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Recent Climate Change Influence on Flood Magnitude and Frequency, Channel Widening, and Bar Deposition in Big River, Missouri Ozarks

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RECENT CLIMATE CHANGE INFLUENCE ON FLOOD MAGNITUDE AND FREQUENCY, CHANNEL WIDENING, AND BAR DEPOSITION IN BIG RIVER, MISSOURI OZARKS

A Master's Thesis

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In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geography and Geology

By

Patrick Saulys

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Geography, Geology and Planning

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ABSTRACT

Climate and land use can control the flood regime of a river and regulate channel form and size over periods of decades to centuries. Recent climate change has increased rainfall intensity and flood magnitude/frequency in many watersheds in the midwestern United States. Thus, river channels affected by more frequent and larger floods are expected to respond by increasing width (or depth) by fluvial erosion to accommodate larger peak discharges. This hypothesis was evaluated along 186 km of the Big River in southeast Missouri by analysis of historical aerial photography, precipitation studies, and United States Geological Survey (USGS) flow gage records. From 1937 to the 1970s, nine of eleven channel segments in Big River decreased in average width by 10% or more with the remaining two segments showing no significant change. In contrast, from 1970 to 2018 all eleven segments increased in width by more than 10% and all but one segment had a wider average width compared to the channel width in 1937. To verify these results, a survey of channel width changes was completed for all USGS gaging sites in the Ozarks Highlands with sufficient records for flood analysis. Like the Big River, most sites indicated more frequent and larger floods since the 1970s. Further, channel widening was indicated at 16 of 24 reaches in other watersheds since 1990 at rates ranging from 0.18 m/yr to 0.26 m/yr. Given that land use has not changed measurably during this period, with even more forest cover present today, climate-driven flooding is probably the main cause of recent channel widening in Big River. Further, while more in-depth study is needed, recent channel widening has been documented at most flow gaging sites along rivers in the Ozarks Highlands. These channel adjustments to larger floods are not only indicative of increased flood risk, but also of physical disturbances to aquatic habitats and water quality problems due to bank erosion and the remobilization of stored sediment.

KEYWORDS: climate change, river planform, bars, flood, aerial photograph

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INTRODUCTION

Regional climate trends worldwide have changed due to the influence of human activities including land disturbance and industrialization (Wuebbles and Hayhoe, 2004). The primary cause has been the increase of greenhouse gas concentrations in the atmosphere, with carbon dioxide (CO_2) being of most concern (Pryor et al., 2014). In the American Midwest (Midwest), recent climate change has generally resulted in higher temperatures, greater annual precipitation, and increased peak flood discharges since the 1970s (Andresen et al., 2012; Ahiablame et al., 2017b; Swanston et al., 2018). The hydrologic changes associated with climate change in the Midwest threaten the economy and ecology of the region with impacts, such as increased flooding, already documented (Wuebbles and Hayhoe, 2004; Heimann et al., 2018). Moreover, river channels and sediment transport may be particularly sensitive to the increase in climate-driven flooding (Macklin and Lewin, 2003; Macklin et al., 2010; Bauch and Hickin, 2011). For example, river morphology has been shown to adjust to climate change over millennial periods in the Pleistocene and the Holocene epochs (Knox, 1985; Baker, 2001; Leigh et al., 2004; Leigh and Webb, 2006; Macklin et al., 2010).

Annual and extreme rainfall have been increasing in the Midwest ever since the 1970s leading to increased flooding including northern areas around the Great Lakes as well as in southern areas such as the Ozark Highlands (Heimann et al., 2018; Owen et al., 2011; Pavlowsky et al., 2016; Pryor et al., 2014). This increase in rainfall intensity and amount has increased the number and stage of flood events (Slater and Villarini, 2016, 2017). Increased flooding may be causing the alteration of stream channel morphology due to increased erosion, sediment transport, and channel enlargement as the river responds to the more energetic flood regime

(Bronstert, 2003). Midwest flood frequency has generally increased across the region. However, some locations have shown little change in flood characteristics (Hamlet and Lettenmaier, 2007). These geographic variations in flood magnitude and frequency are likely due to local climate variability and land use change. Nevertheless, more studies are needed to better understand the response of rivers to the recent changes in climate and flooding in the Midwest.

Several studies have indicated that watersheds may be responding to climate change with more runoff and floods causing increased channel activity including bed and bank erosion by fluvial processes (Baker, 1977; Xu, 2000; Bauch and Hickin, 2011; Arnell and Gosling, 2016). Recent changes in river form are typically assessed using aerial photographs and other historical records (Rusnák et al., 2016; Dewan et al., 2017; Langat et al., 2019; Boothroyd et al., 2021). The use of aerial photographs to study rivers has also been used in the Midwest to directly study channel response to climate and land use change (Martin and Pavlowsky, 2011; Owen et al., 2011; Lauer et al., 2017) as well as the effects on wildlife (Lenhart et al., 2013). Aerial photography analysis is commonly used alongside field and/or climate data to help interpret the trends shown by the analysis of aerial photography (Baker, 1977; Dewan et al., 2017).

In addition to the analysis of historical imagery, hydrologic models have been used to predict the effects of future climate change on rivers (Blum and Törnqvist, 2000; Milly et al., 2002; Booij 2005). They indicate that as temperatures rise, more intense flooding and precipitation events are likely to occur which can result in increased flood risk and expansion of flood prone areas (Hu et al. 2005; Karamouz et al. 2011; Arnell and Gosling 2016). Moreover, increased depth and frequency of floods can result in higher bank erosion rates and channel widening (Rumsby and Macklin 1994; Dewan et al., 2017). However, the direction and rate of geomorphic response in channel form can also be affected by local conditions such as relief, bedrock geology, soil erodibility, and land use (Wilby 2006; Singh et al., 2003; Ahiablame et al., 2017a). Downscaling of global climate models in conjunction with river-scale models such as HEC-RAS has been used to predict how rivers will respond to climate change through the next century (Xu, 2000; Graham et al., 2007).

Background

The purpose of this study is to evaluate historical channel adjustments to land use factors and climate change in Big River located in the southeast Ozarks Highland region in Missouri. The focus will be on the analysis of temporal changes in channel width and bar area in the main channel. Important hydrologic and geomorphic concepts relevant to the research goals are described below.

The flood regime of a river is an important part of maintenance of rivers and channel morphology (Eaton and Lapointe 2001; Cunderlik and Burn 2002). Flood regime is defined as the distribution and variability of floods over time and is an important influence on channel form (Friberg et al., 2017). The hydraulic forces and sediment supply generated by floods generally control the width, depth, and lateral shifting of alluvial channels (Rusnák et al., 2016). Bankfull floods that fill the channel to the top of the banks before overflowing onto the floodplain are particularly important for predicting the size and form of stream channels (Edwards et al. 2019) (Figure 1). In relatively free-flowing alluvial channels, channel width, depth, and flow capacity are generally regulated by the bank-full flood discharge which generally has a recurrence interval of about 1.5 years (Rosgen, 1996).

Bankfull discharge is defined as the discharge that fills the channel to the top of the banks before flowing into the floodplain. The bankfull flood is an important control on the dimensions of a stream channel due to its moderate frequency and ability to both erode and deposit sediment (Baker 1977, Blom et al., 2017). More frequent floods tend to do more geomorphic work to control channel size and capacity over time compared to larger infrequent floods. Drainage area is normally positively related to bankfull discharge (Petit and Pauquet, 1997) since it controls the amount of precipitation that is routed to downstream channels (Benda et al., 2004; Stewardson, 2005). An increase in drainage area will result in greater bankfull depth, width, and cross-sectional area resulting in progressively larger channels in the downstream direction (Bieger et al., 2015).

A change in flood regime can force rapid changes in channel form as the stream becomes unstable and its form shifts towards a new state. In general, frequent floods that occur once every one to two years typically maintain river and floodplain form (Rosgen, 1994). However, larger, infrequent floods that occur at recurrence intervals of >10 years can cause episodic adjustments in river form including valley floor features that may become the norm if the frequency of these extreme floods increases over longer periods (Rumsby and Macklin 1994; Shaw and Riha 2011; Rusnák et al., 2016). Larger floods exert more force on channel boundaries, increasing bank erosion and the removal of vegetation along channel banks (Mürle et al., 2003). During the falling limb of floods, large amounts of flood-mobilized sediment can also be deposited along the banks which can form stable bar area for new pioneer species to grow (Mürle et al. 2003). As climate continues to change and large floods become more frequent, geomorphic effects may become more pronounced, resulting in more damage to the floodplain including accelerated bank erosion, surface scour and gullying, and coarse splay deposition (Bauch and Hickin, 2011).

Multiple factors affect how watersheds generate floods and channel systems respond to increased discharge regimes, including geology, soils, slope, vegetation, and land cover (Kiss and Blanka, 2012; Fryirs, 2017). Rivers constrained by bedrock or cohesive soils are more resistant to changes in hydrology and therefore require more time for channel form to respond to hydrologic changes (Alabyan and Chalov, 1998). The slope of a river is also important to the discharge of the stream with steeper slope increasing flow velocity and therefore the potential for erosion and alterations to the channel (Singh et al., 2003). Vegetation within the channel boundaries can also affect a rivers response to flooding and erosion with roots acting to stabilize the channel bed and banks (Wynn and Mostaghimi, 2006; Death et al. 2015). Soils can have similar effects as vegetation with some soils being more cohesive and resisting erosion from precipitation and streams, also reducing changes to channel form (Fryirs, 2017).

Land cover that tends to reduce runoff rates such as forests will increase soil infiltration rates and buffer against geomorphic responses compared to a less permeable surface such as urban areas (Jacobson and Primm, 1997; Nelson et al., 2006). Urban development and agricultural lands can generate increased runoff resulting in a quicker more dramatic response in rivers. Therefore, land cover alterations are often the primary factor leading to more floods, higher channel erosion rates, and changes in channel geometry (Wolman, 1967; Alabyan and Chalov, 1998; Hu et al., 2005; Brion et al., 2011). Increased flooding and related stream power can result in channel widening by bank erosion as the stream responds to increased stream power by adjusting towards a new equilibrium (Simon and Hupp, 1987; Simon, 1989).

Channel widening by bank erosion can release additional fine and coarse sediment to a stream as stored alluvium is reworked and transported downstream (Baker, 1977; Merritt et al., 2003). Thus, flood regime changes also impact the sediment carried and deposited by the channel and is often indicated by bar formation and planform disturbance patterns (Martin and Pavlowsky, 2011). Bar formation occurs by deposition of sand and gravel sediment due to excess sediment transport or a reduction in transport capacity as controlled by imposed stream power or channel adjustments (Duró et al., 2015). Climate change can increase the runoff and sediment flow into the river due to the increase in extreme precipitation events leading to instability and higher rates of bar formation (Bronstert, 2003; Booij, 2005; Church, 2006; Death et al., 2015) Bar formation tends to increase when the channel becomes unstable (Duró et al., 2015). A study on the Lower Padma River in Bangladesh found that as the channel widened bar area increased with a higher percent of the channel taken up by bars (Rashid 2020). This finding suggests that increased bar area can be used as an indicator of channel instability.

Purpose and Objectives

The Midwest has been experiencing an increase in precipitation and flooding due to recent climate change (Wuebbles and Hayhoe, 2004; Heimann et al., 2018; Hayhoe et al., 2009). It is important to understand how rivers are responding to these changes due to the predicted damage that can be caused to infrastructure and natural ecosystems (Hamlet and Lettenmaier, 2007). Flooding and increased stream power are the main drivers of channel modification and formation (Eaton and Lapointe, 2001; Cunderlik and Burn, 2002; Edwards et al., 2019). More frequent and larger magnitude floods have been shown to increase the amount of the energy in a channel, causing increased bank erosion and sediment transport (Alabyan and Chalov, 1998; Bernier et al., 2021; Fryirs, 2017), thus possibly leading to increased bar area (Duró et al., 2015). Previous studies of climate change in the Midwest have reported increasing precipitation regionally since the 1970s resulting in a more energetic flood regime, however evidence of channel response is lacking with few studies indicating a link between changing hydrology and channel instability (Andresen et al., 2012; Pavlowsky et al., 2016; Heimann et al., 2018; Byun et al., 2019).

