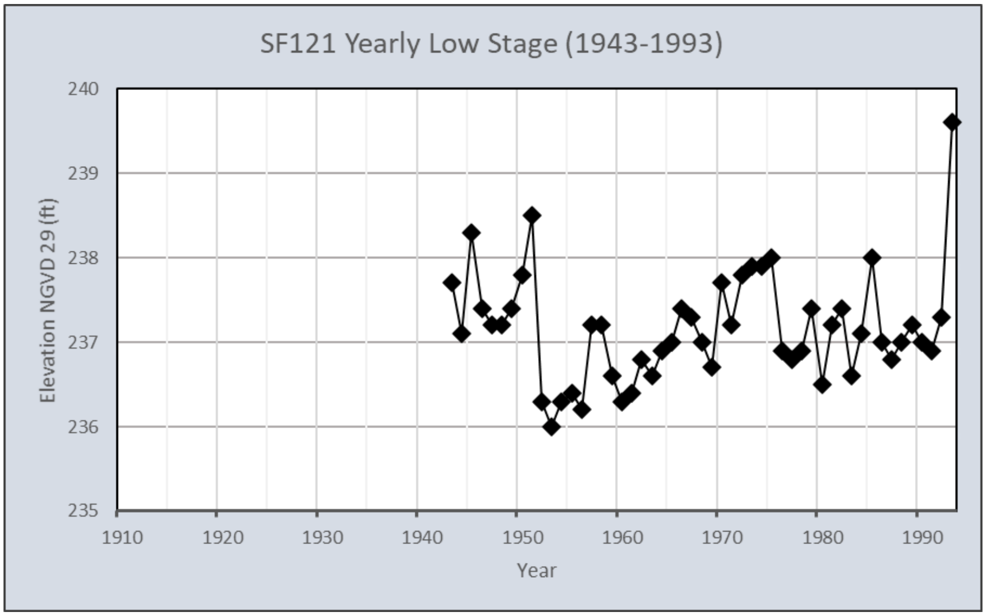
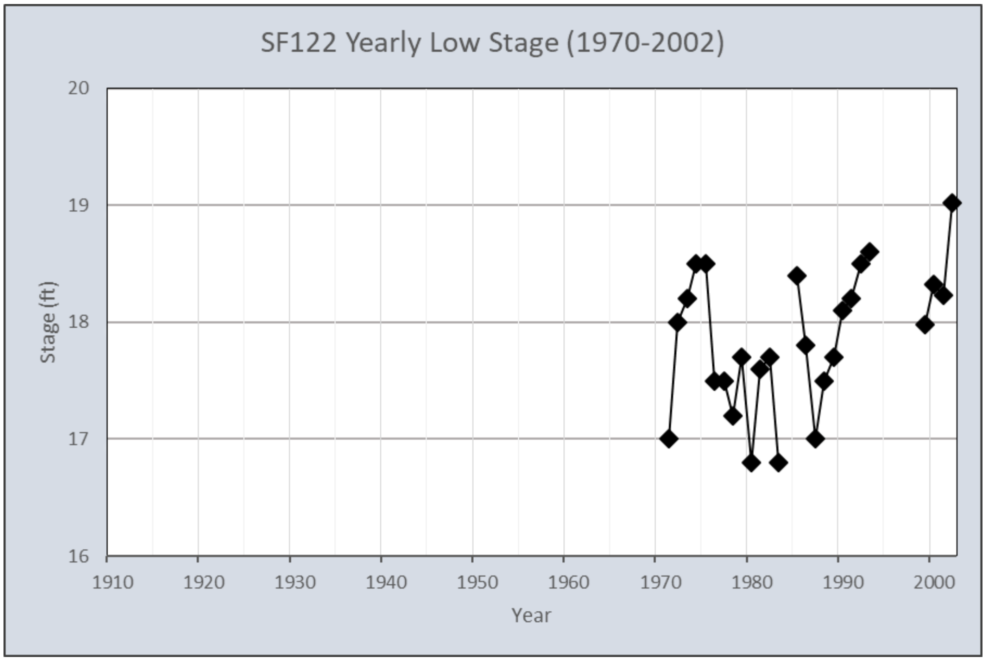
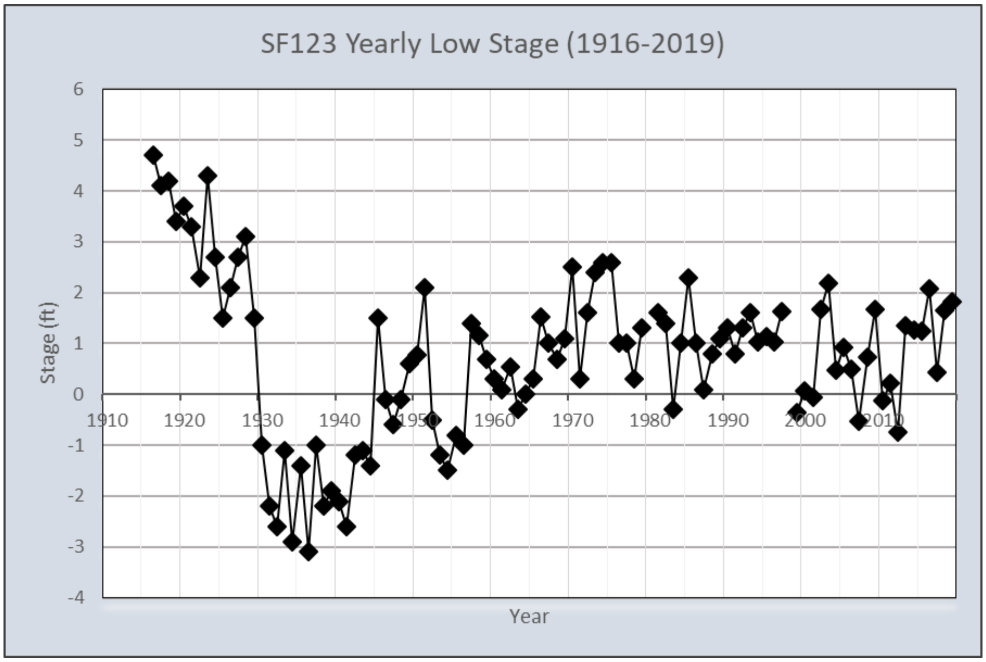


Figure 24. Yearly low-stage plot for SF122–St. Francis River at Hopkin's Bridge.



Yearly low stages for SF123 (St. Francis at Lake City) dropped significantly between 1929 and 1932 (Figure 25). Stages increased approximately 5 ft between 1940 and 1970 and have remained relatively stable since the 1970s. The St. Francis Lake Control (constructed in 1976) is located approximately 18 mi downstream and maintains a pool elevation in the lake. Because this area is part of the Sunken Lands, the slope in this reach is very low. The control structure is likely influencing low stages. Therefore, it is difficult to determine geomorphic change from the low-stage plot for this reach.

Figure 25. Yearly low-stage plot for SF123–St. Francis River at Lake City.



Overall, decreases in low stage were observed in the upper part of the watershed, and increases were observed in the lower part of the study area.

4.4 Aerial Imagery Analysis

Table 7 provides the reach centerline mileage between each gage on the St. Francis River between SF114 (St. Francis at Wappapello) and SF119 (St. Francis at Holly Island) for each year in which aerial imagery was available. River mileage below SF119 (St. Francis at Holly Island) could not be determined due to the complexity of the river system within the floodway below Highway 90. Flow through this reach is split between multiple channels and distributaries and typically flows levee to levee within the floodway. River mileage from this table provided needed input for the slope and stream power analysis. Figure 26 shows how the stream centerline between SF115 and SF117 changed for 1961, 1973, and 2011.

Table 7. St. Francis reach lengths from 1953 to 2020 from Wappapello to Highway 90.

Year	Length (mi)					
	SF114–SF115	SF115–SF116	SF116–SF117	SF117–SF118	SF118–SF119	Total
1953*	–	–	25.1	9.9	13.9	–
1956	22.1	35.8	25.0	9.4	14.0	106.3
1961	22.3	36.0	24.6	9.9	14.0	106.7
1967	22.4	36.23	23.43	10.0	14.0	106.0
1973	22.4	32.8	10.0	9.9	14.1	89.0
1999	22.5	22.0	10.0	9.7	14.1	78.3
2009	22.4	22.1	10.1	9.9	14.2	78.7
2011**	22.6	22.2	10.1	9.9	14.2	78.8

*Aerial imagery was not available for the entire study reach for 1953.

**No change in stream length occurred between 2011 and 2020.

The St. Francis River between Wappapello and Highway 90 was shortened by 28 mi, or approximately 27%, between 1956 and 2011. The greatest change in stream length occurred between SF116 and SF117 between 1967 and 1973. This was primarily due to Wilhelmina Cutoff. Several small cutoffs were constructed as well, and in total, the river reach was shortened by 14.6 mi between 1961 and 1973. Numerous small cutoffs were constructed between SF115 and SF116 during the 1960s and 1970s. The cutoffs in this reach shortened the river by 14 mi. Stream lengths in the reaches SF114–SF115, SF117–SF118, and SF118–SF119 remained essentially constant for the time period in which aerial imagery was available.

Figure 26. St. Francis River stream centerlines from 1961 to the present.

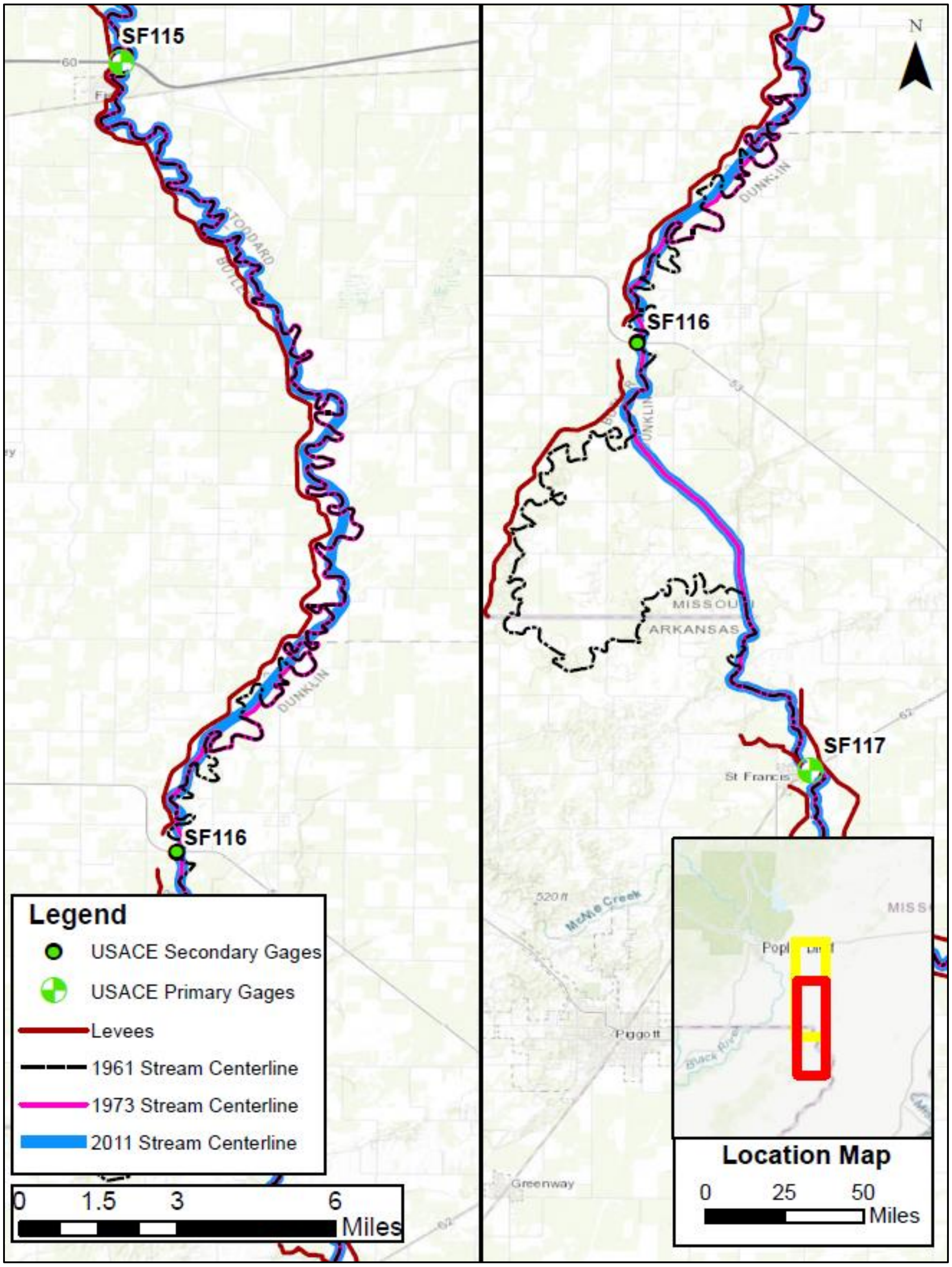


Table 8 shows the calculated sinuosity for each reach for the centerlines traced for 1967 and 2011. For the reaches in which no cutoffs were constructed (i.e., SF114–SF115, SF117–SF118, and SF118–SF119), only small changes in sinuosity were calculated. Sinuosity was significantly decreased in the SF115–SF116 and SF116–SF117 reaches due to the cutoffs.

Table 8. Sinuosity for each reach for 1967 and 2011.

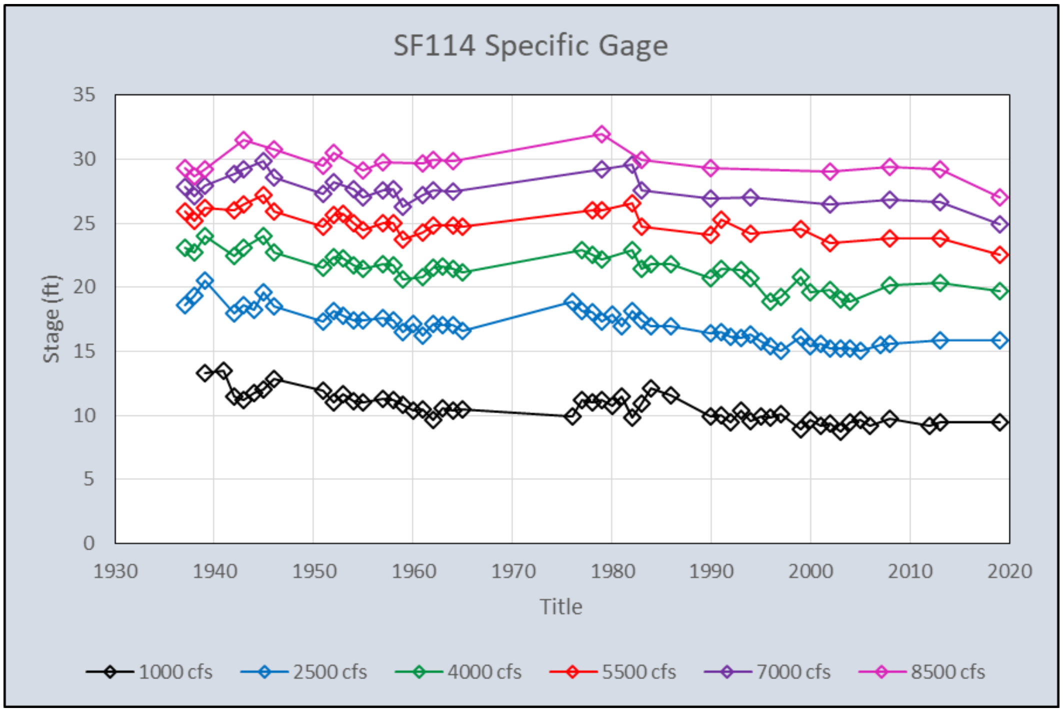
Reach	1967 Valley Distance (mi)	2011 Valley Distance (mi)	1967 Stream Length (mi)	2011 Stream Length (mi)	1967 Sinuosity	2011 Sinuosity
SF114–SF115	11.4	11.4	22.38	22.56	1.96	1.97
SF115–SF116	16.9	16.9	36.23	22.15	2.14	1.31
SF116–SF117	13.8	8.9	23.43	10.04	1.70	1.13
SF117–SF118	6.1	6.1	9.96	9.88	1.63	1.62
SF118–SF119	12.8	12.8	14.00	14.19	1.09	1.11

4.5 Specific Gage

Figures 27 to 33 show specific-gage plots for the primary and secondary locations analyzed using the rating curve method (Biedenharn et al. 2017). Stage was plotted over time for a specified discharge to assess changes in water surface elevation over time. Specific gage records can exhibit variability from year to year, but long-term trends in water surface elevation can indicate geomorphic change or channel stability. The 50 and 99 PCE values were utilized to develop flow bins for the specific gage analyses. SF114 through SF116 utilize bins between the two frequency flows. The Wappapello water control plan cites 3,800–4,200 cfs as the channel capacity from the dam to SF116 and 7,000 cfs as the channel capacity from SF116 to SF117 (USACE St. Louis District 2016). Gages SF117 through SF123 are located within the floodway, where a channel design flow does not exist; therefore, 10,000 cfs was the maximum flow to ascertain trends within the primary channel.

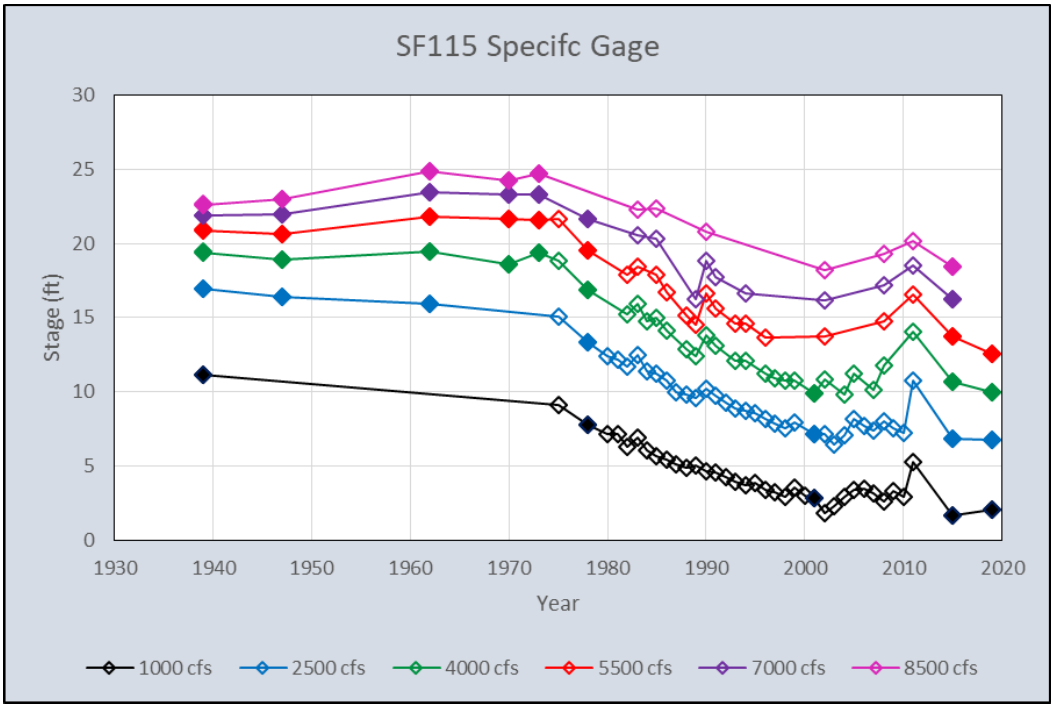
The specific-gage plot for SF114 shows a slight decreasing trend in stage for all discharges from the 1940s to 1960s (Figure 27). This trend is most apparent for the 1,000 cfs flow. While there was a gap in the data between 1965 and 1975, there was an overall increase in stage for the upper five discharge bins. After 1980, the stages showed a slightly decreasing trend for 5,500 cfs, 7,000 cfs, and 8,500 cfs flows. Stages showed a slightly decreasing trend for 2,500 cfs and 4,000 cfs until the mid-2000s. For 1,000 cfs, stages have remained relatively constant since 1990.

Figure 27. Specific-gage plot for SF114/USGS 7039500–St. Francis River at Wappapello, Missouri.



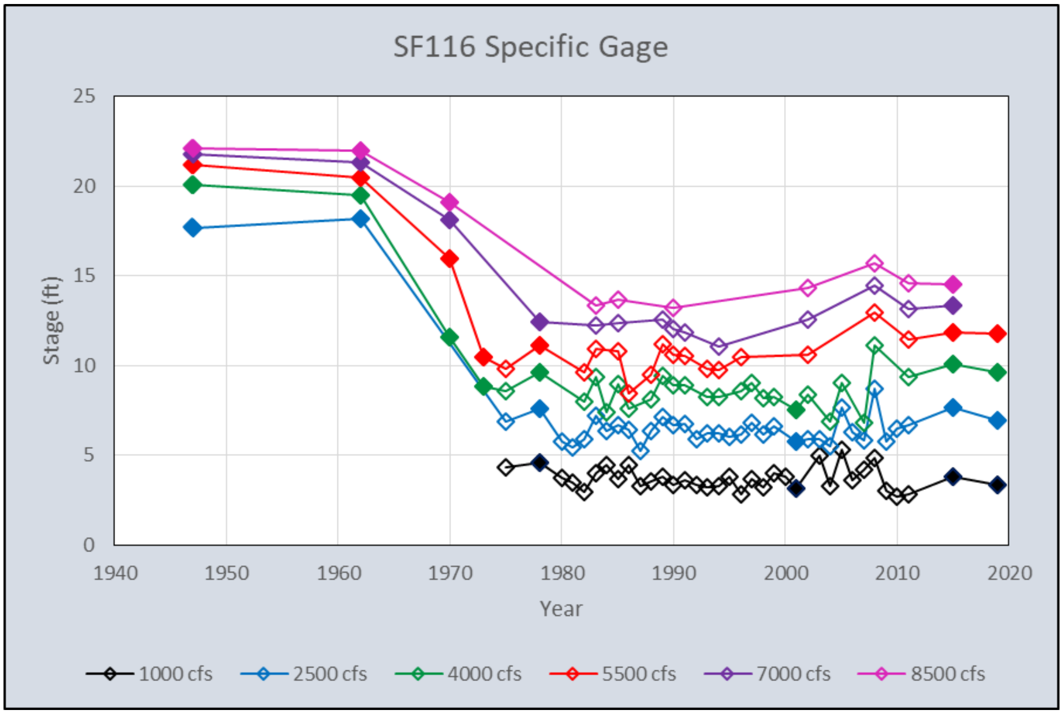
SF115 (St. Francis River at Fisk) is located upstream of the channel cutoffs. During the precutoff period, stages showed a slightly increasing trend at the higher discharge bins (i.e., 5,500–8,500 cfs) and a slightly decreasing trend at lower discharges (Figure 28). Starting in 1975 and lasting until the early 2000s, a pronounced decreasing trend was observed for all discharges. For a discharge of 4,000 cfs, nearly an 8 ft drop in stage was observed in this time period. Flood stage at SF115 is 20 ft. Prior to the mid-1970s, a flow of 4,000 cfs would have resulted in stages just below flood stage. Currently, a discharge of greater than 8,500 cfs would be required to reach flood stage. The channelization below Fisk was completed in 1975, and an immediate change was observed in the stage discharge relationship. This can likely be attributed to channel degradation in response to the downstream channelization. While there appears to be a slight increasing trend from 2000 to 2011, the time period is not sufficient to draw conclusions. Overall, there appears to be a slight decreasing trend developing between 2000 and the present.

Figure 28. Specific-gage plot for SF115–St. Francis at Fisk, Missouri. *Solid symbols* reflect multiple years combined into a single rating curve.



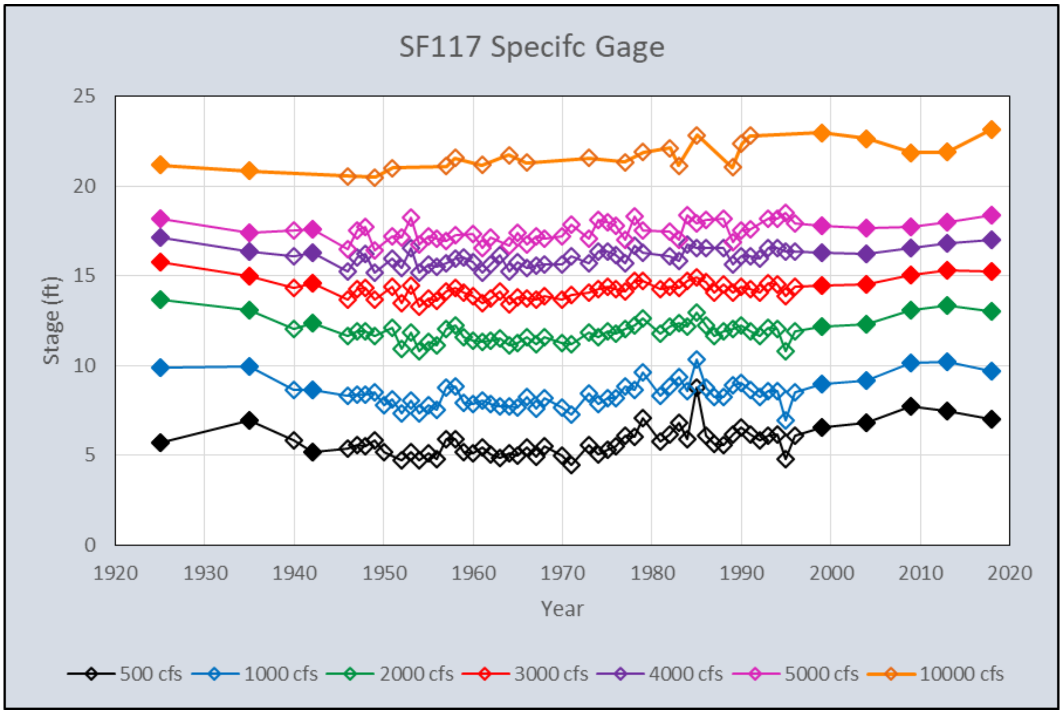
SF116 (Dekyn's Store) is a secondary location in the middle of the channelized reach and immediately upstream of Wilhelmina Cutoff. SF116 stages showed an abrupt decreasing trend for all discharges starting in the mid-1960s (Figure 29). For a discharge of 4,000 cfs, a drop in stage of over 10 ft was observed between the early 1960s and mid-1970s. The drop in stages occurred earlier than it did for SF115, which indicates a headcut moved upstream in the river. Stages at all discharges generally showed a stable trend from 1980 to the early 2000s. From 2000–2010, a slight increasing trend in stage for the midrange and higher discharges and a relatively stable trend for the low discharge was observed.

Figure 29. Specific-gage plot for SF116–St. Francis River at Dekyn's Store, Missouri. *Solid symbols* reflect multiple years combined into a single rating curve.



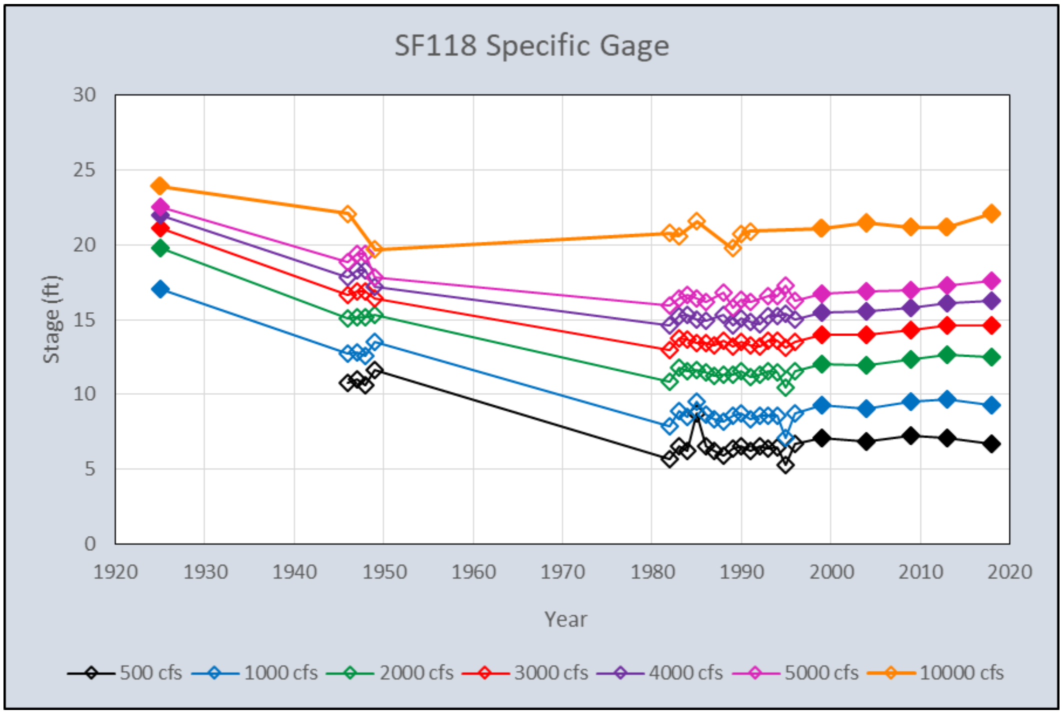
SF117 (St. Francis River at St. Francis) is a primary station and is located downstream of the cutoffs and just below where the St. Francis River cuts through Crowley's Ridge. The specific-gage record (Figure 30) showed generally stable trends in stage at higher flows for the early part of the period of record (1920–1940s). A slightly decreasing trend was observed for the mid- and lower-range discharges (i.e., below 4,000 cfs). A slightly increasing trend was shown for all flows from the 1970s to 2010. This increasing trend was more pronounced at the lower flows (i.e., 500 and 1,000 cfs) and begins immediately following the channel cutoffs. Midrange flows from 2010 to the present have a stable trend. High-range flows (i.e., above 4,000 cfs) show increasing trends, and low-range flows show decreasing trends in recent years. However, limited measurements were available during this time. Generally, this reach appears to be relatively stable through the entire period of record.