The purpose of this study is to help fill the gap in our understanding of how increased climate-driven flooding may affect stream channel morphology in the Ozark Highlands. This study uses aerial imagery to evaluate historical width trends of Big River, Missouri from 1937 to 2018. The use of aerial imagery allows for the assessment of channel width and bar areas to evaluate historical planform change as a potential outcome of recent climate change with similar techniques used in many locations in the past (Winterbottom and Gilvear, 2000; Cadol et al., 2011; Martin and Pavlowsky, 2011; Dewan et al., 2017; Boothroyd et al., 2021). Although several Studies have been completed in the Ozark Highlands on stream response to human disturbances from early settlement and mining (Jacobson, 1995; Jacobson and Primm, 1997; Martin and Pavlowsky, 2011; Owen et al., 2011; Pavlowsky et al., 2017), none have addressed the response of Ozarks rivers to recent climate change. The specific objectives of this study are: (1) assess historical trends in channel width along 186 km of Big River; (2) evaluate the relationship between bank erosion rates and local bar deposition; and (3) discuss influence of land use changes, increased flooding, and channel response to climate change.

Bank width change and bar activity are good indicators of a changing flood regime (Alabyan and Chalov, 1998; Bauch and Hickin, 2011; Carson et al., 2007; Duró et al., 2015; Ghinassi et al., 2018). The increased rainfall in the Midwest is likely to be causing a change in flood regime which can cause rivers to become unstable (Pryor et al., 2014; Ahiablame et al., 2017). In general, a relatively long period of uniform climate/rainfall and land cover conditions will produce a river system in balance with discharge, sediment, and wood inputs that is often referred to as being in a stable or equilibrium state (Rosgen, 1996). When rivers are forced out of their “equilibrium” state they will respond by becoming unstable and shifting towards a form representing a new equilibrium state more in balance with current conditions such as larger floods in this case (Simon, 1989; Simon and Hupp, 1987; Simon and Rinaldi, 2000; Villarini et al., 2011). It is hypothesized that Big River is responding to the recent period of increased flood magnitude and frequency by increasing channel width and bar activity as channel enlargement and channel/floodplain sediment redistribution occurs.

Benefits

The Big River is particularly important for study due to the area’s past land use exploitation and potential for future ecological disturbance. Lead and zinc mining was prevalent in the area from 1869 to 1972. Legacy sediment generated by agricultural settlement in the mid-1800s and early 1900s has been deposited in the banks and floodplains of Big River below Leadwood, Missouri (Owen et al., 2011; Pavlowsky et al., 2017). This legacy sediment is contaminated with high levels of lead and zinc from largescale mining activities in the Old Lead Belt in Saint Francis County Missouri (Pavlowsky et al., 2017). If channel widening is occurring due to climate-driven flooding, then the remobilization rates of contaminated sediment will increase and could threaten aquatic life (Knox, 1977; Martin and Pavlowsky, 2011; Pavlowsky et al., 2017; James, 2018). Understanding how channels are presently responding to changing climate will help understand and prepare for possible releases of contaminated sediment pulses to downstream segments and into the Meramec River.

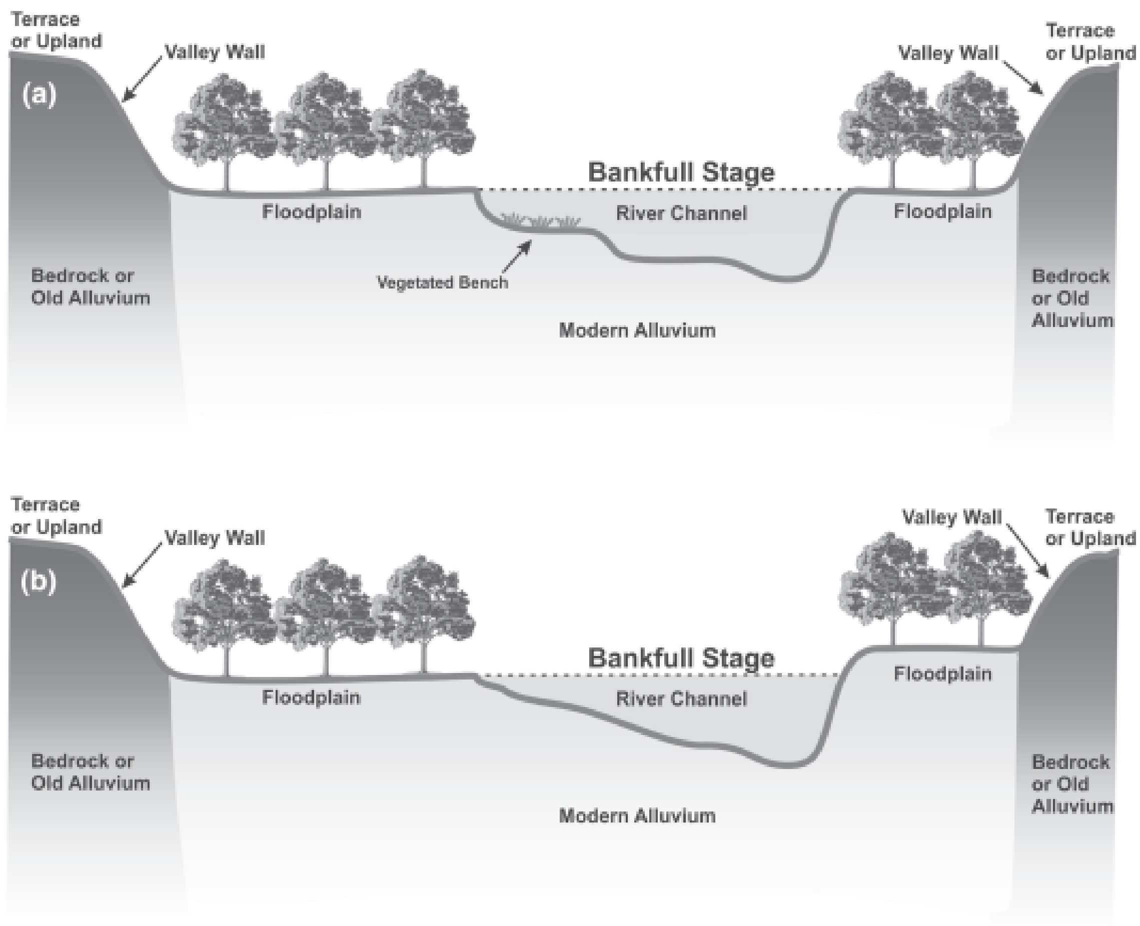


Figure 1. Bankfull stage diagram (Lindroth et al., 2020)

STUDY AREA

Regional Geology and Soils

Big River in Missouri is 222 kilometers long and drains 2,473 km^2 of the Ozark Plateau (Meneau,1997). Most of the watershed is within Washington, St. Francois, and Jefferson counties with small parts of it contained within Franklin, Iron and St. Genevie counties (Figure 2). Big River flows into the Meramec River at Eureka, Missouri which flows into the Mississippi River below Saint Louis, Missouri. The bedrock of the watershed is mostly dolomite and limestone with some sandstone and shale being found along the lower segments (Meneau,1997) (Figure 3). The soils in the area are formed from thin glacial loess over cherty residuum formed primarily from dolomite, limestone, and shale (Meneau, 1997). Most of the soils in the study area are included in the Reuter-Sonsac-Useful association and Caneyville-Crider-Gasconade association (Brown, 1981; Skaer, 2000; Skaer and Cook, 2005). The floodplains are mainly composed of Haymond, Kaintuck, and Wilbur series soils. The well drained Haymond series occurs on floodplains composed of fine-grained overbank deposits overlying a buried gravelly channel bar deposit ("Official Series Description - HAYMOND Series," n.d.). The Wilbur series is poorly drained and occurs in lower floodplains and backswamps ("Official Series Description - WILBUR Series," n.d.). The Kaintuck series occur on sandy lower floodplains or alluvial benches ("Official Series Description - KAINTUCK Series," n.d.). Undisturbed Ozark streams typically have gravel-cobble gravel beds with bedrock exposures common in some channels (Jacobson, 1995).

Climate and Hydrology

The climate of Big River and southern Missouri is humid subtropical with hot summers and cold winters. Over the past 30 years, the Midwest has had an average increase in temperature of 1.5 degrees as well as increased humidity and heat wave frequency (Pyror et al, 2014). Precipitation and peak flows have increased and are expected to continue increasing with climate change (Wuebbles and Hayhoe, 2004; Pryor et al., 2014; Demaria et al., 2016; Hayhoe et al., 2009). The average annual discharge for Big River is 24.4 m^3/s at the United States Geological Survey (USGS) gage at Byrnesville (2,375 km^2) with lower discharges usually occuring in August and the highest in April (Meneau, 1997). Flood records from three different flow gages on Big River show that the majority of the five largest flows have occurred since the 1970s (Table 1). The Big River gage at Byrnesville (#07018500) is in Jefferson County and was installed in 1922. The Richwoods gage (#07018100) is also located in Jefferson County and was installed in 1942. The Irondale gage (#07017200) is located furthest upstream in Washington County and was installed in 1965. The largest flows recorded before 1970 included the largest peak flow on record at the Byrnesville gage in 1915 and the fourth largest flow at the Richwoods Gage in 1957. The Byrnesville gage has the most complete record with the Richwoods and Irondale gage missing several years of annual peak flood data.

Mining History and Land Use

Important ore deposits containing lead, zinc, copper, and barite have been found in the Big River watershed resulting in a long history of mining activity beginning in the 1700s and ending in 1972. Mining activity has led to large scale lead contamination of the channel sediments and floodplain deposits due to metal tailings (Pavlowsky et al., 2017). The largest amount of land use change occurred when lead mining began in the Old Lead Belt. Missouri became the largest producer of lead in the United States in 1920. Mining of the Old Lead Belt ended in 1972 (Meneau, 1997). During this time the population started to increase, and areas became more urbanized. In 1992, 48% of the watershed was forested, 26% pasture, 9% urban, 7% row crops and 10% other. Land use cover changed very little between 1992 (Figure 4) and 2019 (Figure 5). The primary changes were increases in forest cover from 48% to 59% and decreases in pastures from 26% to 18%. Urban area remained at 9% from 1992 to 2019. Increased rainfall amount and intensity on disturbed ground including mining and urban areas would be expected to deliver more sediment and pollutants to local streams and Big River which could further degrade water quality and aquatic habitats (Wuebbles and Hayhoe, 2004; Villarini et al., 2011; Pryor et al., 2014a; Pavlowsky et al., 2017).

Table 1. Five largest flows from the three USGS gages on Big River

Byrnesville (Ad= 2375 km^2)		Irondale (Ad= 453 km^2)		Richwoods (Ad= 1904 km^2)	
Flow (m^3/s)	Year	Flow (m^3/s)	Year	Flow (m^3/s)	Year
2,265	1915	1,390	1994	7815	2018
1,800	1993	1,223	1973	1894	2017
1,772	2017	1,121	1986	1693	1993
1,435	1994	1,042	2009	1580	1957
1,339.	2008	937	2010	1495	2008

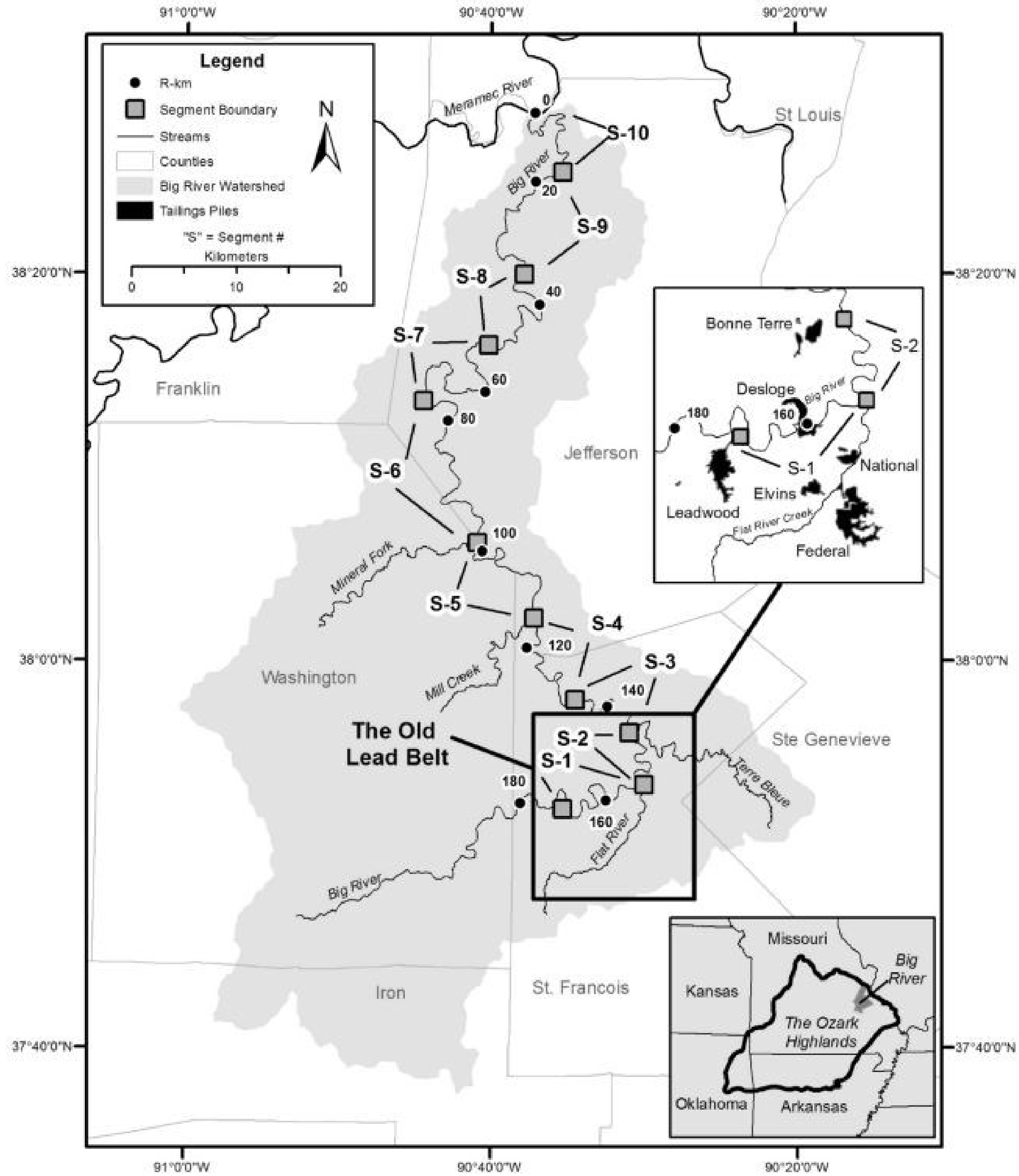


Figure 2. Big River watershed in Missouri. River-kilometer distances and segment locations are the same as those published by Pavlowsky et al. (2017).

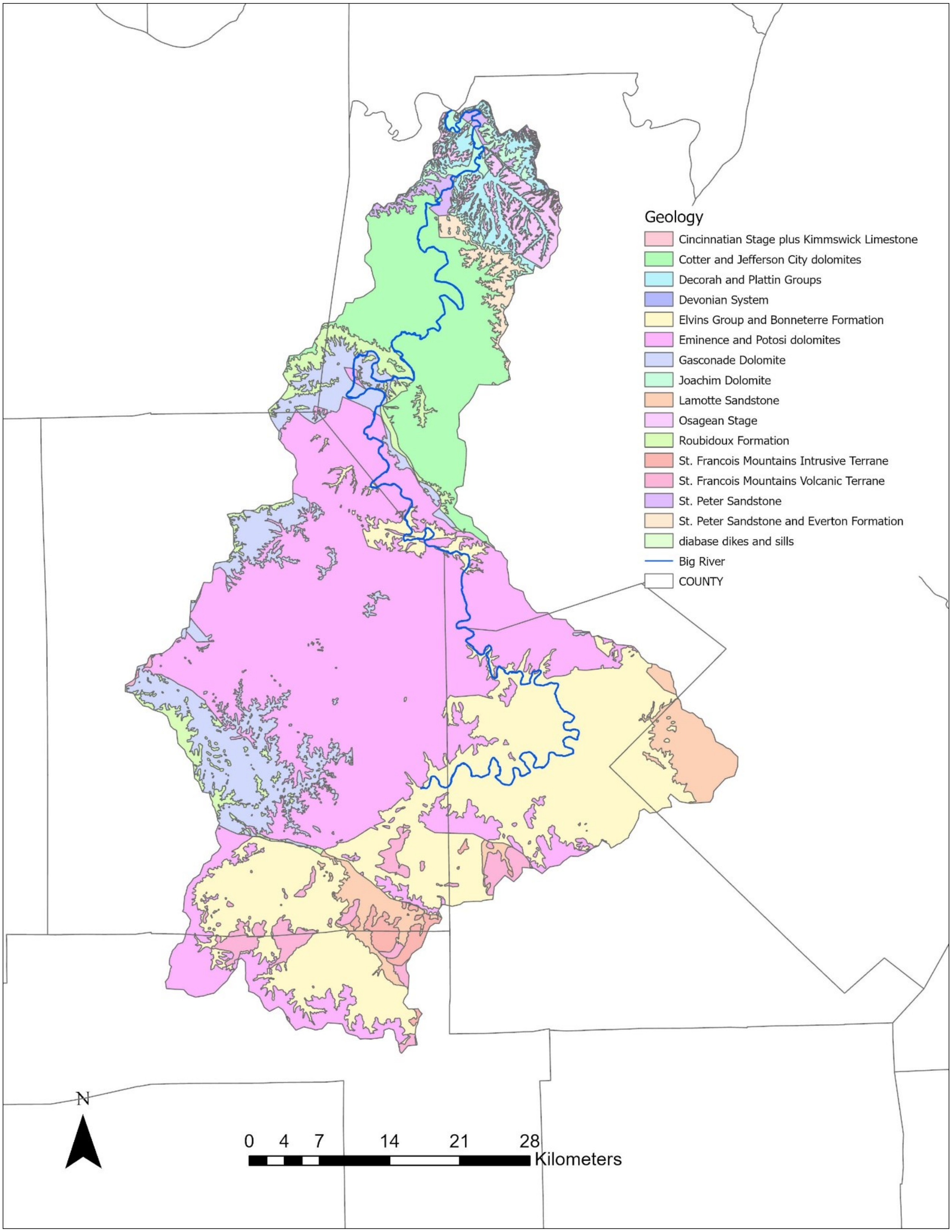


Figure 3. Geologic map of the Big River watershed.

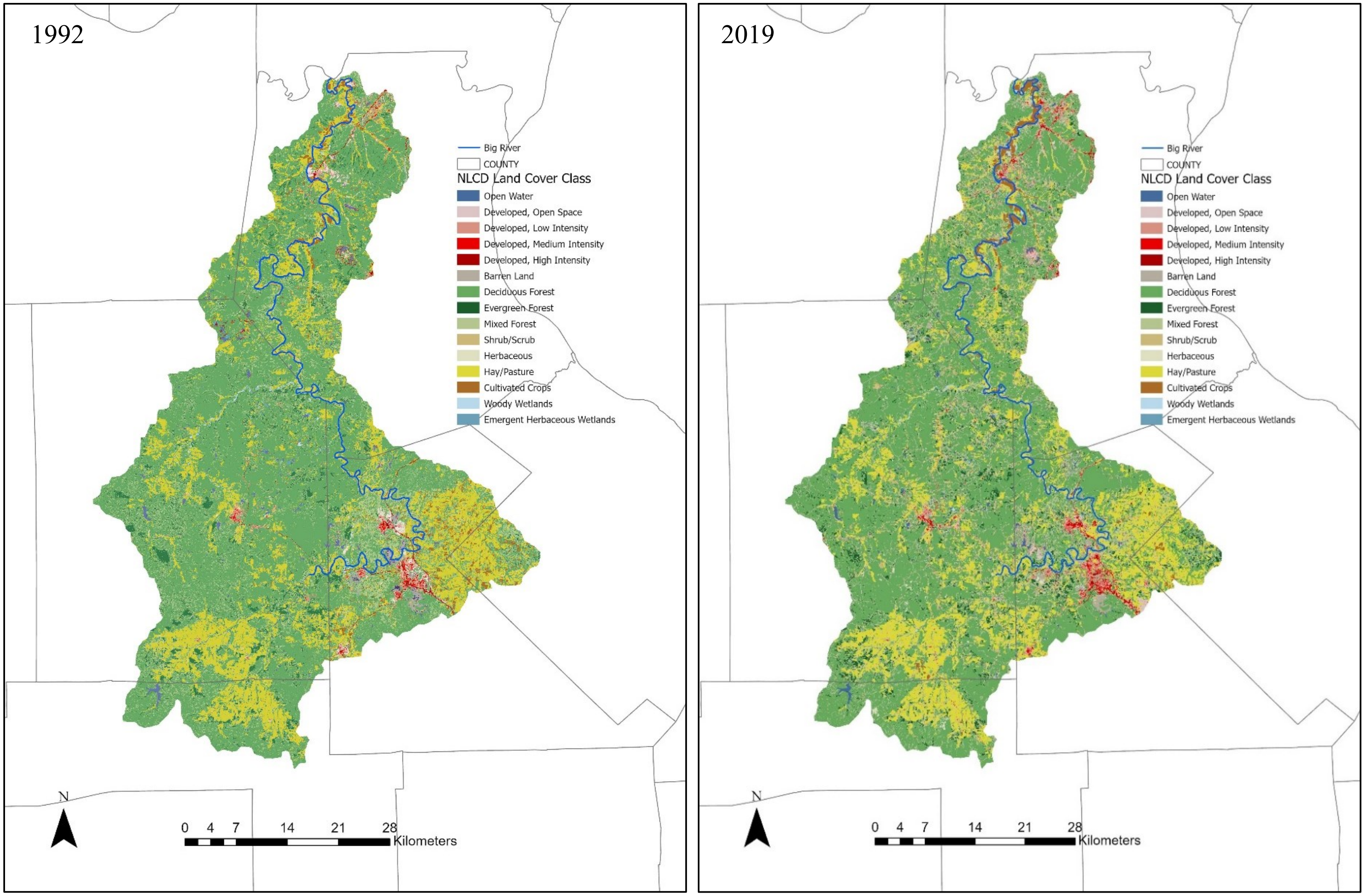


Figure 4. Land use of the Big River watershed from 1992 (left) and 2019 (right) (mrlc.gov/data).

METHODS

The methods used for this study are described in three sections: fieldwork; aerial photography data and analysis; and hydrological analysis using USGS gages. Most of the effort spent in this study was on digitizing channel banks and bar areas from aerial photographs and assessing feature changes over time. Historical USGS gage records and images were used to evaluate hydrologic and geomorphic changes. Field work was performed at selected sites previously surveyed by Pavlowsky (2010) to compare with the channel width measurements over time and used as evidence for the aerial photograph measurements. River locations are referred to by river-kilometer (R-km) above the mouth as described in Figure 2.

Fieldwork

Fieldwork was conducted in December 2020 to resurvey sites from the 2010 Big River Mining Sediment Assessment project to assess changes in channel width over a decade at reaches located at river kilometers 32.5, 49.6, 79.3, 97, 115.5, 136.7, 156.4 (Pavlowsky, 2010). A tape was stretched across the channel to get the active channel width at the same locations previously surveyed. Obstructions, such as large woody debris, obstructed some transects, therefore only seven of ten sites were used for this study. Resurveyed widths were compared to previously surveyed width from 2009 by Pavlowsky (2010) to assess width changes. Rapid bank assessments were also completed to note bank condition and stability. Similar bank assessments have been noted to be a good way to determine the current condition of the channel (Downs and Thorne, 1996).

Aerial Photograph Analysis

Aerial photographs of Big River were available for the years 1937, 1954, 1976, 1990, 2007 and 2018. The images from 1937 to 1990 are black and white geotiffs supplied by the USGS. The 2007 images were obtained from the Missouri Spatial Data Information Service (MSDIS) and are true color digital orthophotos (quarter quadrangle) (DOQQ). The 2018 images are from the United States Department of Agriculture's National Agriculture Imagery Program (USDA NAIP). According to the metadata the resolution of the images range from 0.6 m to 1.3 m. Analysis of aerial images has become a common technique for measuring changes in rivers (Nelson et al., 2006; Peixoto et al., 2009; Owen et al., 2011; Rusnák et al., 2016; Dewan et al., 2017; Pavlowsky et al., 2017; Langat et al., 2019). The images were uploaded into ArcGIS, georeferenced (Table 2), and then bank lines and bars were digitized. The digitization was done at a scale of 1:1500. The root mean square error (RMSE) for the images was under or near the resolution of the images used for the analysis. The 2018-2019 NAIP images were geo rectified and reviewed for accuracy before being published.