Figure 30. Specific-gage plot for SF117–St. Francis River at St. Francis, Arkansas. *Solid symbols* reflect multiple years combined into a single rating curve.



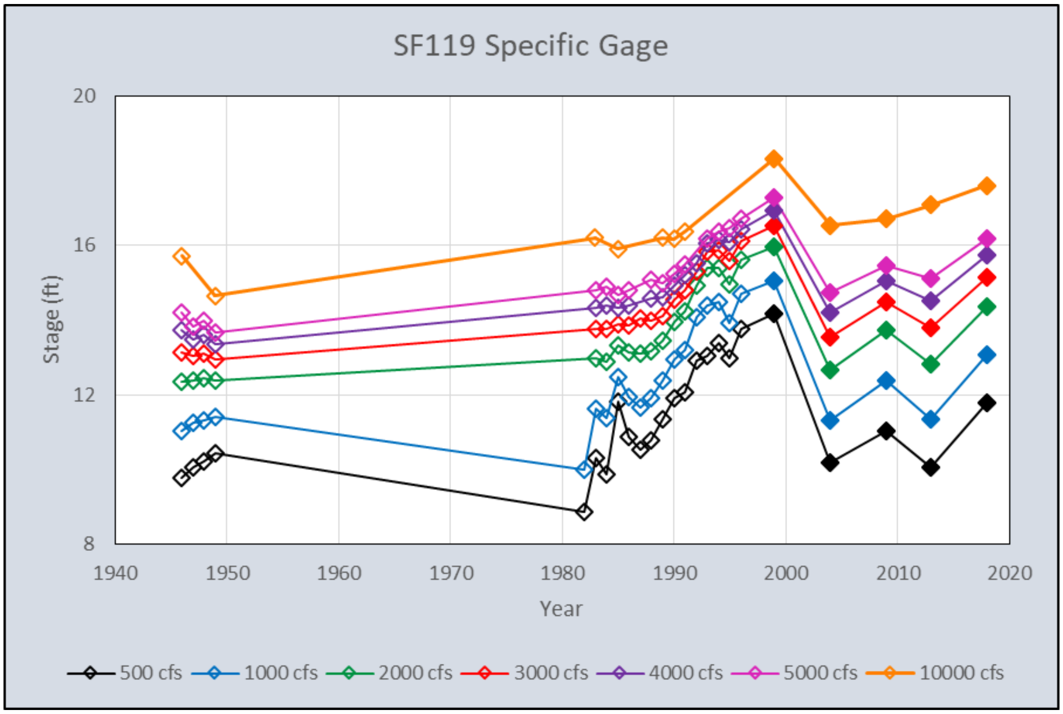
SF118 (St. Francis at Brown's Ferry) is a secondary location within the floodway and uses discharge measurements from SF117 because no tributaries enter the floodway between SF117 and SF119. No lag was applied to daily stages because the time lag between SF117 and SF118 is less than one day. From the 1950s to 1980, discharge measurements for SF117 only had a year and a stage associated with them; the date was not recorded. Therefore, the discharge measurements could not be matched with corresponding stages at SF118 and SF119, and limited data points were available pre-1980. While there was a considerable gap in data between 1920 and the mid-1940s and between 1950 and 1980, stages generally dropped at all flow values from the 1920s to the 1980s (Figure 31). The decreasing trend was less pronounced for the highest flows (i.e., 10,000 cfs). Stages showed a very slightly increasing trend from the 1980s to 2000 for all discharges and a stable trend from 2000 to the present.

Figure 31. Specific-gage plot for SF118–St. Francis River at Brown's Ferry. *Solid symbols reflect multiple years combined into a single rating curve.*



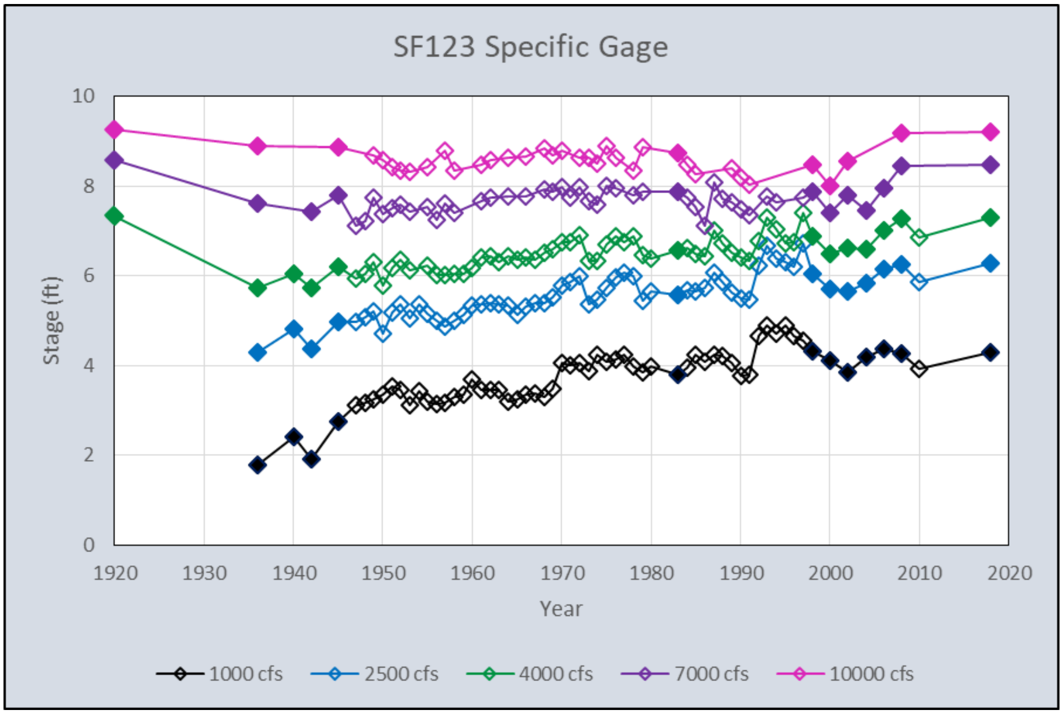
SF119 (St. Francis River at Holly Island) is a secondary station that uses discharges from SF117. A one-day lag in discharge was applied when determining stages for corresponding discharges (Figure 32). However, limited data were available prior to 1980, so it was difficult to get an accurate picture of stage-discharge trends during this time period. After the early 1980s until 2000, a distinct increasing trend in stages was shown. This trend was more pronounced for 500 and 1,000 cfs. A dramatic decrease in stage for all discharges occurred from 1998 to the mid-2000s. This time frame corresponds with the construction of the drainage channel below Highway 90 that happened in 2000, which explains the dramatic decrease in stages. Following the construction of the drainage channel, an increasing trend in stages for all discharges was seen. This agrees with the significant aggradation observed below Highway 90.

Figure 32. Specific-gage plot for SF119–St. Francis River at Holly Island near Kennett, Missouri. *Solid symbols* reflect multiple years combined into a single rating curve.



SF123 (St. Francis River at Lake City) is a primary location in the St. Francis Sunken Lands, just upstream of St. Francis Lake. Low- and midrange flow (i.e., 1,000, 2,500, and 4,000 cfs) stages showed a pronounced increasing trend from mid-1930 to 1990 (Figure 33), while stages at higher flows (i.e., 7,000 and 10,000 cfs) were generally stable. Since 1990, low- and midrange flows showed relatively stable trends in stages, with some year to year fluctuations. A slightly increasing trend was observed at the higher range flows. A stage of approximately 6 ft results in bankfull flows. Prior to 1960, this would have been a flow of 4,000 cfs, while currently 2,500 cfs exceeds bankfull.

Figure 33. Specific-gage plot for SF123–St. Francis River at Lake City, Arkansas. *Solid symbols* reflect multiple years combined into a single rating curve.



Overall, the specific gage plots showed the river is responding to the cutoffs as expected. The specific gage plots indicated degradation in the reach from upstream of Crowley's Ridge to upstream of Fisk (SF115) following channelization, indicating a headcut moved up through the system. Because the stages at SF114 have remained relatively stable, there may be a bridge, boat ramp, or geologic feature acting as grade control in this reach, or the reach may have reached a stable slope. St. Francis (SF117), located immediately downstream of the cutoffs and at the start of the floodway, has remained relatively stable over time, with potentially some slight aggradation. St. Francis is located within the floodway, just below Crowley's Ridge. Flow through this area bottlenecks upstream as the channel capacity changes from 10,000 cfs through the cutoff to 2,000 cfs at Brown's Ferry. Numerous sanding claims were made in 1979, between Dekyn's Store and Brown's Ferry, as more frequent overbank flooding was observed. SF118 (Brown's Ferry) showed degradation prior to 1980, but it appears to be relatively stable presently. Because degradation was not observed upstream at St Francis, there could be a feature (e.g., bridge or geology) acting as a grade control between SF118 and SF117. At SF119 (Highway 90), the specific gage indicates aggradation is occurring throughout the period of record.

4.6 Water Surface Slope

Slope is an important parameter that is closely related to sediment transport capacity and energy in a channel. Changes in slope can occur for a variety of reasons, including aggradation, degradation, or channel shortening. Therefore, trends in slope over time can be used to understand geomorphic change in the system. Yearly average water surface slope was determined for the reaches between consecutive gages using daily stage records. Because stream lengths could not be determined for the reach below SF119 due to the complexity of the flow paths, slope and stream power analyses stop at SF119. Figures 34 through 38 show yearly average slopes over the period of record for each reach.

Yearly average slopes for SF114–SF115 (Wappapello to Fisk) were relatively constant; they were at approximately 0.5 ft/mi from 1920 to 1964 (Figure 34). Slopes have increased gradually, to around 0.7 ft/mi, since 1965. This corresponds with the degradation at SF115 observed following the channel cutoffs. Since 1990, the rate of increase in slope has reduced as SF115 has stabilized.

Figure 34. Yearly average water surface slope between SF114 and SF115 (St. Francis River at Wappapello to Fisk).

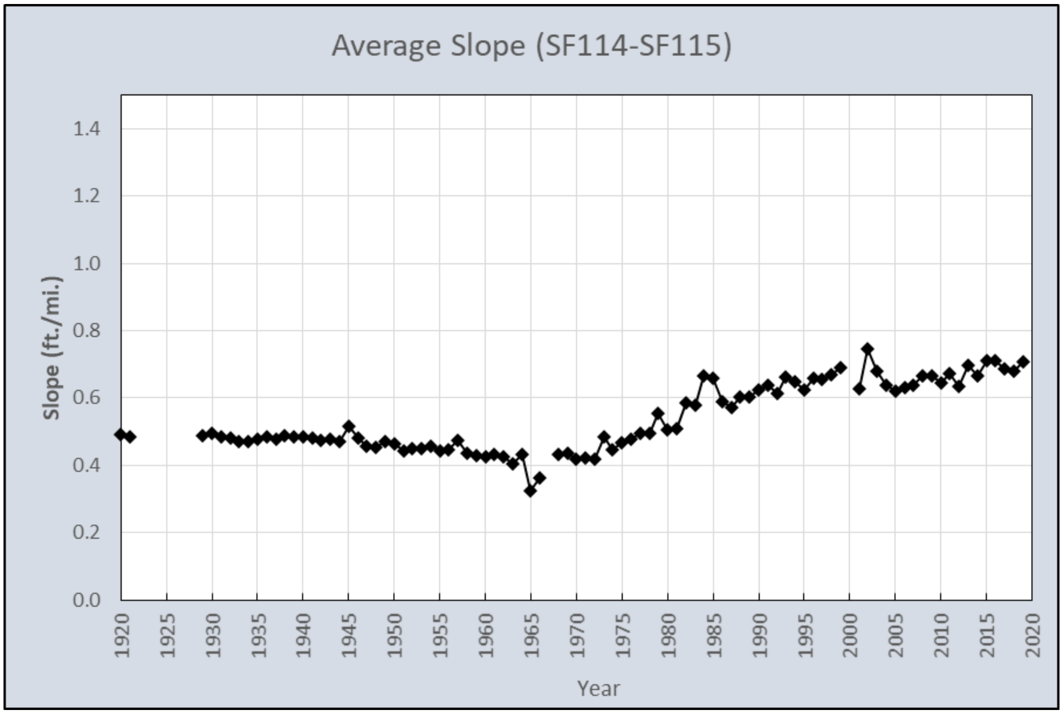
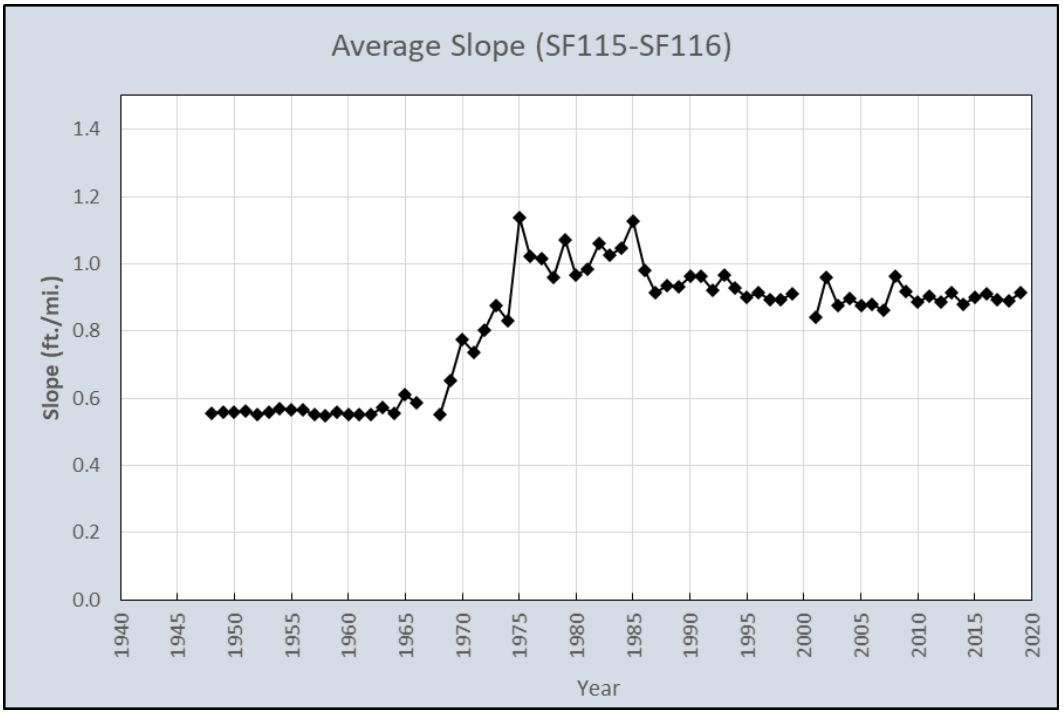