The river was then divided into 500-meter cells to analyze width and bar area change at the reach-scale. The measurements from the cells were then aggregated to get the average value for larger segments. The segments in this study delineated by Pavlowsky et al (2017) and analyzed similar to Martin and Pavlowsky (2011) for channel width and bar activity (Table 3). The intersections of major tributaries were chosen as the boundaries for the segments from Pavlowsky et al (2017) with a segment labeled zero added upstream to cover the area of Big River that is included in this study but not that of Pavlowsky et al (2017) (Table 3). The digitized channel was separated into 500-meter cells starting at the intersection of Big River and the Meramec River.

Using the digitized photographs, the average width and bar area was calculated for each cell. To calculate the average width, the area of the channel in each cell was divided by the cell length (500 m). The average bar width per cell was calculated in a similar way. These values were then averaged to determine the characteristics of each segment. The number of bars within the cell area greater than 5 meters wide were then counted for each segment to assess the number of total bars and the density of bars per kilometer which were then compared to the rate of change in the channel width. Compiling bar variables at the segment reduces errors due to local factors while still providing information about variations in channel form from the reach scale (20 bankfull widths) to segment scale (10-20 reaches). Comparing the segments over time allows for changes in channel and bar width to be calculated and the spatial patterns to be determined.

Using aerial photography to measure the changes of a river planform is affected by errors that are unavoidable with this technique, but steps are taken to minimize these. First is the differing quality of the images used for the digitization. In this study, the images were of similar resolution making it possible for accurate comparison. The RMSEs were also relatively low compared to the resolution of the images used for georectification. To reduce the error in digitizing the same person digitized the channel and bars for all photos and the work was checked by an experienced supervisor.

Regional Analysis

Additional aerial images and USGS gage records from the Ozark Highlands region were used to expand the results of this study to the larger Ozarks Highlands region. Twenty-three additional USGS gages from rivers draining the Ozark Highlands (Table 3) were used to compare changes in peak flood discharge for recent (1990-2020) and past (1941-1971) periods for recurrence intervals of 2-, 5-, 10-, 50-, and 100-years. To calculate the flows for each return interval, USGS gage annual peak discharge data were downloaded into software provided by the U.S. Army Corps of Engineers, Hydrologic Engineering Center's (HEC) Statistical Software Package (HEC-SSP) and a general frequency analysis was performed with a log-Pearson type III distribution following the USGS recommendation for this type of analysis in the United States ("Guidelines for Determining Flood Flow Frequency Bulletin 17C," 2019). Flood analysis was completed for two time periods: past, 1941-1971 and present, 1990-2020. These time periods were chosen to evaluate trends for 30 years of continuous flood records from before the beginning of significant global warming trend in the late 1970s and the warming event. Further, 1941 was the earliest date for which all gages had a continuous flood record. The 1990-2020 peak flow was then divided by the 1941-1971 peak flow for the same recurrence interval to create a ratio indicating the degree of change (if any) in flood magnitude since the past period. The ratio results were grouped and compared by region to control for geographic variations in climate and weather patterns. Note that the gage records for Cedar Creek and Big River near Richwoods were affected by missing data and therefore not included in the regional analysis.

To determine if changes in flood regime relate to changes in channel width the channel, aerial photograph analysis was performed near each USGS gage in the Ozarks. The GPS data from the USGS was entered into Google Earth Pro to find the location of each gage and compared to the map location on the USGS website to ensure the right location was found. At each gage site, width measurements were collected at two reaches separated by >1 km within several kilometers of the gage site with little influence by major tributaries, anthropogenic obstacles like bridges or dams, or extreme channel bends. Ten width measurements spaced at intervals of two channel widths were collected at each reach and the average width used for analysis. The measure tool in Google Earth Pro was used to assess the width of the channel at each cross section. These measurements were completed for a recent image ranging from 2013 to 2020, and an earlier image ranging from 1994 to 1997. Only one reach was assessed at the gage site at Little Piney Creek at Newburg due to limitations by poor bank visibility on the aerial photographs. The following variables were calculated for each reach: overall change in width (m), rate of change in width (m/yr), and percentage change in width (%).

Table 2. Aerial photograph characteristics.

Date	Resolution (m)	RMSE (m)	R-km	Byrnesville Discharge (m^3/s)
1937, July 23	0.9	0.2-0.9	185.75 - 175.25	17.2
1937, July 27	0.9	0.4-0.9	165.75- 136.75	9.1
1937, Aug. 14-15	0.9	0.9-2.3	136.25-0	3.2
1937, Aug. 24	0.9	0.5-0.9	175.25-166.25	10.3
1954, Oct. 17-18	1.3	0.4-0.9	183.25-169.75, 159.25-141.75, 123.75-0	N/A
1954, Nov. 13-16	1.3	0.3-2.7	169.25-159.75, 141.25-133.25, 132.75-124.25	2.9
1974, July 31	0.9	N/A	18.25-0	3.2
1974, May 12	1	N/A	62.25-48.25	19.4
1974, Aug. 4	0.9	N/A	47.75-18.75	3.2

Table 2. Continued.

Date	Resolution (m)	RMSE (m)	R-Km	Byrnesville Discharge (m^3/s)
1976, Feb. 23	0.8	0.3-0.9	62.75-124.25	8.4
1978, Oct. 21	0.9	0.6-0.9	186.25-124.75	3.1
1990, Feb. 20	1	0.7-1.0	182.25- 55.75	37.2
1992	1	N/A	55.25-0	N/A
2007 ortho	1	N/A	26.25-0	N/A
2007, Mar 8-10	0.6	Reference	185.75-26.75	15.2
Winter/Spring 2018	N/A	N/A	N/A	N/A
July/November 2018	N/A	N/A	N/A	N/A
2019	N/A	N/A	N/A	N/A

Table 3. Big River segments.

Segment	R-km	Length (km)	Tributary
0	186.5	15.5	N/A
1	171	16	Eation Branch at Leadwood
2	155	10.5	Flat River Creek
3	144.5	12	Terre Bleau Creek
4	132.5	17	Cabanne Course Creek
5	115.5	16.5	Mill Creek
6	99	26.5	Mineral Fork
7	72.5	20.5	Ditch Creek
8	52	17	Dry Creek
9	35	18	Belews Creek
10	17	17	Heads Creek

Table 4. USGS gaging stations in the Ozarks that met continuous data requirements. (waterdata.usgs.gov/nwis/rt)

Gage Title	Number	Ad (km^2)	Elevation (m)	Region	Hydraulic Unit
Big Cabin Creek near Big Cabin, OK	7191000	1166	2041	Arkansas River Basin	11070209
Illinois River near Tahlequah, OK	7196500	2461	2182	Arkansas River Basin	11110103
Spring River near Quapaw, OK	7188000	6516	2449	Arkansas River Basin	11070207
Elk River near Tiff City, MO	7189000	2204	2463	Mississippi River Basin-Arkansas River	11070208
Shoal Creek above Joplin, MO	7187000	1106	2901	Mississippi River Basin-Arkansas River	11070207
Spring River near Waco, MO	7186000	3015	2735	Mississippi River Basin-Arkansas River	11070207
Big River at Byrnesville, MO	7018500	2375	1423	Mississippi River Basin-Meramec River	7140104
Big River near Richwoods, MO	7018100	1904	1716	Mississippi River Basin-Meramec River	7140104
Meramec River near Eureka, MO	7019000	9811	1326	Mississippi River Basin-Meramec River	7140102
Meramec River near Steelville, MO	7013000	2023	2237	Mississippi River Basin-Meramec River	7140102
St. Francis River near Patterson, MO	7037500	2476	1215	Mississippi River Basin-St. Francis River	8020202
Bryant Creek near Tecumseh, MO	7058000	1476	1882	Mississippi River Basin-White River	11010006
Current River at Doniphan, MO	7068000	5278	1055	Mississippi River Basin-White River	11010008
Current River at Van Buren, MO	7067000	4318	1454	Mississippi River Basin-White River	11010008
Eleven Point River near Bardley, MO	7071500	2054	1349	Mississippi River Basin-White River	11010011
Jacks Fork at Eminence, MO	7066000	1031	2022	Mississippi River Basin-White River	11010008
James River at Galena, MO	7052500	2556	3024	Mississippi River Basin-White River	11010002

Table 4 continued.

Gage Title	Number	Ad (km^2)	Elevation (m)	Region	Hydraulic Unit
Gasconade River at Jerome, MO	6933500	7356	2158	Missouri River Basin-Gasconade River	10290203
Little Piney Creek at Newburg, MO	6932000	518	2276	Missouri River Basin-Gasconade River	10290203
Cedar Creek near Pleasant View, MO	6919500	1088	2426	Missouri River Basin-Osage River	10290106
Eleven Point River near Ravenden Springs, AR	7072000	2927	958	White River Basin	11010011
Kings River near Berryville, AR	7050500	1365	3160	White River Basin	11010001
Spring River at Imboden, AR	7069500	3056	863	White River Basin	11010010
Strawberry River near Poughkeepsie, AR	7074000	1225	978	White River Basin	11010012

RESULTS AND DISCUSSION

River Morphology and Flood Trends

Channel slope using 2016 LiDAR data decreases downstream by segment and both channel width and confinement ratio using 2018 aerial photographs increase (Table 5, Figure 5). Channel slope averages 0.0008-0.009 above Flat River Creek at R-km 155, then gradually decreases from 0.0007 to 0.0005 to R-km 52 and finally lowers from 0.0003 to 0.0004 from there to the mouth. Segment 7 has a relatively high slope of 0.000562 compared to the upstream segments with a relatively narrow valley and wide channel (Figure 5) suggesting bedrock control may be influencing this reach more than others (Whitbread et al., 2015). Average channel width tends to range from 30 m to 40 m above and 40 m to 50 m below Mineral Fork, the largest tributary to Big River. The most upstream segment at R-km 186.5-171 has a relatively wide channel averaging 46 m (Table 5). However, this segment has been affected by gravel mining both in the channel and on the floodplain thus possibly artificially widening the channel in places as indicated by a high coefficient of variation (Cv%, 1s) of 41%, about two times larger than the other segments (Table 5).

Recall that all three of the USGS gages along Big River have shown an increasing trend in flood magnitude and frequency since 1990, with the majority of the five largest floods at each gage occurring after the 1970s (Table 1) (Heimann et al., 2018). The Byrnesville gage has the longest record and shows that four of the five largest floods have occurred since 1993. A flood frequency analysis for the Byrnesville gage showed that peak annual flows with return intervals from 2 to 100 years have increased during 1990-2020 compared to 1941-1971 (Table 6). Recent higher peak flows include the relatively frequent 2-year and 5-year return interval floods which have increased by over a third and are considered the most important floods related to geomorphic channel adjustments (Blom et al., 2017; Dury, 1961; Lawrence, 2007; Petit and Pauquet, 1997). Peak flood discharge has increased by 1.26 to 1.39 times for all recurrence intervals during the past three or four decades in Big River (Table 6). Therefore, it may be expected that channel width and depth may expand to accommodate these larger flood flows (Ahiablame et al., 2017b; Bauch and Hickin, 2011; Langat et al., 2019). However, given that depth to bedrock along the channel bed in most Ozark rivers including Big River tends to be <1-2 m, channel width might be expected to be more responsive to increased flood regime compared to depth (Pavlowsky et al., 2017).

Historical (1937-2018) Channel Width Changes

Most 500-meter channel cells (Appendix A) assessed by this study narrowed from 1937 to the 1970s and widened from the 1970s to 2018 (Table 7) (Figure 6) (Appendix B). The value of +0.1 m/yr was used to determine widening and -0.1 m/yr for narrowing because a 0.1 meter per year change indicates about a meter of change between images at the approximate limit of image resolution and distortion. Before 1970, only 20-30% of the river cells indicated widening with 54-64% indicating narrowing. During this period the Big River may have been narrowing due to the effects of improved soil conservation practices after the 1920s or the transition from row crops to pasture and grazing cattle production after the 1940s that reduced runoff rates from agricultural lands (Jacobson and Primm, 1997). However, between 1970 and 2018, a clear widening trend is observed with 65-70% of all cells indicating widening and only 18- 24% indicating narrowing (Figure 6). The trend of channel widening in recent times aligns with increased precipitation intensity and higher flood magnitude and frequency in the region (Heimann et al., 2018; Pavlowsky et al., 2016; Pryor et al., 2014).