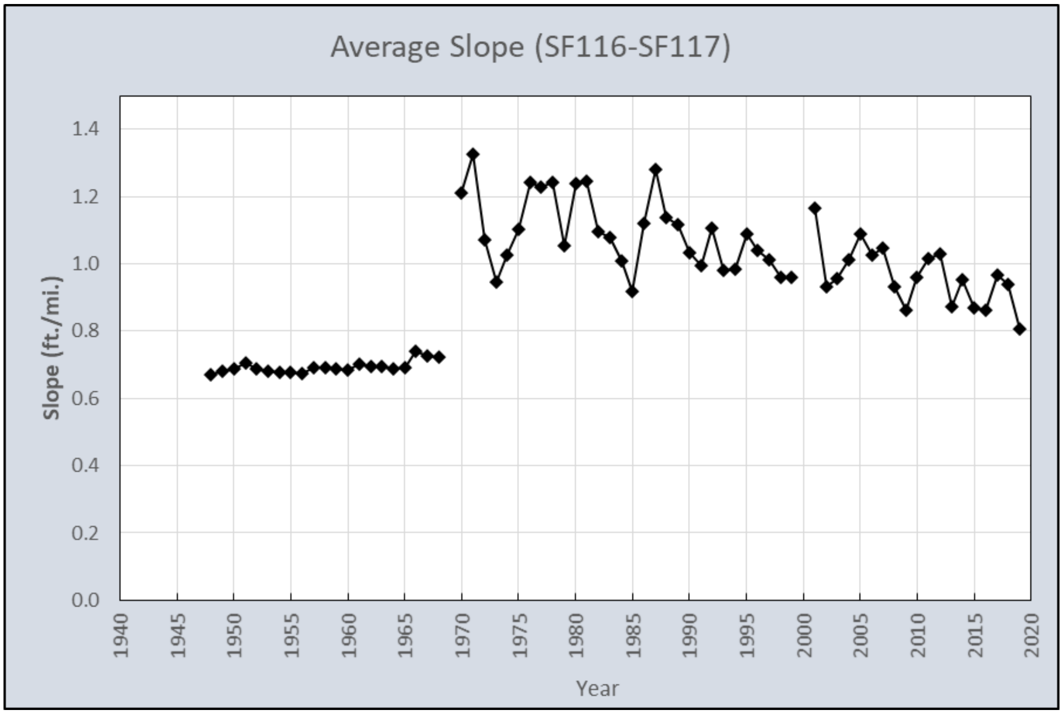
Figure 35 shows average slopes for the reach SF115 to SF116 (Fisk to Dekyn's store). Slope was stable in this reach from 1948 to 1966. Channelization began in this reach in 1966, and a dramatic increase in slope was observed after the river was shortened. Slope nearly doubled from 1967 to 1975. After 1987, the average slope dropped as the channel began to reach an equilibrium. Since 1985, the slope has remained essentially constant at around 0.9 ft/mi.

Figure 35. Yearly average water surface slope between SF115 and SF116 (St. Francis River at Fisk to Dekyn's Store).



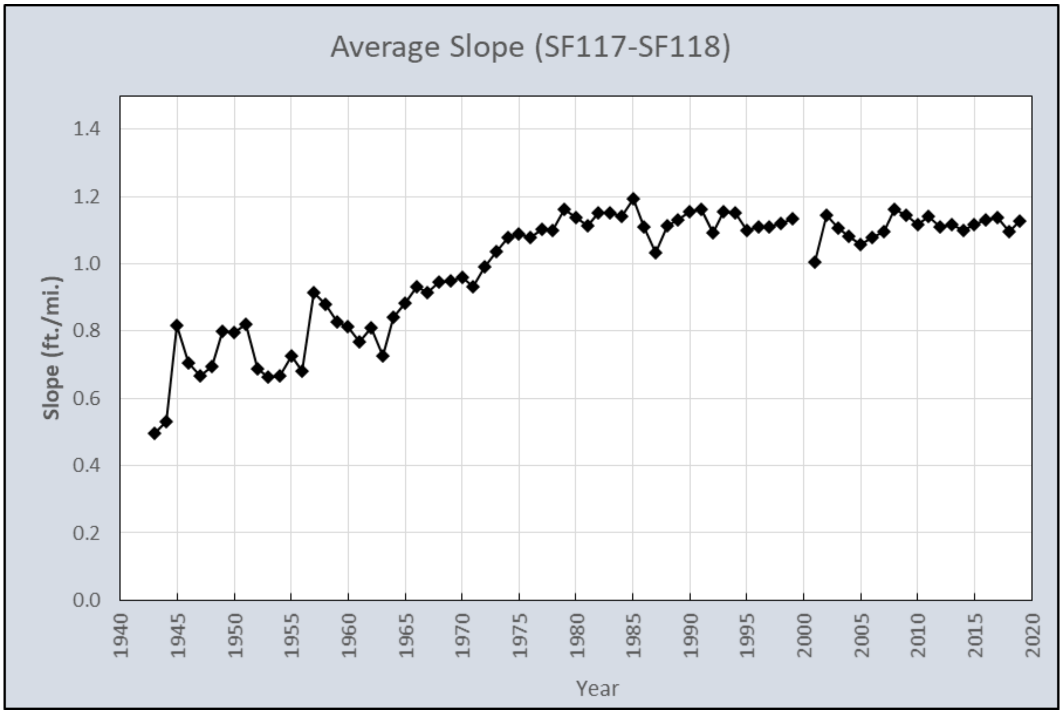
SF116 to SF117 is the reach that contains Wilhelmina Cutoff. Average slopes were relatively stable prior to the channel cutoff (Figure 36). Following the cutoffs, water surface slope increased from approximately 0.7 ft/mi to approximately 1.2 ft/mi, or by around 71%. The slope in this reach oscillated by around 0.2 ft/mi in the postcutoff time period, but it showed an overall decreasing trend. The overall decreasing trend indicates the reach is adjusting to a new equilibrium slope. The channel is degrading at SF116, but it is slightly aggrading downstream as it adjusts to a flatter slope. This reach appears to still be adjusting to an equilibrium slope.

Figure 36. Yearly average water surface slope between SF116 and SF117 (St. Francis River at Dekyn's Store to St. Francis).



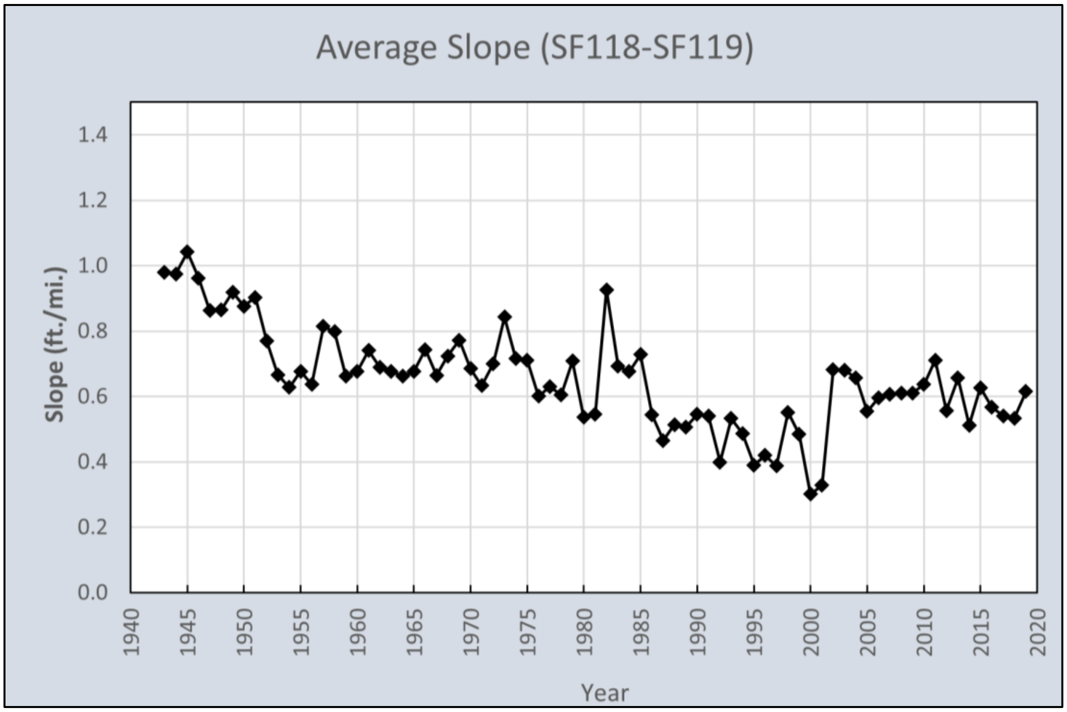
The stream length from SF117 to SF118 (St. Francis to Brown's Ferry) remained essentially constant during the study period. Prior to the cutoffs and channelization in the upstream reaches, slope steadily increased in this reach from 1943 to 1980 (Figure 37). During this time period, the slope almost doubled. The specific gage and yearly low stage for SF118 indicated degradation at this location, while SF117 remained relatively stable. The slope has been generally constant since 1980, with some minor year to year variations, and appears to have reached an equilibrium slope. Specific gage results at SF117 and SF118 indicate that stage trends at both gages are increasing at similar rates.

Figure 37. Yearly average water surface slope between SF117 and SF118 (St. Francis River at St. Francis to Brown's Ferry).



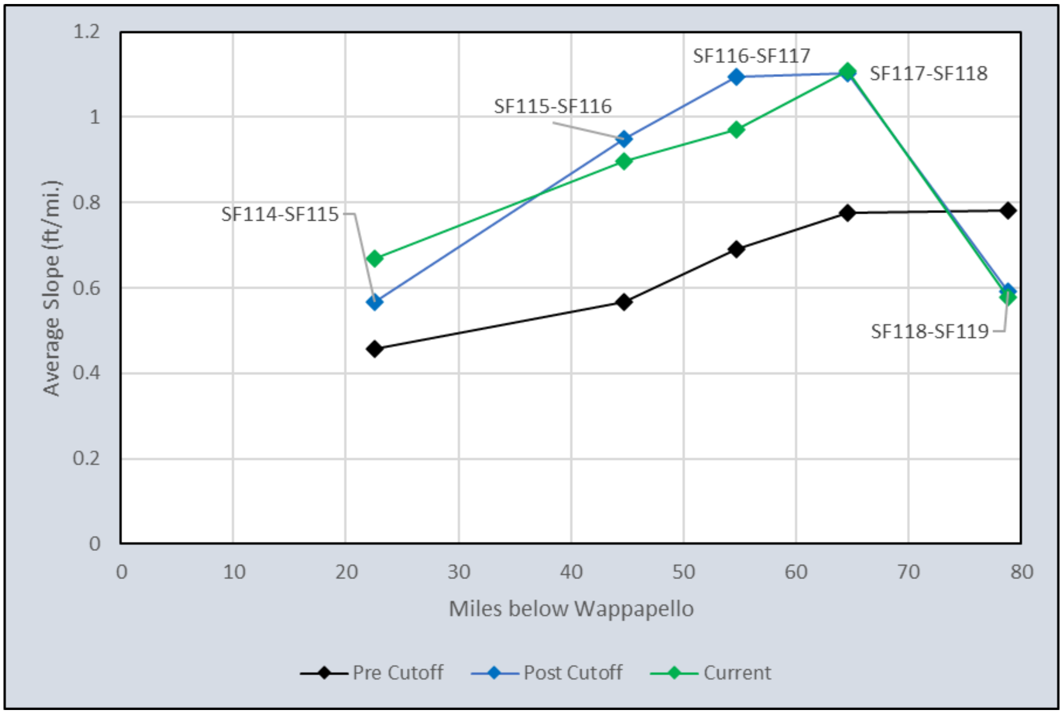
SF118–SF119 is the reach upstream of the blockage below Highway 90. Water slopes have shown an overall decreasing trend since the 1940s (Figure 38), with a period of relatively stable slopes from 1950 to 1980. The reach downstream aggraded and the reach upstream degraded during this time period. The decrease in slope from 1980 to 2000, along with the aggrading trend at both SF118 and SF119 given by the specific gage trends, indicates the downstream end of the reach was aggrading at a faster rate than the upstream end. Average slopes decreased from 1 ft/mi to 0.4 ft/mi in 2000. The construction of the drainage channel below Highway 90 in 2000 increased the slope by 0.3 ft/mi.

Figure 38. Yearly average water surface slope between SF118 and SF119 (St. Francis River at Brown's Ferry to Holly Island).



For the precutoff (i.e., before 1970), postcutoff (i.e., 1970–2000), and current (i.e., 2000–2019) time periods, the average water surface slope for each reach was plotted as a function of miles below Wappapello Dam (Figure 39). During the precutoff period, slope increased in the downstream direction. Slopes were approximately equal in the two reaches from SF117 to SF119. Postcutoff, the slope increased for the first four reaches, and a dramatic drop in slope occurred from SF117–SF118 to SF118–SF119. Average slopes decreased from 1.1 ft/mi to 0.6 ft/mi between the two reaches.

Figure 39. Average water surface slopes for each reach during precutoff (i.e., 1942–1969), postcutoff (i.e., 1970–1999), and current (i.e., 2000–2019) time periods as a function of distance below Wappapello Dam.



The greatest increases in slope occurred in the SF115–SF116 reach (67% increase) and the SF116–SF117 reach (59% increase) between the pre- and postcutoff time periods. A decrease in slope occurred in the SF118–SF119 reach. Water surface slope decreased by 25% in the SF118–SF119 reach between the pre- and postcutoff periods. This analysis shows the cutoffs constructed in the St. Francis River during the 1960s and 1970s prompted significant geomorphic change. The three upstream reaches have continued to adjust in the current (i.e., 2000–2019) time period, with the most upstream reach becoming steeper. The two reaches in which the cutoffs and channelization occurred (i.e., SF115–SF116 and SF116–SF117) showed a slight decrease in slope between the postcutoff and current time periods. The postcutoff increase in slope likely increased sediment transport capacity in the first three reaches and decreased the sediment transport capacity in the last reach. SF117–SF118 showed an increase in slope prior to the completion of the cutoffs due to the degradation at SF118. Therefore, the increase in slope in this reach cannot be attributed to the cutoffs and channelization upstream.

4.7 Stream Power

Daily discharges and slope (determined from daily stages) were used to generate average yearly values for stream power (*QS*) and cumulative yearly stream power for each year. Stream power is the product of the active forces, or discharge and slope, acting on the streambed. It is influenced heavily by yearly weather and climate patterns. This type of direct influence makes it difficult to visually identify trends. Plots for each reach can be found in Appendix B. An example of a yearly average *QS* plot for SF115–SF116 is shown in Figure 40. A dramatic increase in stream power was observed in this reach following the cutoffs.

Figure 40. Example yearly average stream power for SF115–SF116 (Fisk to Dekyn's Store).