Rates of channel widening do not differ significantly between bends and straight reaches. The average rate of change for straights and bends along the river were very similar with the largest difference occurring in the period from 2007 to 2018 with bends averaging 0.5 meters per year and straight segments 0.7 meters per year. However, a two-sample t-test showed that there was no significant difference between segments located on a straight or bend in the channel for any year with all t-critical values being greater than the t-statistic (Table 7). Correlation analysis at the segment scale shows a significant correlation between increasing slope and channel narrowing as well as an increase in bar frequency as slope variance increases (Table 8). The negative correlation between the slope and channel width shows that narrow valleys along Big River have a steeper slope which lessens as the valley widens. A positive correlation between bar density and slope variation implies that segments of the river with abrupt changes in reach slope or variable bedrock control may produce a greater density of bars.

Grouping the cells by segment (Appendix C) shows that the most active segments vary spatially between time periods (Figure 7). Active segments are locations of the river that have changed in width by at least one standard deviation (greater than +1.5 m/yr or -1.5 m/yr) and could be indicators of possible disturbance zones (Martin and Pavlowsky, 2011). The number of cells with a high rate of change and the location of these cells changes between photograph sets. Exceptions to this occurred at river km 57.5, 70, 81, 173, and 186.5 which had a high rate of change between 3 of the 5 photo sets. These segments may have included a higher density of disturbance zones due to the constant higher rate of change compared to most of the channel. Width changes in these segments ranged as follows: R-km 57.5 from -7.4 to 4.4 m/yr; R-km 70 from -4.3 to 2.5 m/yr; R-km 81 from -5.0 to 1.6 m/yr, R-km 173 from -7.7 to 12.2 m/yr, and R-km 186.5 from -2.9 to 7.5 m/yr (Figure7). Disturbance zones are relatively unstable and may respond to changes in flood regime more rapidly and broadly compare to straight, stable reaches (Jacobson, 1995; Martin and Pavlowsky, 2011; Rumsby and Macklin, 1994; Rusnák et al., 2016).

The active channel of Big River has widened since the 1970s with most segments now having a larger average width with ratios ranging from 1.1 to 1.9 (Table 9). Most of the segments were the largest in 2018 with the exception of segment 0, segment 7 and segment 9 where 2018 was the second widest. Before the recent period, the channel was narrowing between 1937 to the 1970s. This narrowing period could be due to the changing agricultural practices that would have been put int place in the 1930s due to the Soil Conservation act being passed (Jacobson and Primm, 1997). The improved agricultural practices would reduce soil erosion and runoff and possibly reduce flood frequency. Channel narrowing would then occur as the river responds to the new, lower energy, flood regime. The upstream segments seem to be more active as shown by the higher overall change in the four upstream segments that occurred during both the narrowing and widening periods (Table 9) (Figure 7).

Figure 7 shows the rate at which the channel has changed as well as the ratio of the width between each set of photographs. Each segment that had narrowed had done so at a rate less than 0.5 meters per year except for river segment 0 which had the largest rate of narrowing at 1.3 m/yr. The recent period of widening had multiple segments among photo sets showing an increased widening rate > 0.5 meters per year. The highest rates of change occurred from the 1970s to the 1990s with exceptions being river segments 0, 5, and 10 (Figure 7). These segments saw the fastest period of widening from 2007 to 2018 and 1990 to 2007. The specific rates of channel widening and width variability in general varied among segments and years. For example, the most active segment from 2007 to 2018 was river segment 0, but from 1990 to 2007 segment 6 was most active (Figure 7). Factors such as localized flood impacts and sediment inputs as well as local land use change and physical composition of the banks could be playing a part in controlling the rates of change for each segment from year to year (Ahiablame et al., 2017b; Fryirs, 2017; Montgomery and MacDonald, 2002; Owen et al., 2011). However, the overall trend of increased widening since the 1970s is clear.

Historical trends in channel width are better detailed spatially when width change ratios are separated into two periods: narrowing period, before the 1970s, and widening period, after the 1970s (Figure 8). While the overall trend indicates recent widening, the upstream segments show relatively higher rates of change. While upstream segments above Mineral Fork average 10 m narrower compared to lower segments thus may appear wider in ratios, even the absolute rates of change are higher upstream (Figure 7). The segments that experienced the most widening during the recent period also experienced the largest amount of narrowing during the 1937-1970s period (Figure 8). This may suggest that upstream segments with higher bed slopes are more susceptible to larger floods causing channel adjustments due to excess stream power (Blom et al., 2017; Nelson et al., 2006). Moreover, higher rates of channel instability could be a lasting effect of mining sediment pulses of more mobile sand and fine gravel sized tailings within present-day deposits in the channel extending from R-km 170 to 140 in the upper segment (Pavlowsky et al., 2017). One exception to this broad trend is river segment 10 which has widened during the recent period but showed little change during the earlier period of narrowing. Overall, all segments are presently wider than they were in 1937 except for segment 0 which was affected by gravel and soil mining. Further, upstream segments have generally widened more than the downstream segments (Figures 7 and 8).

Recent channel widening is expected given recent climate change effects of increased precipitation rates with little change in land use patterns (Graham et al., 2007; Hu et al., 2005; Pryor et al., 2014; Seneviratne et al., 2012; Shaw and Riha, 2011). Further, as precipitation amounts and rate are predicted to increase, channel widening is likely to continue in the Midwest (Heimann et al., 2018; Hamlet and Lettenmaier, 2007; Pryor et al., 2014; Swanston et al., 2018). This increase in precipitation is supported by the widening channel of Big River from the 1970s to 2018 with most segments being wider in 2018 compared to 1937. Before the 1970s was a period of narrowing along the river from 1937 to the 1970s probably due to improved soil conservation practices and forest regrowth which would reduce runoff rates across the watershed. The most upstream segments of Big River (river segments 1 to 3) were more active during both time periods which could be a lasting effect of the introduction of significant load of mobile sand and fine gravel tailings to the channel (Pavlowsky et al., 2017).

Historical Bar Changes

Variable flow stages during the different dates of aerial photograph collection sometimes made it difficult to consistently compare bar areas between cells and segment since higher stages would yield lower bar areas compared to lower stages (Table 2). For example, the largest discharge for a photograph series occurred in 1990 at 37.2 m^3/s. Discharge for the 1970s ranged from 3.2 m^3/s to 19.2 m^3/s with an average of 7.5 m^3/s. The image layers available for upstream segments in 1990, downstream segments in 2007, and all of 2018 were created from images taken on multiple days and because of this a specific discharge value could not be determined for these images collected at different times for a given year (Table 2). To try to remove some of the stage bias and account for the variations in stage on bar analysis, only the number of bars with an average width over five meters were counted within each segment and divided by the segment length to yield the number of bars per km (Table 10).

Bar activity is an important planform variable because it can indicate instability in a river. For example, an increase in bars could indicate an increase in sediment input into the channel which could be a result of land use change or increased erosion due to flooding (Blondeaux and Seminara, 1985; Wolman, 1967). Overall, the total number of bars per year (Appendix D) is higher in recent times with 172 in 2007 and 147 in 2018 compared to the past with 127 bars in the 1970s and 125 bars in 1954 (Table 10). This follows the trend of larger flows and widening channels in the recent period which would cause more sediment to enter the channel from tributary inputs and bank erosion (Blondeaux and Seminara, 1985; Merritt et al., 2003; Rodrigues et al., 2015). The lowest total bar count occurred in the 1990s with 98 bars, but this could be due to bars being hidden because of the high discharges during those years (Table 2). Highest correlations between absolute width change (m) and bar density (#/km) were found in segments 0 and 6 with r^2 values of 0.69 and 0.53, respectively, and with the other segments having r^2 values ranging from 0.53 to 0.05. These low relationships could be a result of the effect of variable stages adding error during aerial photograph comparisons. However, more research is needed to determine how bar area and density is being affected by channel widening along Big River.

Field Assessment

Field measurements were made to verify the width changes shown in aerial photograph analysis. In December 2020, width measurements were made at several sites along Big River that were previously surveyed about a decade earlier during the Big River Mining Sediment Assessment Project (Pavlowsky et al., 2010, 2017). Of the seven locations resurveyed, all nine original transects could only be resurveyed at two sites, Browns Ford and Blackwell (Table 11). Transects at some sites were blocked by obstructions such as large woody debris jams and fast currents. In general, resurveys indicated widening over the past decade. Both Browns Ford Park and Blackwell experienced an average increase in width of 2.5 m and 6.2 m, respectively. Five of the seven sites widened with two sites having a widening ratio over 1.1, and the other three having a ratio of at least 1.05. The sites with the largest ratio were at Blackwell with a ratio of 1.16 and Above highway 67 with a ratio of 1.4. The sites that did not widen were Mammoth and Cedar Hill. Mammoth only had three sites where the field width could be measured and Cedar Hill Park had less than a meter difference (Table 11) possibly due to stabilization effects by a breached dam downstream that reduced channel slope in the assessed reach. While these field results were generated based on opportunity and limited access, they support the aerial photograph-based results indicating increasing channel width over the past 20-30 years in Big River.

Bank assessments showed geomorphic signs of widening that support the measurements from recent aerial photographs (Figure 9). The most common indicators of bank retreat observed at these locations were raw cutbanks, reduced bank vegetation and the lack of root protection, recent slump scars, and undercut and fallen trees. Further, bank erosion was occurring on both opposing sides of the channel along many transects thus indicating actual widening and not just bank erosion due to channel migration. The locations that did not widen but showed signs of erosion and slumping could still be in the initial process of widening with more time needed to exceed natural resistance factors such as the presence of vegetation, lower bank angles, and shifting currents based on bedrock outcrops and shifting bars. Recent slumping and bank failures could introduce sediment into the channel to be deposited at the base of the bank. This sediment deposit could appear as a narrowing phase of the channel since it has not had time to be eroded away.

There is the possibility that the 2020 tapeline widths were biased towards slightly larger widths since the tape would sag and thereby add length. While this limitation could possibly add width to the channel measurement, it is unlikely to account for >2 meters of width change observed at most sites. The signs of bank erosion and measured width changes support the channel widening observed in the aerial photo analysis.

Regional Flood Frequency Analysis

To verify the flood trends in Big River, flood frequency analyses were completed for 24 other river gages in the Ozark Highlands to determine if there was a regional correlation between more frequent and larger floods and increased channel widths (Appendix E-1,2). When the modern time period, 1990-2020, was compared to the pre-warming period, 1941-1971, 58% showed an increased peak flow of over 10% for the 2-year and 10-year flood, and 50% for the 2-year, 10-year, 50-year and 100-year flood events. Only one gage, USGS gage 07191000 Big Cabin Creek near Big Cabin, OK, showed a decrease in flow of more than 10% for either the 2-year or 10-year event. For the 2-year flood, Little Piney Creek had the largest increase at 58% with Spring River near Quapaw experiencing the second highest with a 42% increase in peak flood discharge. For the 100-year flood the largest increase occurred at Eleven Point River near

Ravenden which increased in discharge by 208%. The 100-year flood experienced the greatest percent change for 17 of the 24 gages (Appendix E-1). This shows that the 100-year flood is being most affected by the changing climate. This pattern has been noticed by previous research into the changing flood regime in the Midwest and could be a driving factor of the widening channel (Andresen et al., 2012; Hayhoe et al., 2009; Pryor et al., 2014). Larger floods in the recent period were also reported during an analysis of 49 gaging stations in the Ozark Highlands and surrounding areas by Heimann et al (2018). The median annual or 2-yr recurrence interval peak streamflow generally increased at most of the gages from 1975 to 2017. From 1989 to 2017, 47% of the gages studied experienced a median increase in annual peak flow from 8-10% per year with only 10% showing no difference (Appendix E-1).

In this study, gage records for all Ozark Highland regions showed an increase in flood peaks for all return intervals (Table 12) (Figure 10). The largest relative change in percentage was an increase in discharge of the 100-year flood by 101% in the Mississippi River Basin-White River region. This is most likely driven by the large increases in Bryant Creek and Eleven Point River near Ravenden. The 100-year flood was also the recurrence interval that experienced the largest percent increase in discharge for the Ozark Highlands as a whole. When the return periods were averaged for the Ozark Highlands region the 2-year event increased by 24%, 10-year event by 30%, 50-year by 37%, and 100-year by 41%. This follows the findings that more extreme events are being effected most by climate change (Andresen et al., 2012; Hayhoe et al., 2009; Pryor et al., 2014), with this trend also being found in the Ozark Highlands (Andresen et al., 2012; Dirmeyer and Kinter, 2010) which supports the findings of this study of an increased in larger floods.