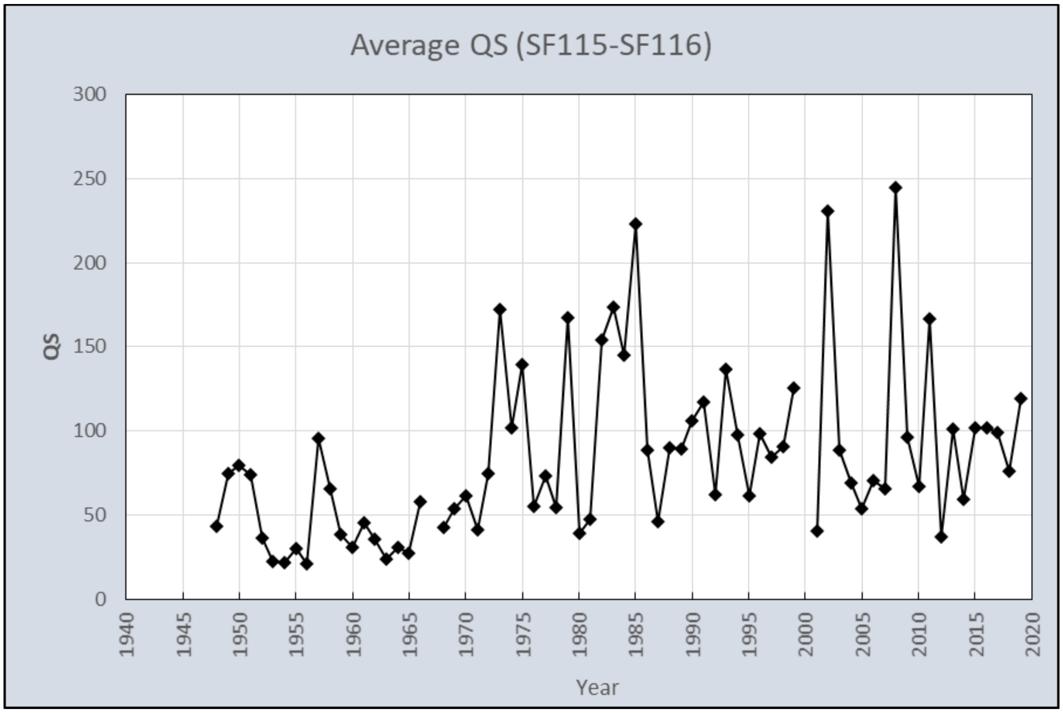
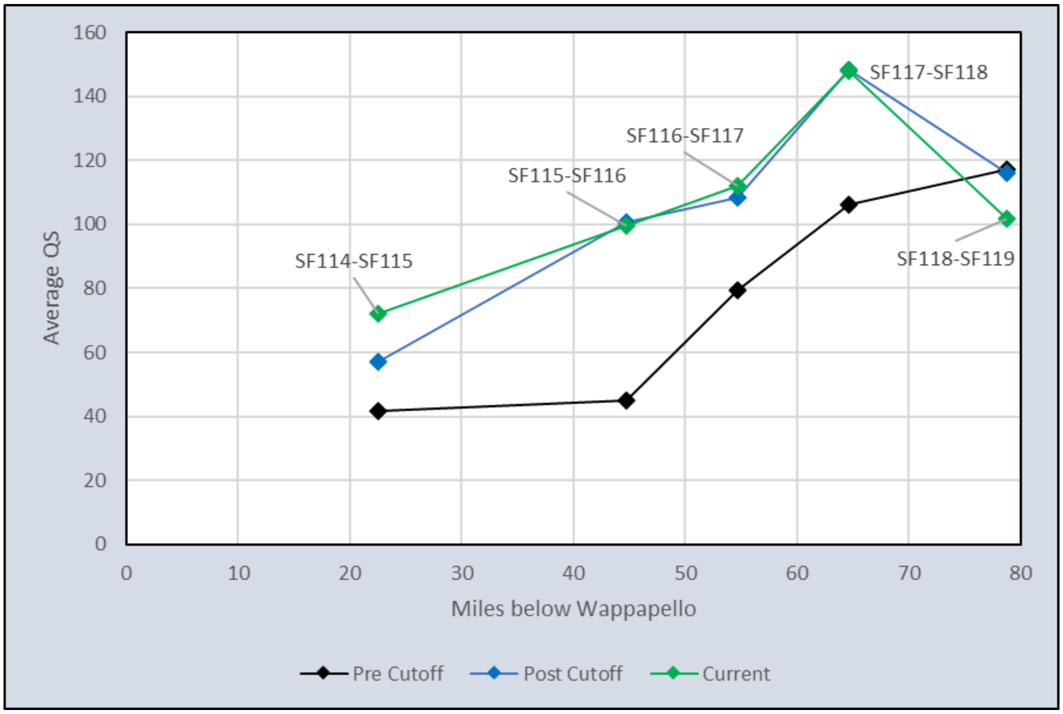


Figure 41 shows average stream power for the pre- and postcutoff time periods plotted as a function of miles below Wappapello Dam. During the precutoff time period, the stream power generally increased in the downstream direction, with the greatest increase occurring in the two reaches between Dekyn's Store and Brown's Ferry (i.e., SF116–SF117 and SF117–SF118). This increase occurred as the river crosses Crowley's Ridge at Chalk Bluff, which is just upstream of SF117. This increase can be attributed to the increase in slope in this reach and the increased discharge from tributaries entering the river. Previous analysis showed the channel bed slope to be flatter above Crowley's Ridge than below Crowley's Ridge prior to the cutoffs (USACE 1985).

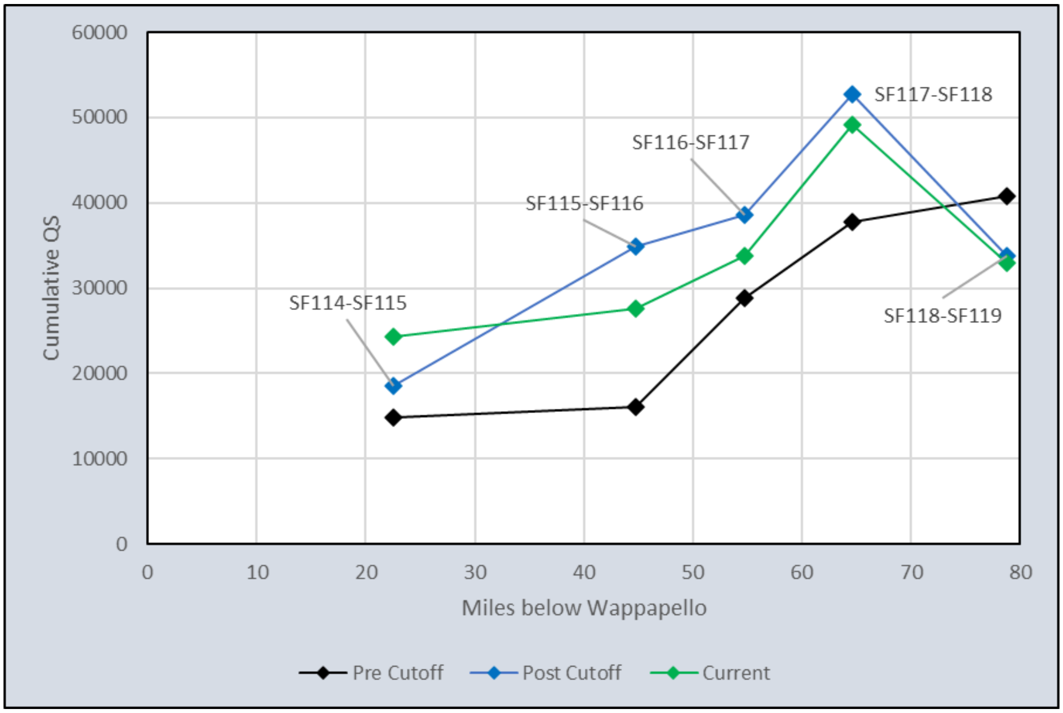
Figure 41. Average stream power for each reach during precutoff (i.e., 1942–1969), postcutoff (i.e., 1970–1999), and current (i.e., 2000–2019) time periods as a function of distance below Wappapello Dam.



Following the cutoffs, average stream power increased for the four upstream reaches, with the greatest percent increase occurring in the SF115–SF116 reach (Figure 41). A slight decrease in stream power was shown for the most downstream reach (i.e., SF118–SF119) between the pre- and postcutoff periods. The average stream power continued to decrease between the postcutoff and current time periods. In the downstream direction, the average stream power increased through the SF117–SF118 reach and then decreased by 25% downstream in the SF118–SF119 reach. The entire reach from SF117 to SF119 is within the leveed floodway, and there are no flow inputs in this reach. Therefore, the decrease in stream power can be entirely attributed to the decrease in slope in the downstream reach. The stream power, which is sometimes thought of as a surrogate for sediment transport capacity, is greater upstream of the SF118–SF119 reach than it is in the reach; therefore, aggradation downstream is expected.

Similar trends are shown for the cumulative yearly stream power values in Figure 42. However, the percent differences are slightly lower for the cumulative stream power when compared to the average stream power.

Figure 42. Cumulative yearly stream power for each reach during precutoff (i.e., 1942–1969), postcutoff (i.e., 1970–1999), and current (i.e., 2000–2019) time periods as a function of distance below Wappapello Dam.



5 Summary, Conclusions, and Recommendations

The St. Francis River is a complex riverine system with many natural geomorphic attributes. The anthropogenic modifications that have been applied to the system make the St. Francis River even more complex and studying the region more difficult. Understanding the historical and current trends in the St. Francis River is vitally important for long-term management of the basin for flood control and drainage. Several statistical and geomorphic analyses of available data and historic research provided an overview of geomorphic trends to evaluate the river stability by reach. To summarize the results, the period of record was divided into three time periods: precutoff (i.e., before 1970), postcutoff adjustment period (i.e., 1970–2000), and modern time period (i.e., 2000–2019). A qualitative classification that identified a decreasing, increasing, or stable trend was given to stages at each gage during each time period (Tables 9–11) based on the visual interpretation of figures presented earlier in this report. In general, all the analyses identified the same trends.

Prior to the cutoffs and channelization, the three upstream gages (i.e., SF114, SF115, and SF116) showed a slightly decreasing trend or stable trend for all analyses (Table 9). Below Crowley's Ridge (SF117), a more pronounced decreasing trend was observed, indicating degradation was occurring prior to the channelization. However, it is likely that local interests were altering the channel prior to USACE involvement and channelization, which could explain the decreasing trends in stages prior to 1970. This assumption was validated by researching archived USACE design memos, which noted significant local alteration prior to federal involvement in the watershed (USACE 1964). The increasing trends occurring at the two downstream gages indicate aggradation.

Table 9. Summary of stage trends from gage analyses for the precutoff period (i.e., before 1970).

Gage	Stage Duration	Yearly Low Stage	Specific Gage
SF114	Stable	Slight decrease	Slight decrease
SF115	Stable	Stable	Stable
SF116	Slight decrease	Stable	Stable
SF117	Decrease	Decrease	Decrease
SF118	Decrease	Decrease	Decrease
SF119	Decrease	Decrease/increase	**
SF123	Slight increase	Increase	Increase

**Not enough data to make a determination.

As shown in Table 10, after channelization, SF114 stages still showed stable trends. A dramatic decrease in stages was observed at SF115 and SF116, which suggests a headcut moved through these reaches following channelization. SF117 showed a slightly increasing trend in stages and likely some aggradation. This is consistent with historical knowledge of the area. Immediately after construction of Wilhelmina Cutoff, landowners began reporting damages due to sanding in the reach extending from the downstream end of Wilhelmina to SF117. Downstream of Crowley's Ridge, at SF118, degradation was still occurring during the postcutoff period. At SF119 (Highway 90), a dramatic increasing trend in stages started in the mid-1970s, and aggradation became a problem in this reach.

Table 10. Summary of stage trends for gage analyses for the postcutoff period (i.e., 1970–2000).

Gage	Stage duration	Yearly low stage	Specific gage
SF114	Stable	Stable	Slight decrease
SF115	Decrease	Decrease	Decrease
SF116	Stable	Decrease	Decrease
SF117	Increase	Slight increase	Stable
SF118	Stable	Stable	**
SF119	Increase	Increase	Increase
SF123	Stable	Stable	Stable

**Not enough data to make a determination.

After the initial adjustment period following the channel cutoffs, the stage trends began to stabilize at SF115, SF116, and SF118 (Table 11). Slight decreasing trends in stage were still noticeable for SF115 and SF116, but they were less pronounced than during the initial postcutoff period. Conversely, strong increasing trends were still observed at SF119, indicating this reach has a continual tendency to aggrade. An increasing trend was also expected downstream of the cutoff at SF118, but this was not the case. This location showed decreasing trends prior to the channel alterations and then stabilization. The change from a decreasing trend to a stable trend could be due to an increased sediment supply from upstream.

Table 11. Summary of stage trends for gage analyses for the current period (i.e., 2000–2019).

Gage	Stage Duration	Yearly Low Stage	Specific Gage
SF114	Stable	Stable	Stable
SF115	Stable	Slight decrease	Slight decrease
SF116	Stable	Decrease	Stable
SF117	Stable	Increase	Increase
SF118	Stable	Stable	Stable
SF119	Stable	Increase	Increase
SF123	Stable	Stable	Slight increase

Stages at SF114 were mostly stable throughout the period of record. This indicates that the effects of the Wappapello Dam construction and Wilhelmina Cutoff were very minor and generally unnoticeable. However, the two gages downstream showed dramatic decreasing trends in stages after channelization. This could indicate the headcut is still moving up through the system, that a geologic or constructed feature is acting as a grade control in this reach, or perhaps that this reach is at a new equilibrium slope. Additional analysis and field investigations are needed to verify.

A similar trend is shown between St. Francis (SF117) and Brown's Ferry (SF118); SF118 showed a dramatic decrease in stage, but SF117 remained stable over time with some slight aggradation.

Figure 43 shows the long-term trends for the study reach for each gage for each of the time periods. Prior to the widespread channelization, the upstream portion of the watershed was relatively stable, while the middle portion showed decreasing trends. Only SF123 showed an increasing trend. Following the cutoffs, degradation occurred above Crowley's Ridge, and sedimentation began below. In the last two decades, the upper portion of the watershed has begun to stabilize, while significant aggradation is still occurring downstream. Channel bed degradation in the main stem is likely only one source of sediment for the downstream aggradational reaches. Bank erosion and sediment sources from the tributaries need to be investigated to give a complete picture of channel sediment sources in the watershed.

Figure 43. Stage trends at each gage location for the precutoff (*left*), postcutoff (*middle*), and current (*right*) time periods.

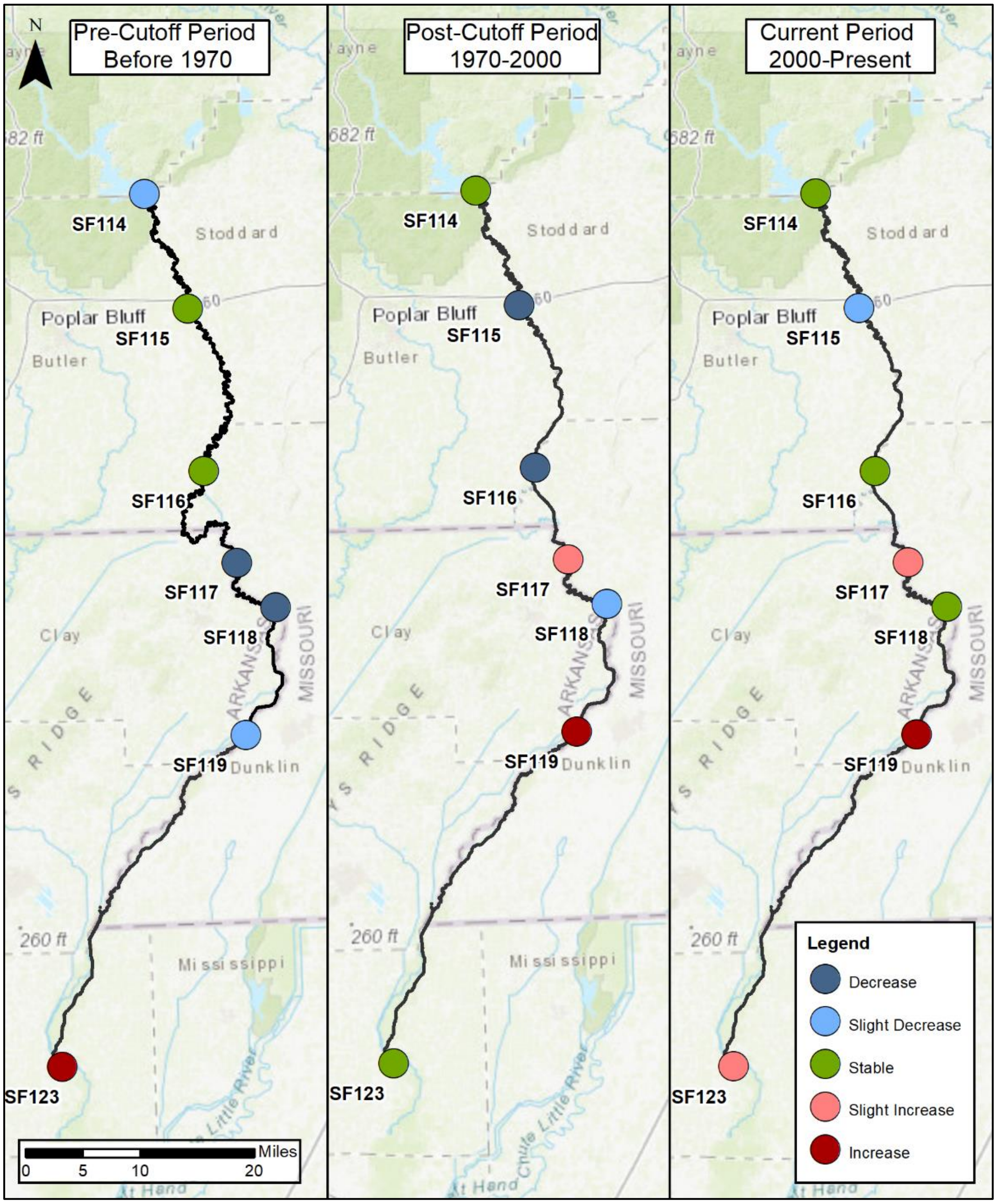
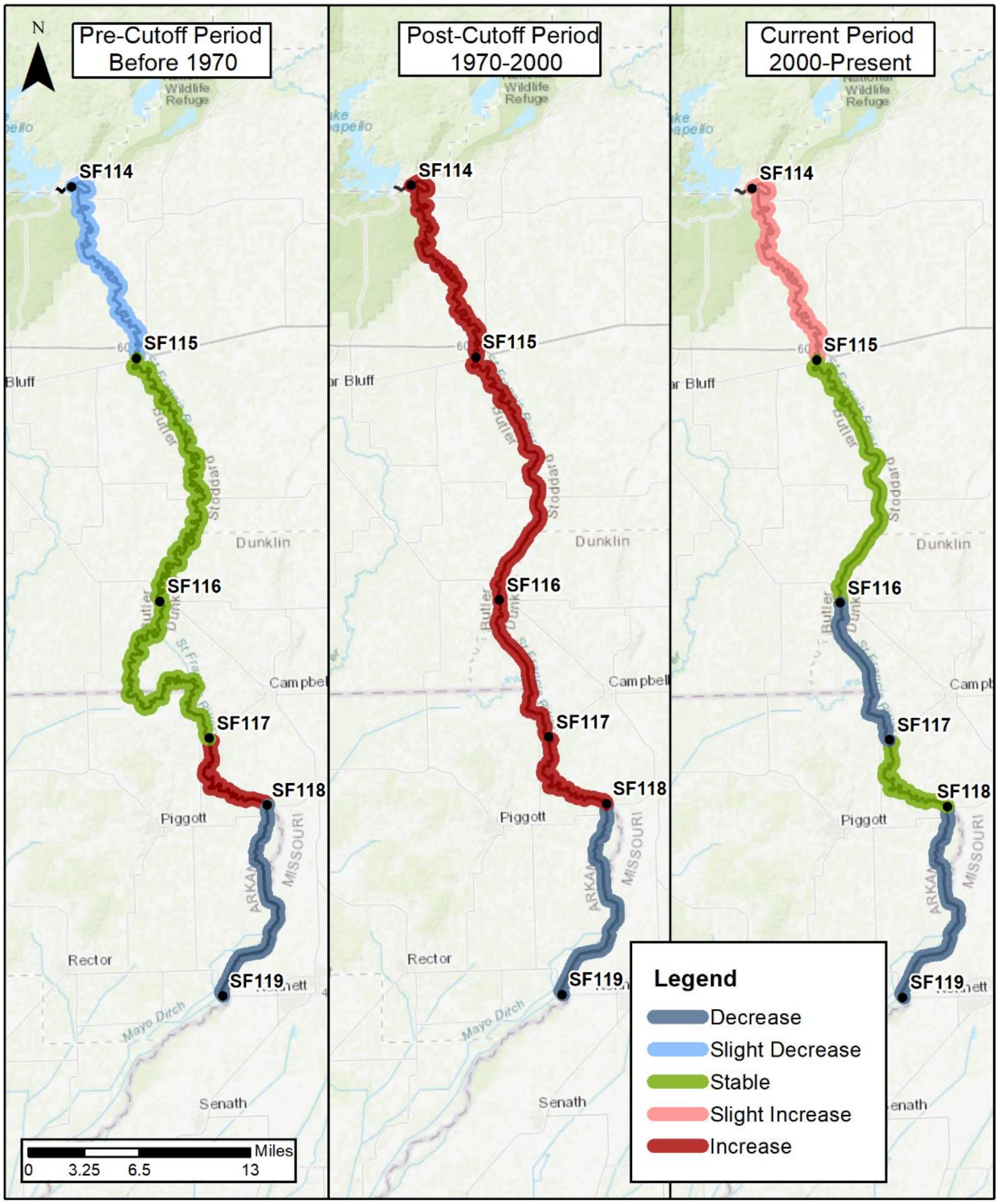


Figure 44 shows the trends in yearly water surface slopes by each reach for each time period. Prior to channelization, the upstream portion of the watershed exhibited relatively stable trends in water surface slopes, indicating that these reaches were in a dynamic equilibrium. Following the cutoffs, increasing trends in slope occurred for all but the most downstream reach as the system began to respond to the channel modifications.

This increase in slopes also increased the stream power and sediment transport capacity during this time period.

Figure 44. Trends in water surface slopes for each reach during the precutoff (*left*), postcutoff (*middle*), and current (*right*) time periods.



The reach from SF115 to SF116 appears to have reached an equilibrium slope in the last 20 years, while the upper reach is still slightly adjusting. The slope for SF116–SF117 initially increased postcutoff, but it began adjusting to an equilibrium slope shortly after the channel alteration and is still showing a decreasing trend in slope as the downstream end of the reach aggrades. SF117–SF118 was showing an increasing trend in slope prior to the cutoffs. During the literature review, little information was found for channel alterations in this reach. This section of the river was heavily altered by local interests prior to MVM's involvement. Currently, it appears to have reached a dynamic equilibrium. This could be due to an increase in sediment supply from the upstream reaches caused by the increase in slope from the cutoffs. For the entire study period, the water surface slopes show a decreasing slope for the most downstream reach because the channel below Highway 90 has continued to aggrade. Sediment from the upper reaches could be transported through the SF117–SF118 reach and deposited below Holly Island, or the sediment might be originating from active bank erosion and channel adjustment within this reach. Further investigation is needed to understand the sediment dynamics through the SF117–SF118 reach.

The analyses presented in this report provided valuable insight into the geomorphic trends occurring in the St. Francis River over the past 80 years. Additional analyses are required to further understand the complex fluvial processes occurring in the St. Francis Basin.

The analyses that follow are recommended:

- Potential geologic controls, particularly in the reach near Crowley's Ridge, should be identified.
- Grade control features in the main stem of the St. Francis River should be identified.
- Slopes from recent channel surveys should be compared to the 2012 lidar to provide additional information to prioritize areas for further detailed study.
- Additional suspended and bed load samples should be collected to gain a better understanding of the sediment transport and discharge relationships for the St. Francis River and to provide valuable information for future geomorphic adjustments.
- Bed and bank material should be sampled and compared with historical samples.
- The tributary watersheds should be studied further to determine if they are a significant source of sediment to the lower St. Francis River.
- The slopes in most reaches appear to be stabilizing, and the river may no longer be eroding; however, significant sedimentation is occurring around SF117 and SF119. The river may also be laterally adjusting;

therefore, further analysis is needed to investigate the severity of bank erosion in the watershed and the amount of sediment coming from bank sources.

- Additional literature review is needed to understand when private channelization occurred within the floodway prior to USACE involvement.
- A search for archived imagery below SF119 should be conducted to understand what channels existed prior to floodway construction.

Understanding the geomorphic changes throughout the basin will provide the basis for the district to adopt a holistic approach to sediment management. This understanding will ultimately feed into the development of a prioritized maintenance plan that adequately addresses maintenance concerns throughout the St. Francis Basin project.

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Appendix A: Frequency Analysis Results

Figure A-1 through Figure A-4 show the graphical frequency analysis plots for SF114, SF115, SF117, and SF123.

Figure A-1. Graphical frequency analysis plot for SF114 from 1942 to 2019.

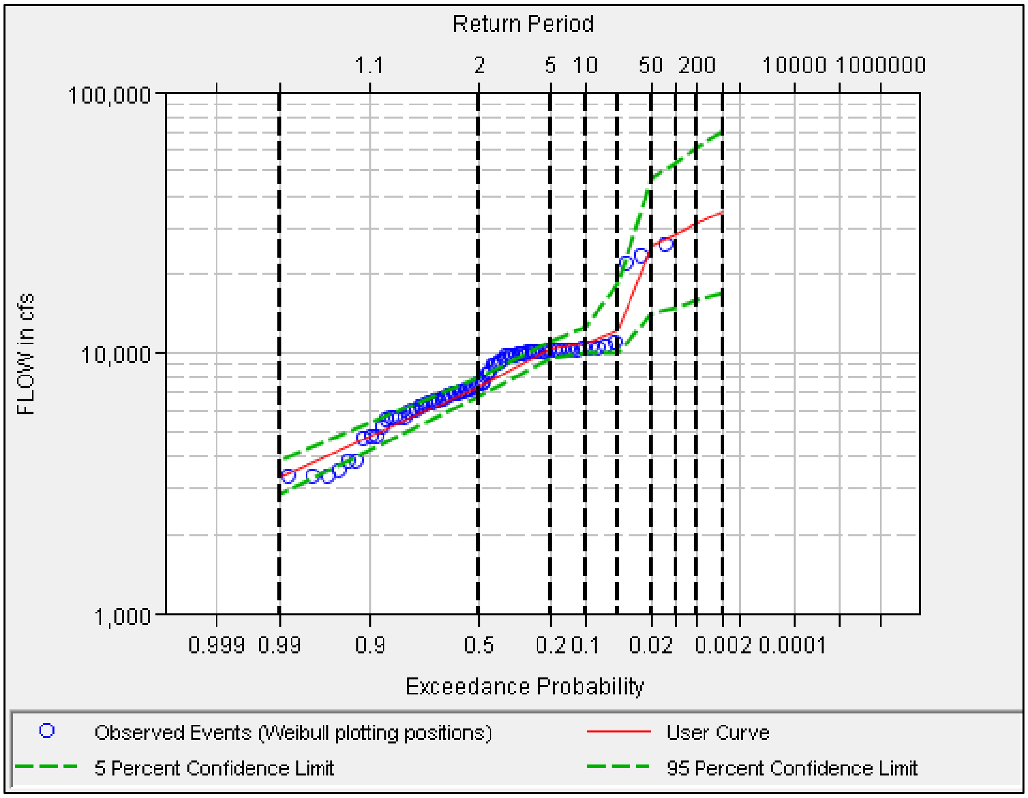


Figure A-2. Graphical frequency analysis for SF115 from 1984 to 2019.

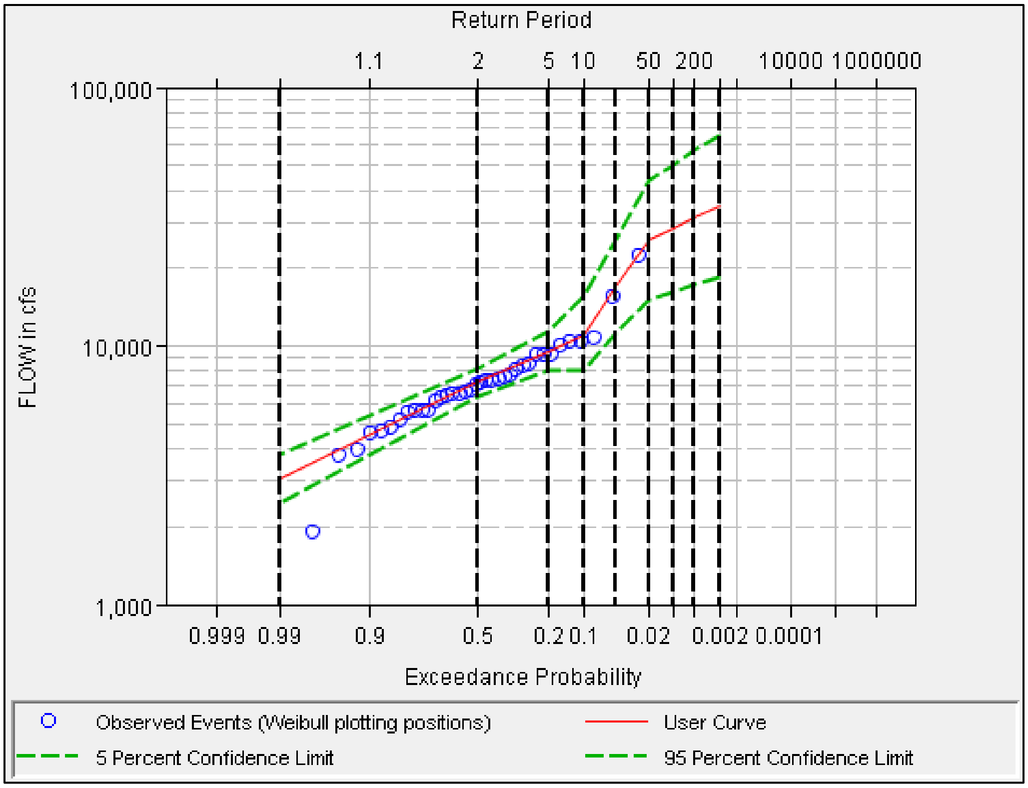


Figure A-3. Graphical frequency analysis plot for SF117 from 1942 to 2019.