Flood frequency analysis does have its sources of inaccuracy especially as the time frame of the flood record in years gets shorter. A shorter period of record such as the 30 years used in this study, could be sensitive to the enhanced effects of multiple large flood events ("Guidelines for Determining Flood Flow Frequency Bulletin 17C," 2019). A few large floods during a relatively short record would make it seem that these large floods were more common compared to the same number of large floods over a longer record. This could result in the large increases in flood magnitude calculated for the 50-year and 100-year events (Figure 11) and possibly explain some of the large increases long return period flood peaks in the Mississippi River Basin- White River, Mississippi River Basin- St. Francis River, and the White River Basin regions.

Channel Width Changes at USGS Gages

The regional effects of climate change on channel width were examined more widely for the Ozark Highlands by evaluating comparisons between recent changes in flood frequency and channel width the Ozark Highlands (Appendix E) then grouped by region (Table 12). There were 47 total reaches measured in Google Earth Pro across the Ozark Highlands with two reaches near each USGS gage but only one near Little Piney Creek. Time intervals over which widening rates were assessed generally spanned a 20-year period from 1994-96 to 2014-16 (Appendix D-2). Overall, 60% of the reaches showed an increase in channel width over 5% between image sets with 23% of the segments showing an increase in width over 10%. To determine if image distortion could be responsible for calculated width changes, structure points on buildings or bridges were geo-located and compare between images (Appendix F). The average differences between images were <0.4 m. This shows that image errors were less than measured differences in channel width.

Channel width in the Ozark Highlands has been increasing on average in recent years across several subregions (Table 12). The highest rate of change occurred in the Missouri River-Osage River basin at 0.71 percent per year but was made up of only two segments. The Mississippi River Basin-Arkansas River had the second highest percent increase at 0.47 percent per year. All regions showed an increase in width with Mississippi River-Meramec River at a rate of 0.11 percent per year. Channel width increases in Big River ranged from 0.11 to 0.36 percent per year which falls within the regional range. Therefore, channel widening trends in the Big River as found by this study reflect regional trends in the Ozark Highlands.

The 2-year flood was suggested to be an indicator of possible channel change. However, it does not correlate with the rate of widening in this study (Figure 12). The 10 year event is more closely correlated to channel widening possibly due to the channels being more sensitive to larger floods over a short time frame which reflect the influence of hydrologic disturbance rather than regime conditions (Blom et al., 2017). The gage locations experiencing the highest rates of widening do not always correlate with the largest increases in flood magnitude. The region with the highest percent change per year, Mississippi River Basin- Arkansas River, had an increase of 27% for the two-year flood and little change in the higher return period floods. The Mississippi River Basin- Meramec River had the highest increase in discharge for the 2-year flood but the least amount of channel change. The lowest change in discharge for the 2-year flood occurred in the White River Basin which experienced the third highest increase in width (Figure 12). This could be due to channel morphology not having time to exceed resistance limits and react to increased flood peaks. Further, this study only evaluated the annual peak discharge per year and not all large floods. Thus, it did not consider the influence of several large floods per year. Also, it only evaluated two reaches per gage locality and not changes for the entire river system as completed for the Big River. Nevertheless, most of the gage sites evaluated indicated recent channel widening.

Summary

Flood analysis of Big River and the Ozark Highlands region indicated that flood peaks have been increasing. Comparisons of the peak discharge trends for different recurrence intervals showed that the discharge has increased in the time period from 1990-2020 compared to 1941-1971 along Big River. An increase in peak discharge for various flood frequencies is also seen more broadly across the Ozark Highlands. The subregions of the Ozark Highlands all experienced increasing discharge for the 2-year and 10-year floods. This indicates that the Ozark Highlands region and not just the Big River could be experiencing an increase in flood discharge due to the increased precipitation in the Midwest (Heimann et al., 2018; Pavlowsky et al., 2016; Pryor et al., 2014).

Along with increasing flood peaks, increases in channel width were also observed along Big River and other rivers in the Ozark Highlands since the 1980s. In Big River the most widespread widening occurred from 1970 to 1990 with 70% of the 500-m cells indicating widening. From 1990 to 2007, 66% of cells widened, and from 2007 to 2018, 65% of cells widened. This resulted in all but river segment 0 being widest in 2018. In the Ozark Highlands, all but two river segments measured were wider in the recent photographs.

Other indicators of channel change and instability are bar activity and river bank conditions. A significant change in the number and location of bars could indicate a change in sediment input and or stream power. From 2007 and 2018, there has been a general increase in the number of bars wider than 5 meters and may thus indicate increased sediment input into the channel as it widens. There were multiple examples of slumping and erosion on both sides of the river indicating that the total width of the channel may be widening and not just migrating laterally.

The 2-year flood is an important driver of channel formation and an increase in discharge for this flood could cause the channel to begin to widen over time (Andrews, 1980; Dury, 1961). The discrepancy between the increased discharge and the channel width increase being seen in the Ozark Highlands can be due to lack of time the channels have had to respond to the increased discharges. Factors such as bank composition as well as the bank steepness and vegetation can influence how channel width will respond to an increased discharge (Michalková et al., 2011; Munn et al., 2018; Petit and Pauquet, 1997; Rusnák et al., 2016). Land use trends may also affect the rates of channel widening within the Ozark Highlands. For example, increased urban area could amplify the effects of the increased precipitation and force the channel to respond faster (Hu et al., 2005). However, the data reviewed here indicated no significant increase in urban area in the Big River watershed during the study period. Further studies would need to be done on land use change in the Ozark Highlands to determine more precisely the extent that land use change is affecting rivers in the area in addition to climate change. The records used consisted of only the maximum flood for each year and possible increases in discharge peaks under the maximum flood of each year, through partial duration flood analysis, could help to better resolved the relationship between flood regime, stream power trends, and channel widening

Table 5. River Morphology (2018).

Segment	R-km[A]	Slope Average[B]	Confinement ratio[C]	Channel width			Bars		
				Channel width (m)[D]	CV% (width)[E]	Rate of change (m/yr)[F]	#/km	Average width (m)[G]	Percent of channel width[H]
0	186.5	0.0009	11	55.8	47	1.06	1.2	20.0	35.8
1	171	0.0008	6	42.7	22	0.14	0.9	8.3	19.5
2	155	0.0008	10	37.2	12	0.30	0.7	5.5	14.9
3	144.5	0.0007	10	46.0	32	0.55	0.8	10.5	22.8
4	132.5	0.0006	8	47.0	13	0.31	0.6	4.5	9.5
5	115.5	0.0006	11	43.6	13	0.08	0.5	5.4	12.4
6	99	0.0005	7	54.1	18	0.03	1.0	15.6	28.8
7	72.5	0.0006	10	55.3	23	-0.28	1.1	16.4	29.7
8	52	0.0004	14	54.1	19	0.29	0.6	11.1	20.5
9	35	0.0004	28	49.6	14	0.01	0.4	7.3	14.7
10	17	0.0003	17	49.5	18	0.65	0.6	7.3	14.7

Foot Notes:

A= upstream border

B= Average slope of 100m intervals

C= Valley width/ Channel width

D= Average cell width change between 2007 and 2018

E= Coefficient of variance per segment

F = Average of cell values from 2007-2018

G= Average bar width per segment

H = (Bar width/ average segment width) *100

Table 6. Byrnesville Flood Frequency analysis (USGS gage number 07018500).

Return interval (years)	Byrnesville Percent Exceedance	Flow (m^3/s) 1941-1971	1990-2020	Ratio
100	0.01	2,775	3,546	1.26
50	0.02	2,552	3,334	1.28
10	0.1	2,065	2,844	1.33
5	0.2	1,867	2,624	1.35
2	0.5	1,617	2,327	1.38
1	1	1,435	2,096	1.39
0.5	2	1,258	1,860	1.4
0.25	4	1,086	1,618	1.4
0.1	10	864	1,286	1.39
0.05	20	696	1,020	1.35
0.02	42.9	500	698	1.28
0.02	50	457	626	1.25
0.01	66.7	368	475	1.18
0.01	80	299	361	1.1
0.01	90	238	264	1.01

Table 7. Comparison of widening for reaches on straight vs bends on Big River.

Period	t Stat	P value
1937-1954	-1.27	0.21
1954-1970	0.89	0.37
1970-1990	-0.24	0.81
1990-2007	0.23	0.82
2007-2018	-1.57	0.12

Table 8. Correlation matrix for geomorphic variables along Big River. Underlined values show significant relationships $r^2 > 0.6$

	Slope Average	Slope CV%	Confinement ratio	bars/km	2018 Channel width (m)	Rate of change (m/yr)
Slope Average	1					
Slope CV%	0.60	1				
Confinement ratio	-0.64	-0.31	1			
bars/km	0.52	0.86	-0.55	1		
2018 Channel width (m)	-0.50	0.28	0.37	0.30	1	
Rate of change (m/yr)	0.34	0.37	0.06	0.18	-0.22	1

Table 9. Historical width trends.

A

Segment #	R-km (upper)	Length (km)	Average Width (m) 1937	1954	1970s	1990	2007	2018	CV%
0	186.3	15.5	60.1	38.2	32.9	44.1	44.2	55.8	20.6
1	171.0	16.0	40.1	37.2	30.8	36.8	41.2	42.7	10.2
2	155.0	10.5	29.8	27.8	24.1	30.8	33.9	37.2	13.6
3	144.5	12.0	36.4	31.8	24.3	38.1	40.0	46.0	18.8
4	132.5	17.0	37.6	37.3	30.6	38.4	43.6	47.0	13.2
5	115.5	16.5	35.0	36.2	31.8	36.5	42.6	43.6	11.1
6	99.0	26.5	41.7	40.1	39.3	44.3	53.8	54.1	13.5
7	72.5	20.5	48.2	47.4	44.5	52.3	58.3	55.3	9.4
8	52.0	17.0	47.6	47.8	42.5	48.7	51.0	54.1	7.3
9	35.0	18.0	47.8	48.9	46.0	50.3	49.5	49.6	2.9
10	17.0	17.0	40.1	40.2	39.3	42.1	42.3	49.5	8.0

B

Segment	R-km (upstream)	Percent cells that widened per segment 1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
0	186.3	13	39	81	81	68
1	171.0	25	25	69	84	59
2	155.0	29	19	90	62	81
3	144.5	13	8	96	67	79
4	132.5	44	12	91	76	71
5	115.5	42	18	79	94	67
6	99.0	30	42	70	89	66
7	72.5	37	37	78	85	56
8	52.0	47	12	85	56	82
9	35.0	61	14	72	50	58
10	17.0	50	41	65	32	94
	Total	31	21	70	66	65

Table 10. Bar Frequency by segment.

Segment	Number of bars > 5m divided by length of segment					
	2018	2007	1990	1970	1954	1937
0	1.2	1.0	0.8	0.6	1.2	1.5
1	0.9	1.2	0.7	1.4	1.1	1.4
2	0.7	1.0	0.7	0.8	0.4	0.6
3	0.8	1.1	0.5	0.9	0.9	1.0
4	0.6	0.9	0.4	0.6	0.6	0.7
5	0.5	0.6	0.2	0.2	0.8	0.7
6	1.0	1.3	0.6	0.6	0.6	1.1
7	1.1	1.3	0.6	0.8	0.8	1.2
8	0.6	0.6	0.5	0.6	0.6	0.5
9	0.4	0.7	0.4	0.6	0.3	0.3
10	0.6	0.4	0.4	0.5	0.1	0.4
Total Bars	147	172	98	127	125	160

Table 11. 2020 resurvey cross section compared to 2010 measurements.

Site Location	R-km	Transects	Active Width (m)		Difference		Ratio	Width CV%	2007-2018 (m/yr)
			2009	2020	Meters	(m/yr)			
Above Highway 67 Desloge	156.4	6	33.9	42.3	8.5	0.8	1.3	5.4	0.2
Cherokee Landing	136.7	4	32.8	34.5	1.7	0.2	1.1	6.1	0.2
Bridge at Blackwell	115.5	9	42.3	47.9	5.6	0.5	1.1	12.6	0.7
Mammoth MDC Access	97	3	61.7	54.3	-7.4	-0.7	0.9	12.9	0.5
Browns Ford Park	79.3	9	40.4	43.3	2.9	0.3	1.1	9.8	0.5
Morse Mill Park	49.6	6	45.0	46.9	1.9	0.2	1.0	10.2	0.2
Cedar Hill Park	32.5	5	43.4	42.6	-0.8	-0.1	1.0	5.8	-0.8

Table 12. Regional width and flow change in the Ozark Highlands. N is the number of river segments within the region.

Region	n	Width change				Flood ratio change	
		m/year	%/year	St. Dev	CV%	2 yr	10 yr
Arkansas River Basin	6	0.18	0.3	1.95	52.71	1.26	1.11
Mississippi River Basin-Arkansas River	6	0.26	0.47	3.23	62.76	1.27	1.19
Mississippi River Basin-Meramec River	8	0.07	0.11	1.57	88.4	1.34	1.37
Mississippi River Basin-St. Francis River	2	0.19	0.29	2.1	55.83	1.10	1.29
Mississippi River Basin-White River	12	0.2	0.29	2.78	67.57	1.17	1.47
Missouri River Basin-Gasconade River	3	0.26	0.31	6	107.43	1.45	1.39
Missouri River Basin-Osage River	2	0.2	0.71	0.11	3.09	1.30	1.24
White River Basin	8	0.22	0.42	4.62	88.61	1.07	1.15

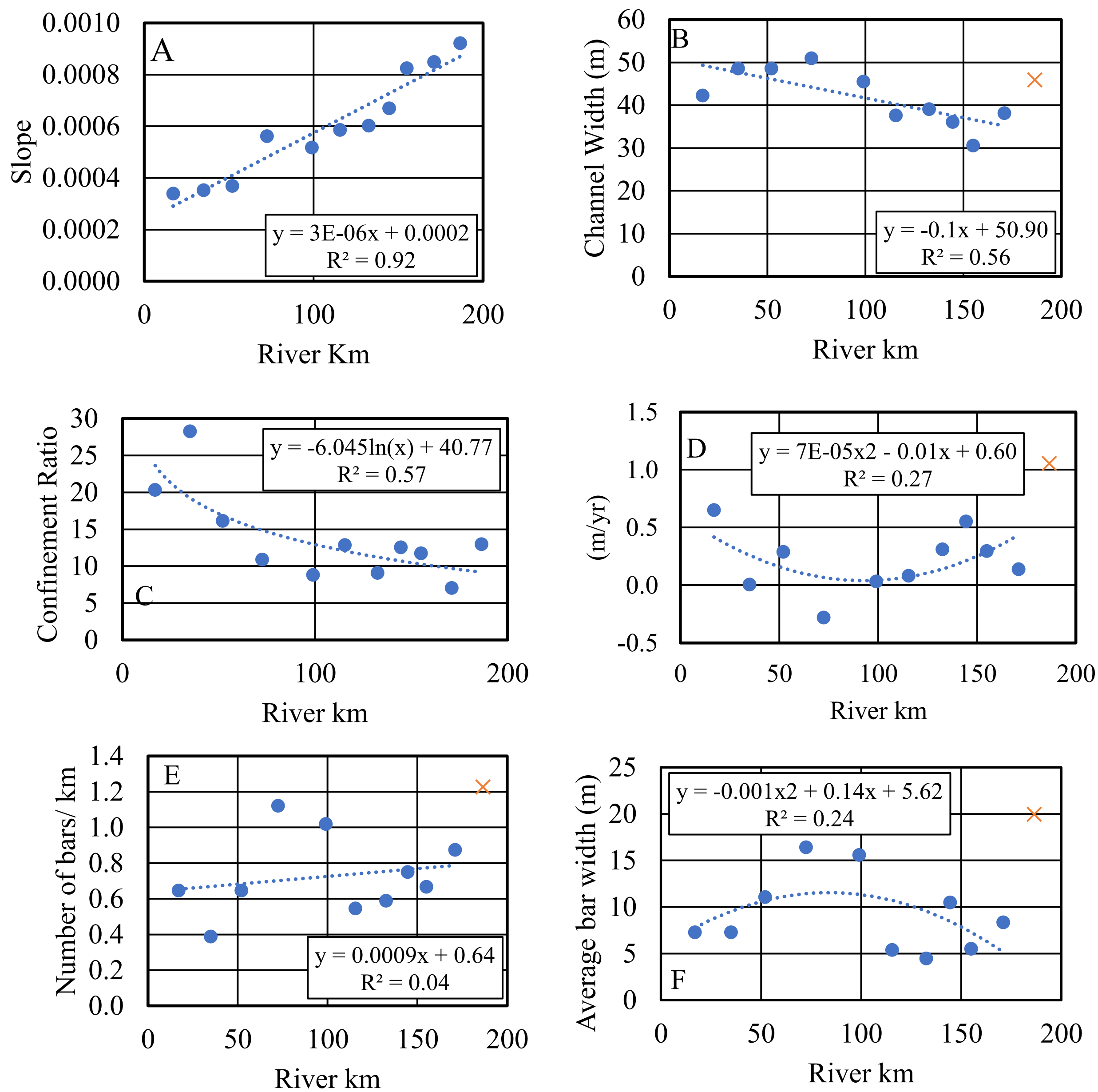


Figure 5. Downstream trends in channel morphology variables: (A) slope, (B) channel width, (C) confinement ratio, (D) rate of widening (m/yr) (2018-2007) with positive values showing widening and negative showing narrowing of the channel, (E) bars per kilometer, (F) 2018 Average bar width. The orange x indicates the segment that was affected by gravel mining and was not included in the line of best fit.

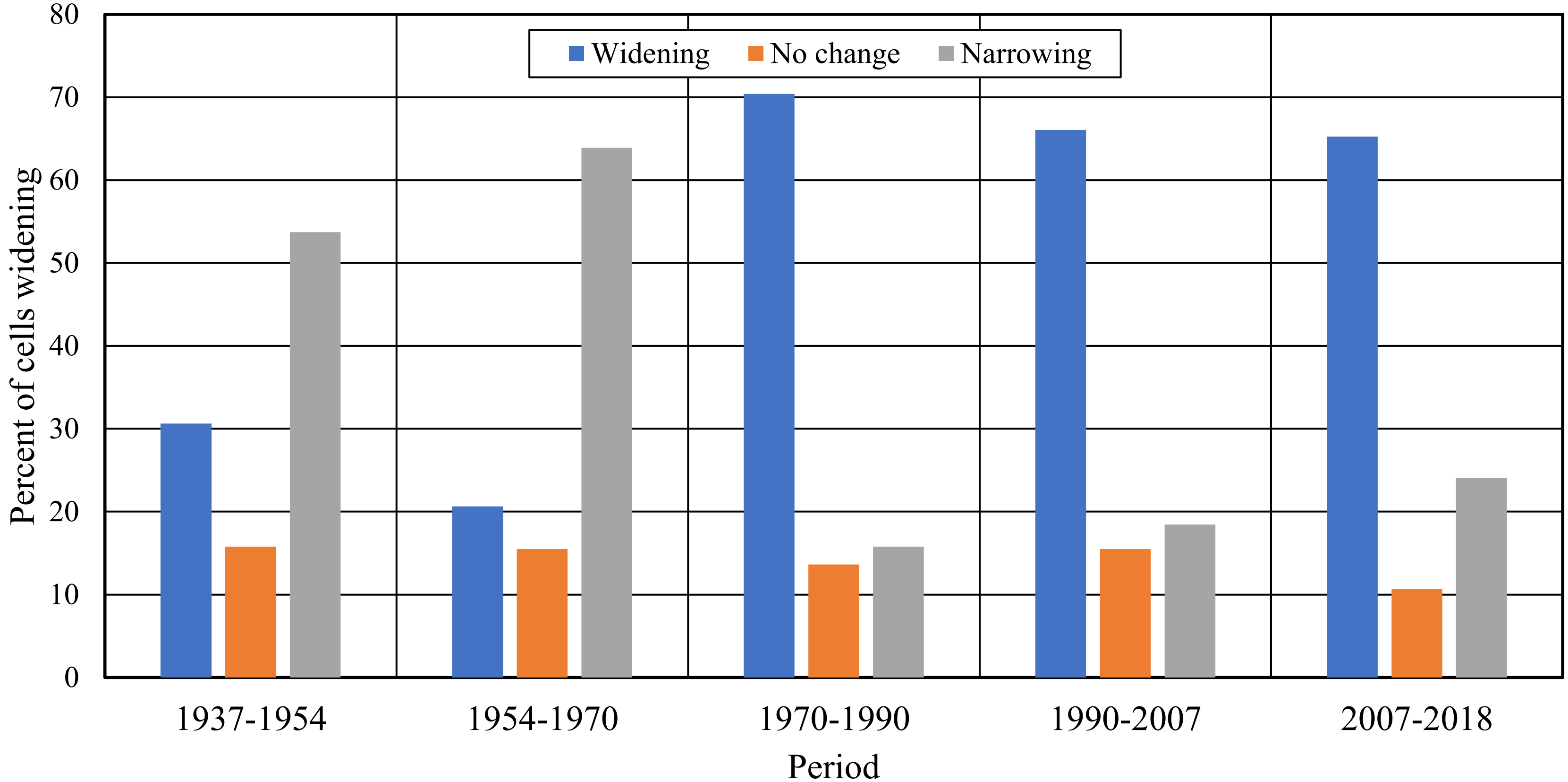


Figure 6. Cell width change.

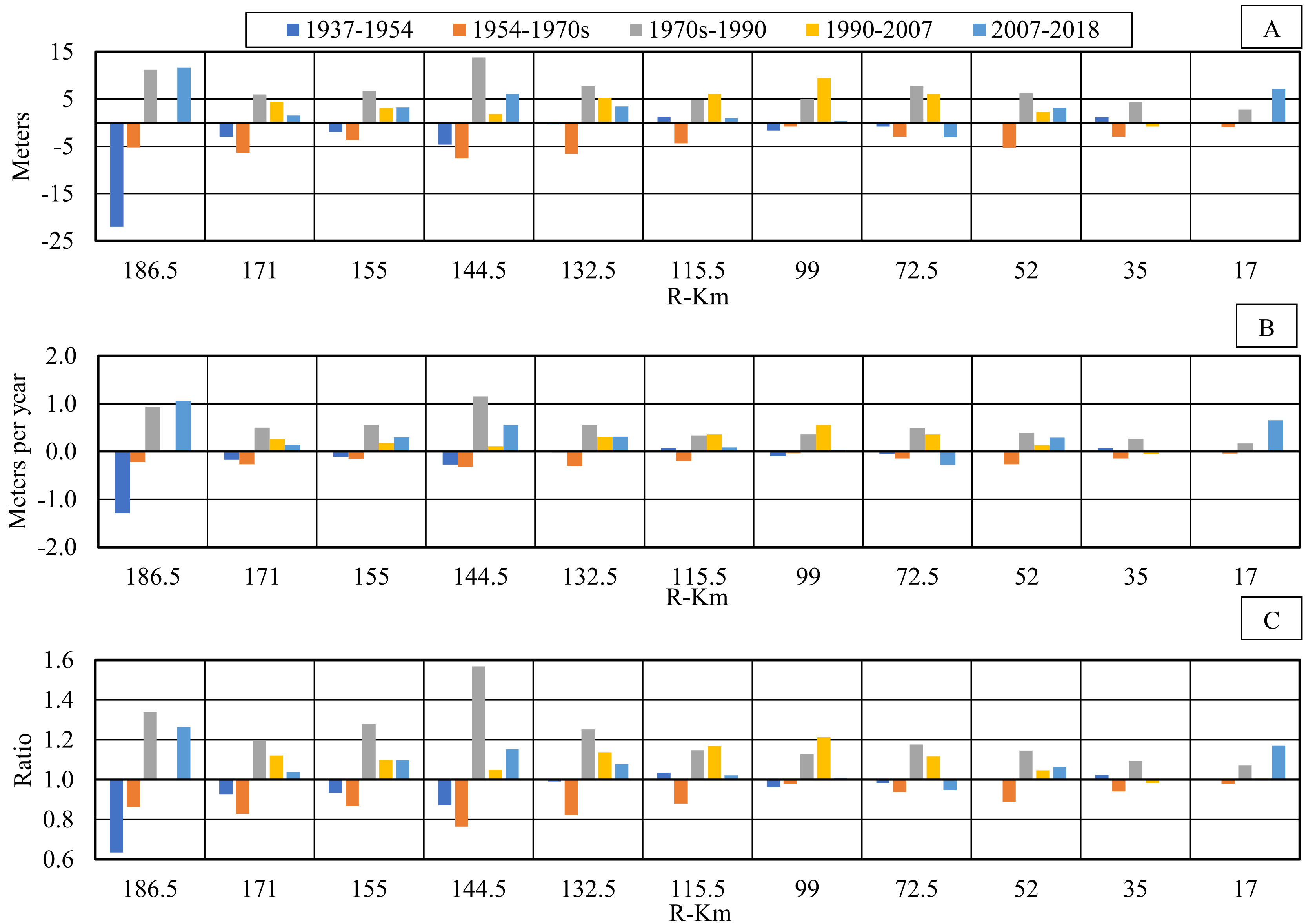


Figure 7. Width changes on Big River by segment using (A) total change in width, (B) rate of change in m/yr (B) and (C) ratio. Ratios above 1.0 indicate channel widening and ratios below 1.0 indicate channel narrowing.