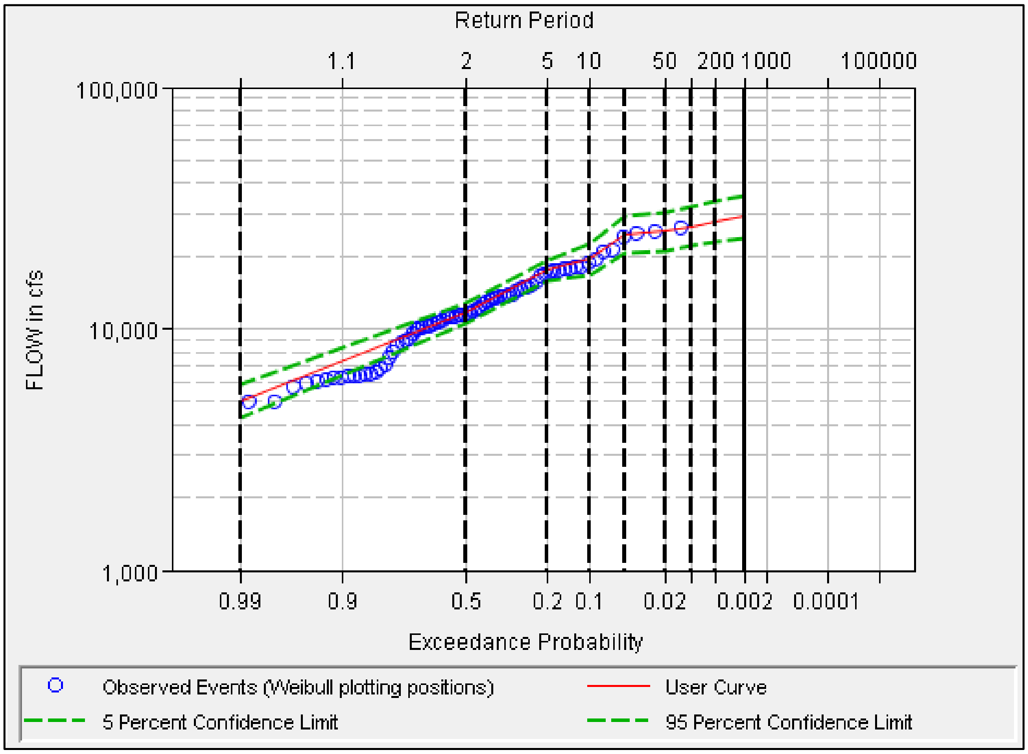
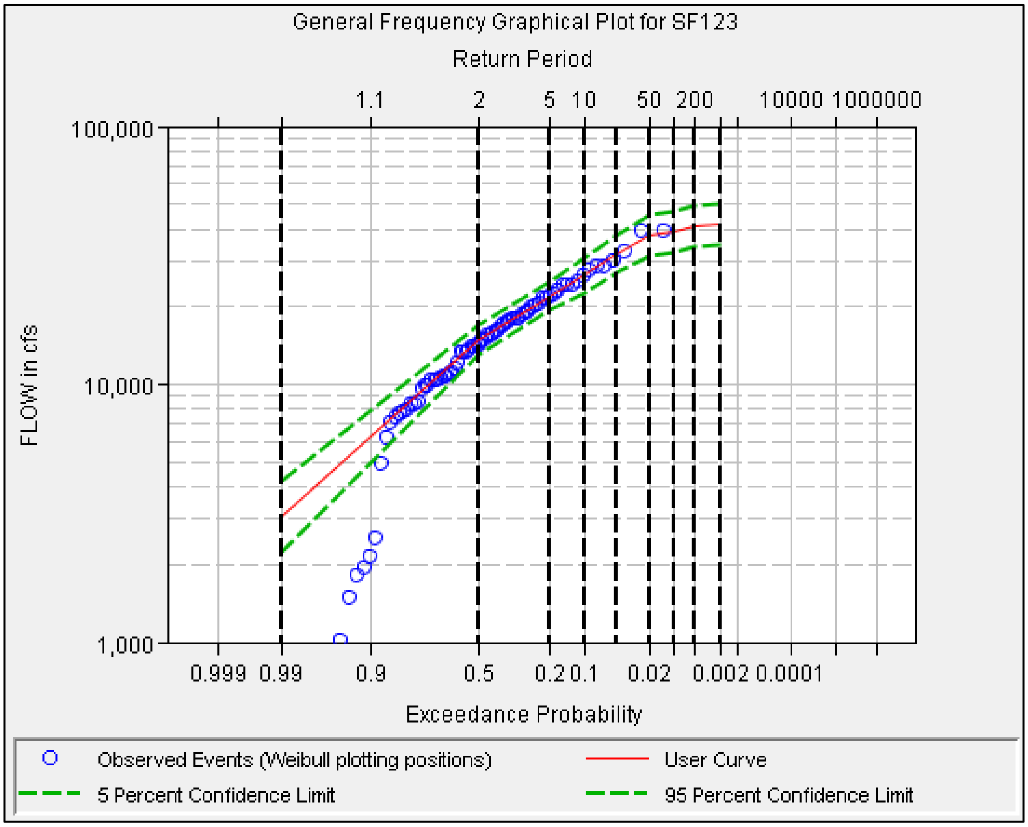


Figure A-4. Graphical frequency analysis for SF123 from 1942 to 2019.



Appendix B: Stream Power Analysis Results

Figure B-1 through Figure B-10 show the average and cumulative stream power for five reaches in the St. Francis Basin.

Figure B-1. Yearly average stream power for SF114–SF115 (Wappapello to Fisk).

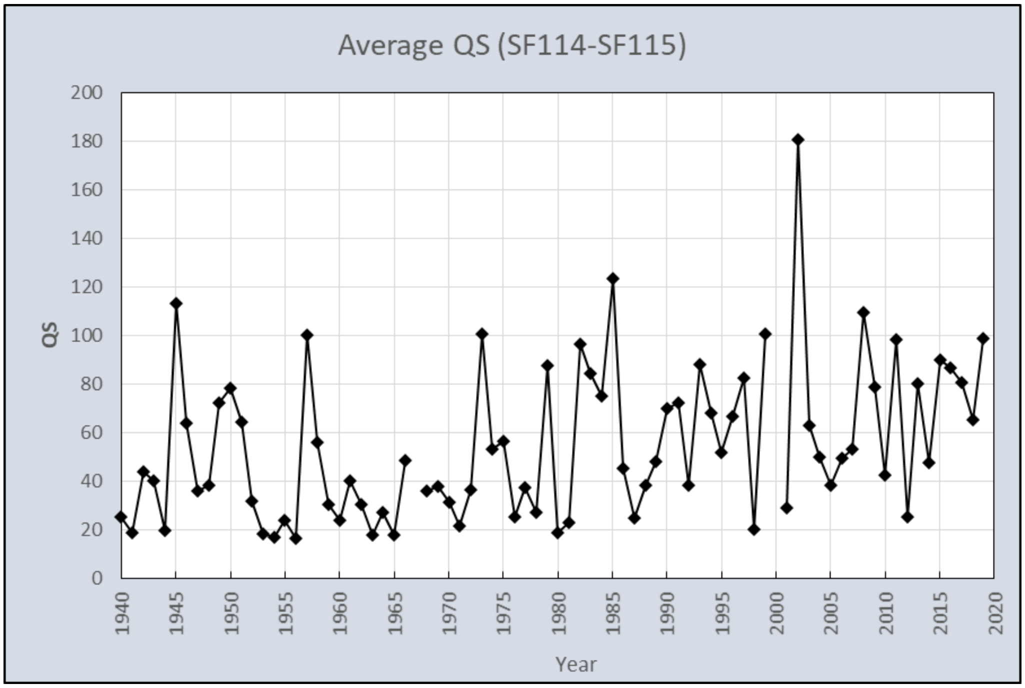


Figure B-2. Cumulative yearly stream power for SF114–SF115 (Wappapello to Fisk).

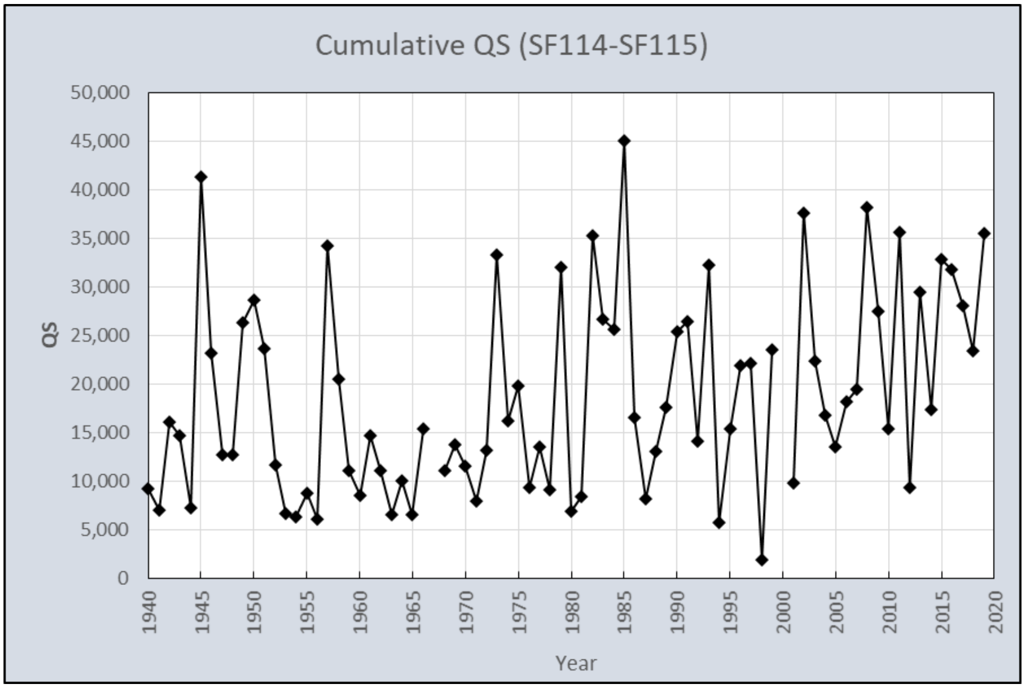


Figure B-3. Yearly average stream power for SF115–SF116 (Fisk to Dekyn's Store).

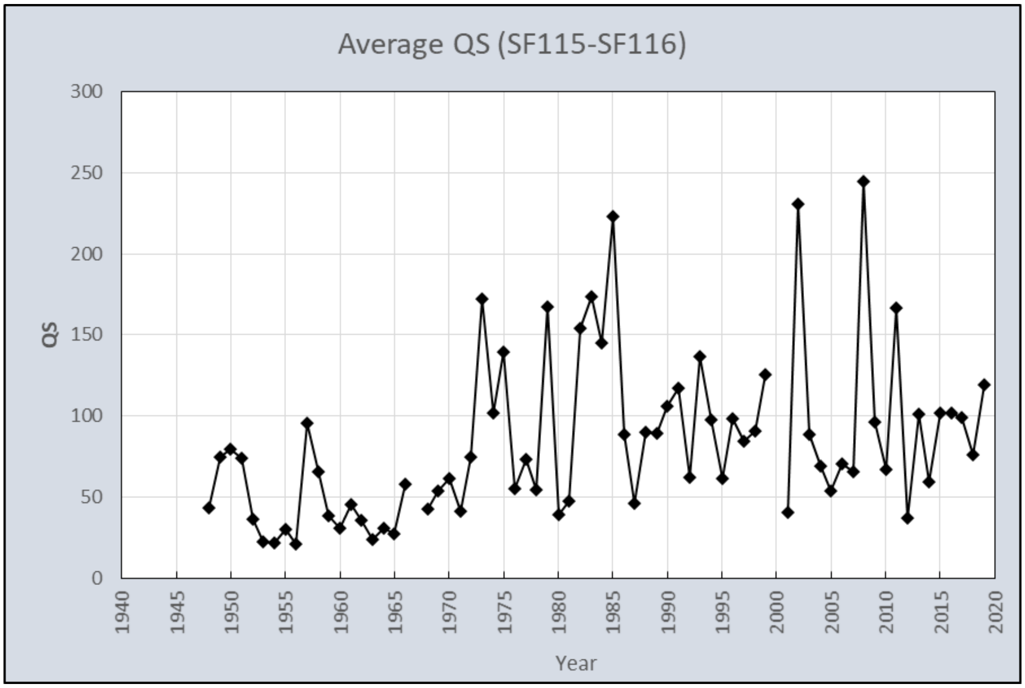


Figure B-4. Cumulative yearly stream power for SF115–SF116 (Fisk to Dekyn's Store).

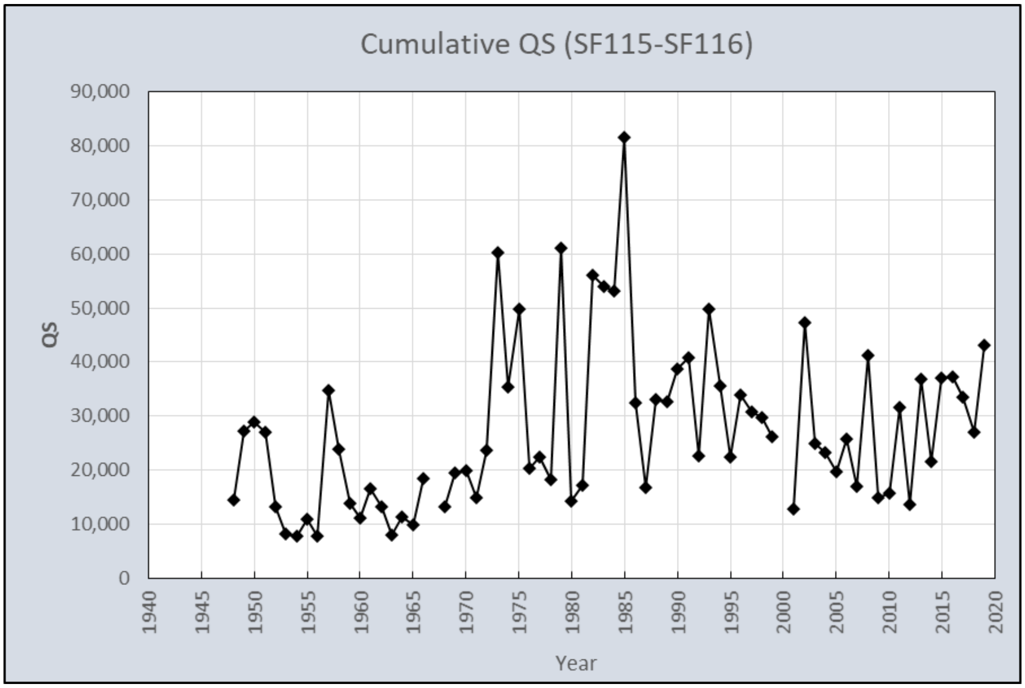


Figure B-5. Yearly average stream power for SF116–SF117 (Dekyn's Store to St. Francis).

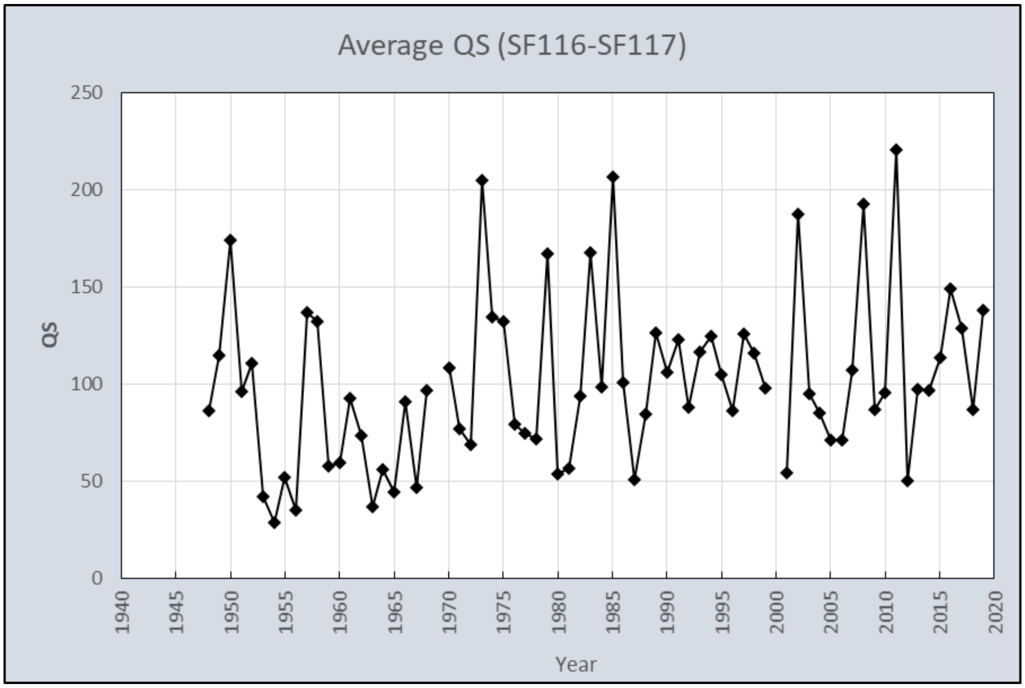


Figure B-6. Cumulative yearly stream power for SF116–SF117 (Dekyn's Store to St. Francis).

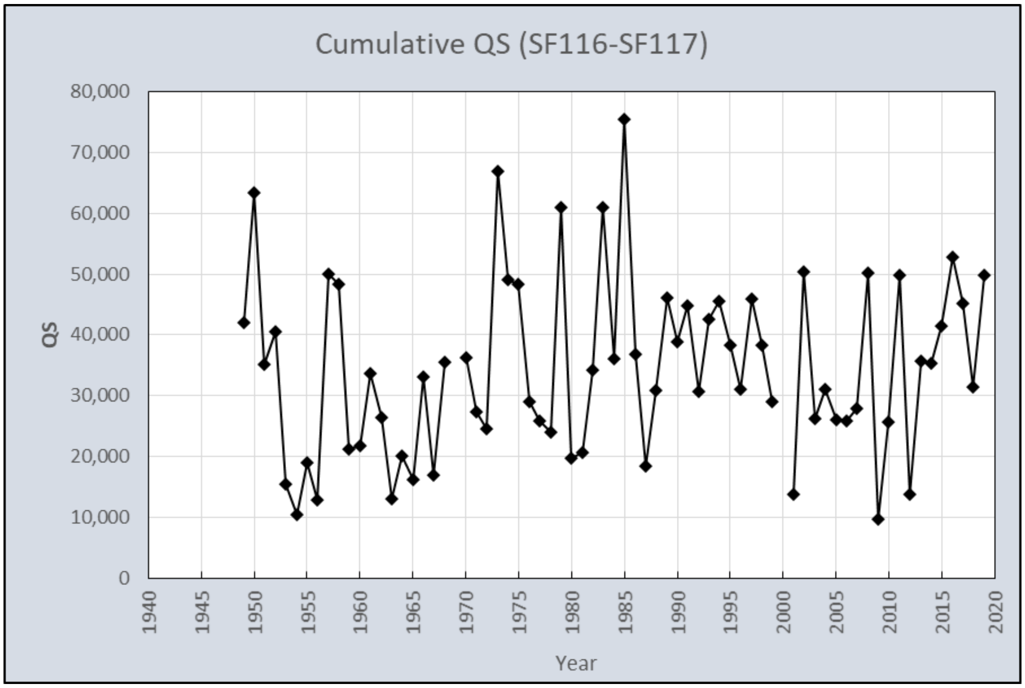


Figure B-7. Yearly average stream power for SF117–SF118 (St. Francis to Brown's Ferry).

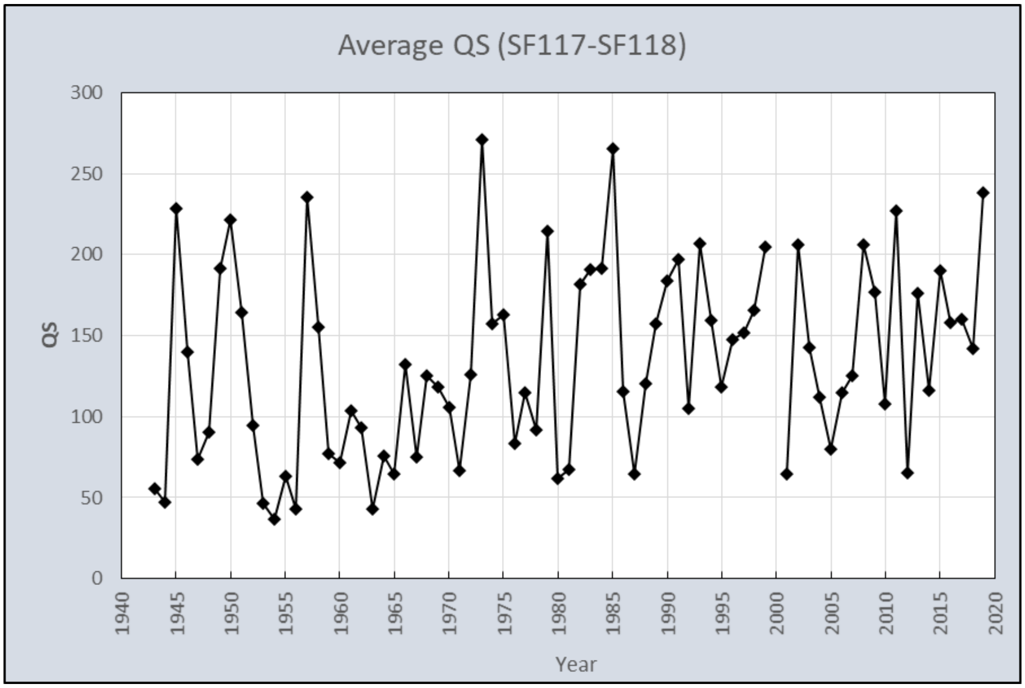


Figure B-8. Cumulative yearly stream power for SF117–SF118 (St. Francis to Brown's Ferry).

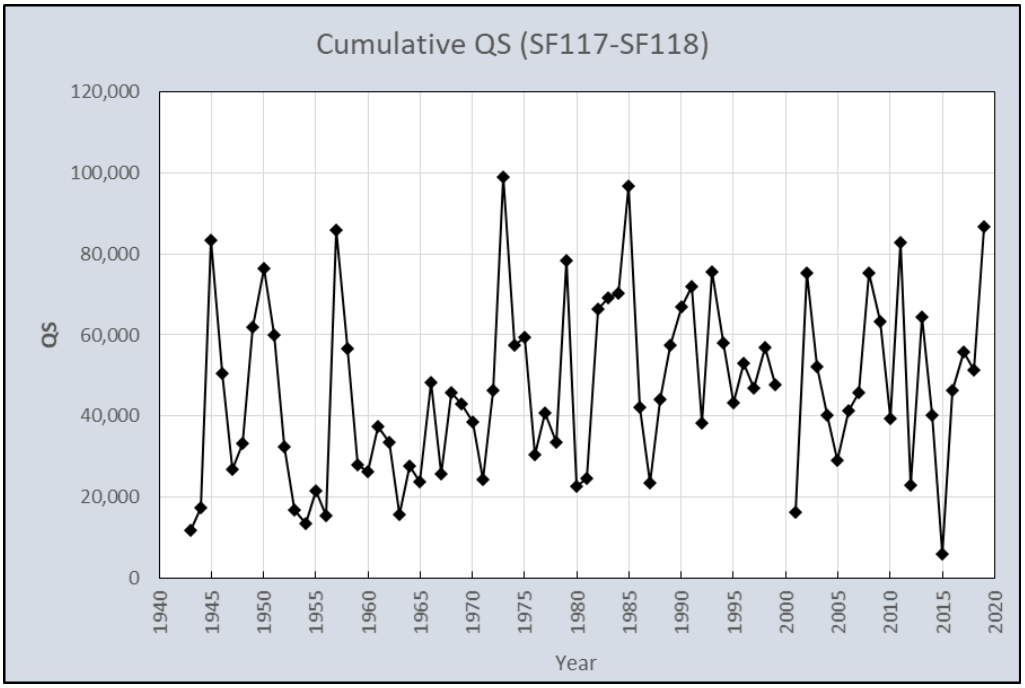


Figure B-9. Yearly average stream power for SF118–SF119 (Brown's Ferry to Holly Island).

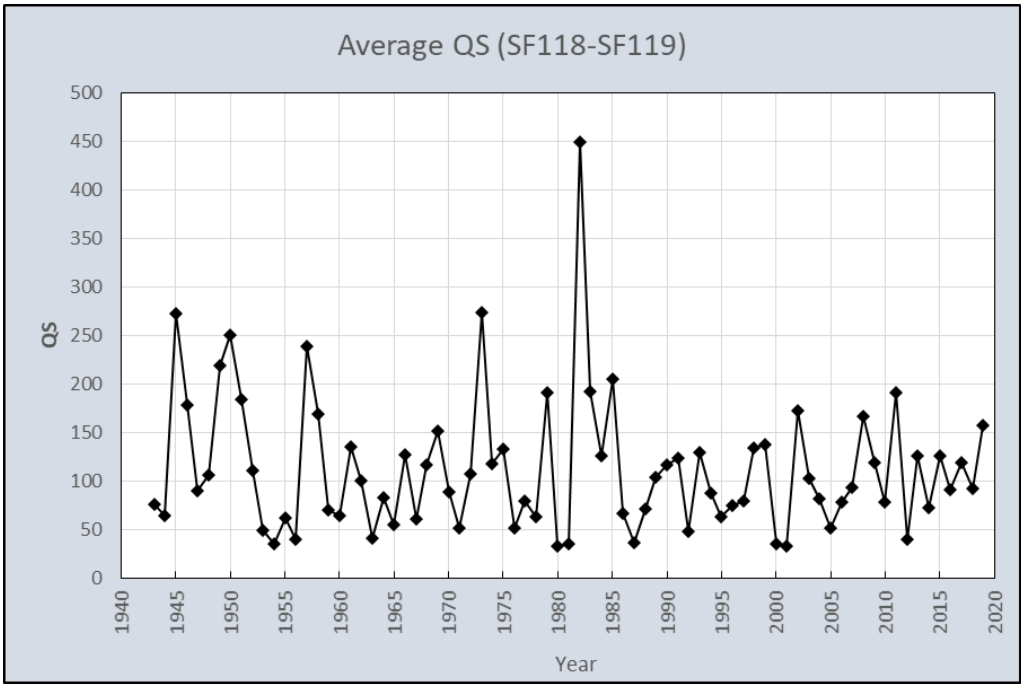
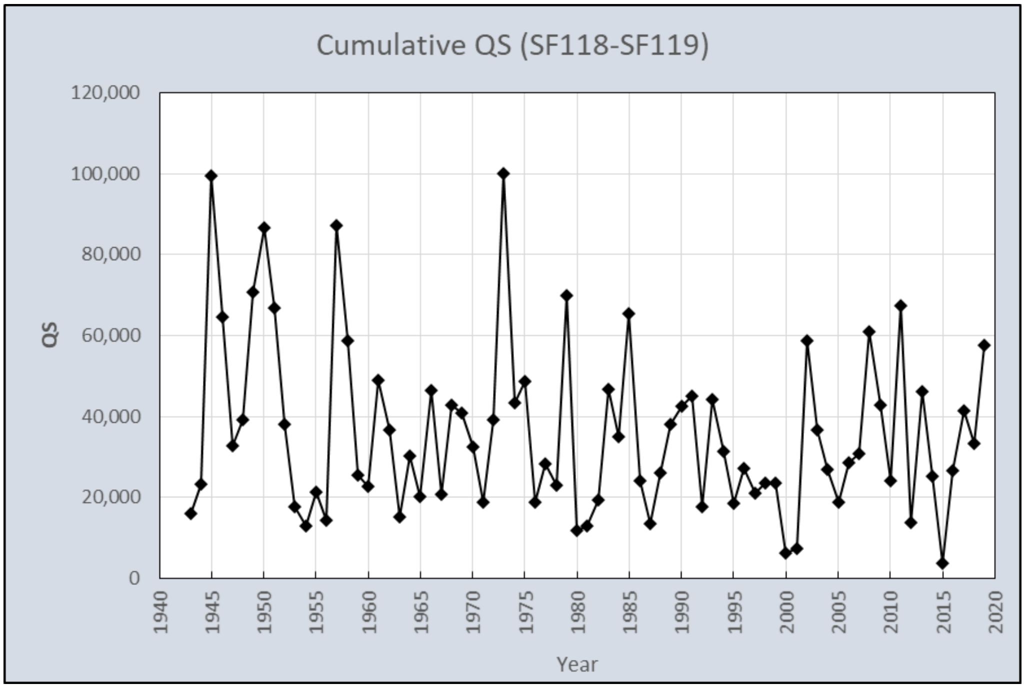


Figure B-10. Cumulative yearly stream power for SF118–SF119 (Brown's Ferry to Holly Island).



Abbreviations

ERDC	US Army Engineer Research and Development Center
GDM	General Design Memorandum
HEC-DSS	Hydrologic Engineering Center’s Data Storage System
LRDD	Little River Drainage District
MVM	Memphis District
PCE	Percent chance exceedance
USACE	US Army Corps of Engineers

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14. ABSTRACT

The St. Francis River is a complex system that lies in the historic floodplain of the Mississippi and Ohio Rivers. The basin has undergone extensive anthropogenic modifications, including reservoir construction, large-scale channelization, and construction of leveed floodways. Several analyses of available gage data, lidar data, and historical research have provided a picture of geomorphic trends and an overall understanding of the river's stability. The types of analysis used to determine trends included yearly low stage plots, stage-duration curves, specific gage analysis, water surface slopes, and stream power changes. The results from these analyses were synthesized to develop an overall assessment of the reach. Channel cutoffs resulted in a significant decrease in channel length and sinuosity and triggered geomorphic change throughout the river. Immediately following channelization, dramatic decreasing trends in stage were observed for Fisk and Dekyn's Store, while St. Francis and Holly Island began to aggrade. Slopes and stream power were significantly increased for the upper portion of the study area and showed a decreasing trend for the lower reach.

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