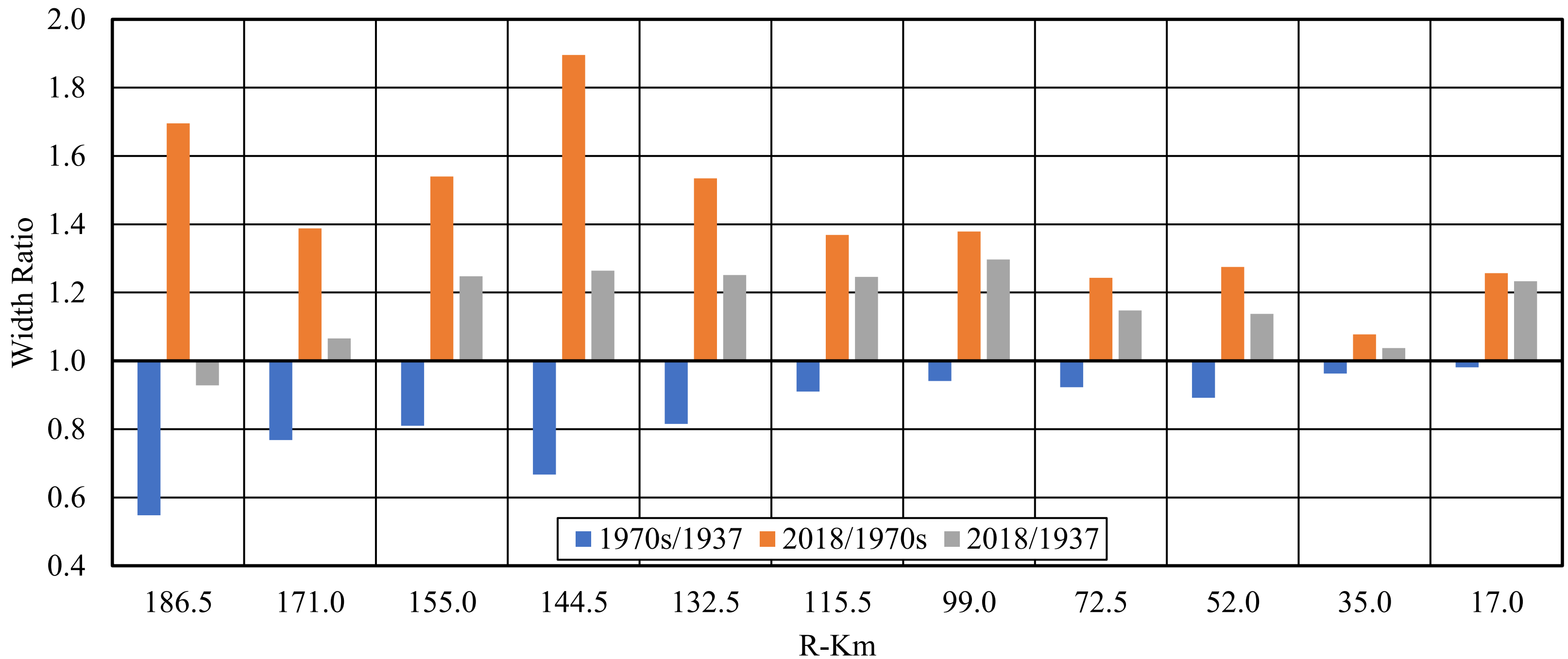


Figure 8. Width changes comparing overall narrowing and widening periods. Ratios >1 indicate widening and <1 channel narrowing.

Figure 9. Big River examples of (A) bars at river km 156.7, (B) slumping at river km 156.7, (C) unstable banks at river km 96.7, and (D) scouring at river km 96.2.

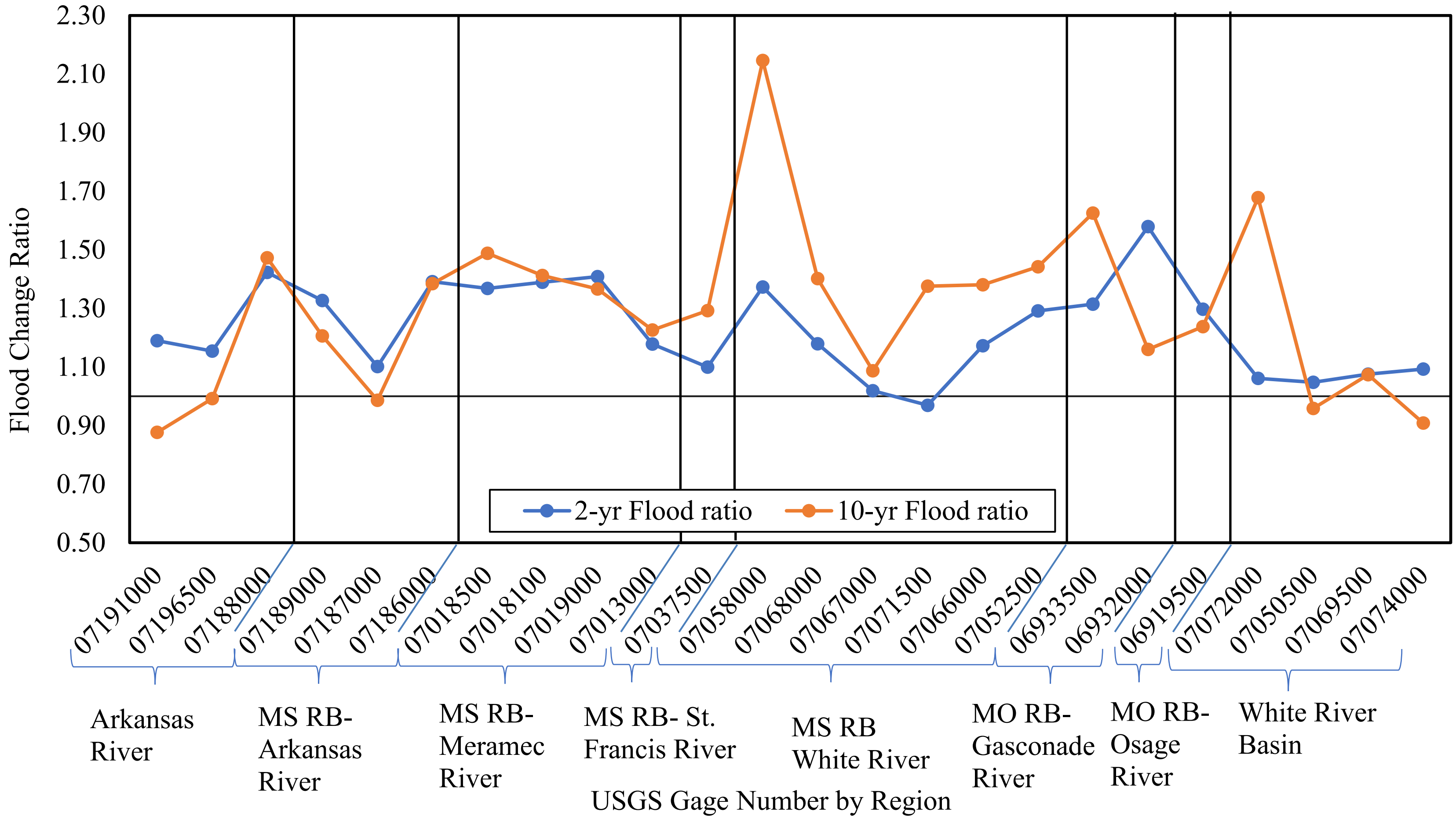


Figure 10. Flood change ratio in the Ozark Highlands region. The recent period (1990-2020) was divided by the past period (1941-1971) to calculate the change in flood discharge for the 2-year and 10-year recurrence intervals. MS RB= Mississippi River Basin; MO RB= Missouri River Basin

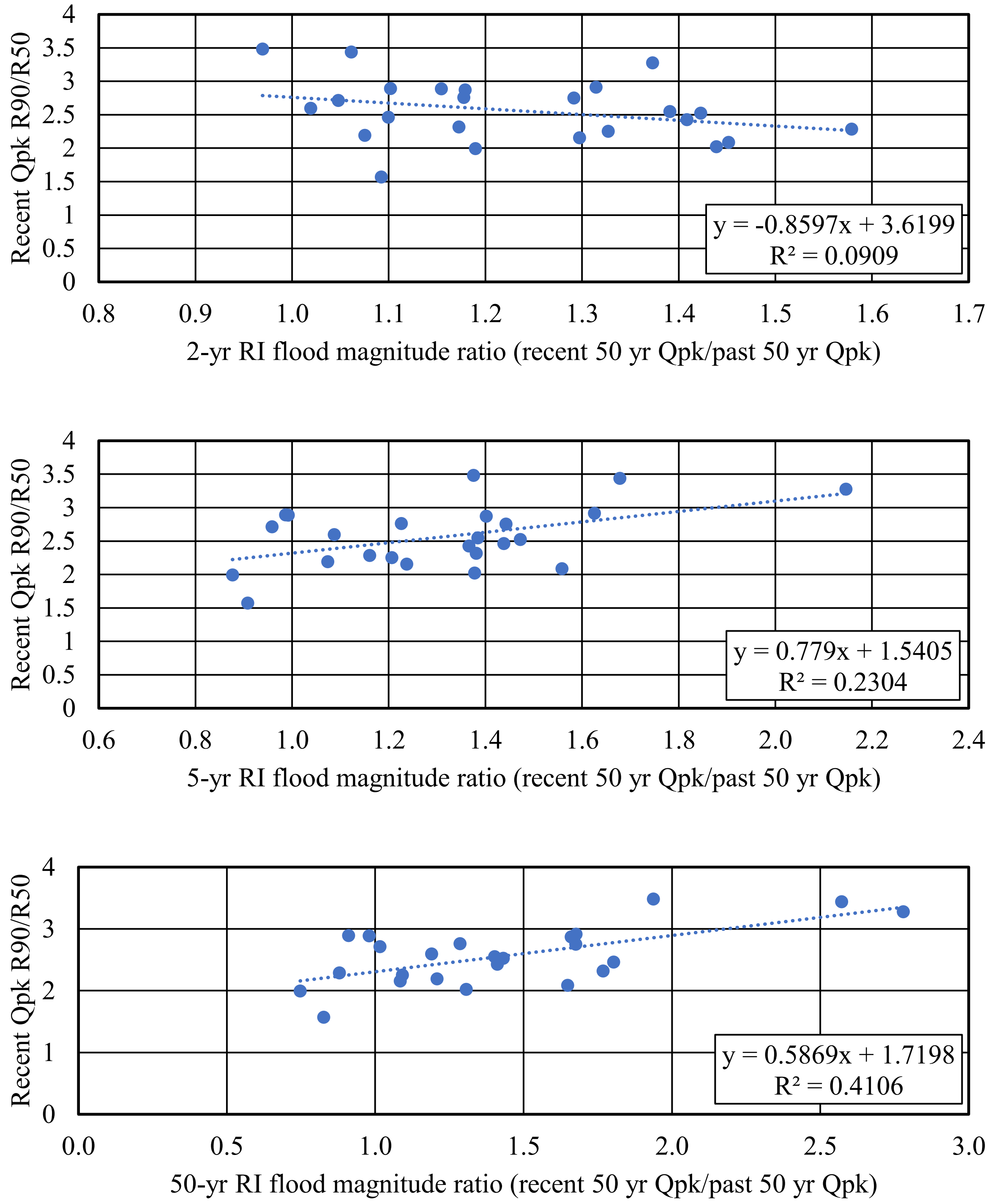
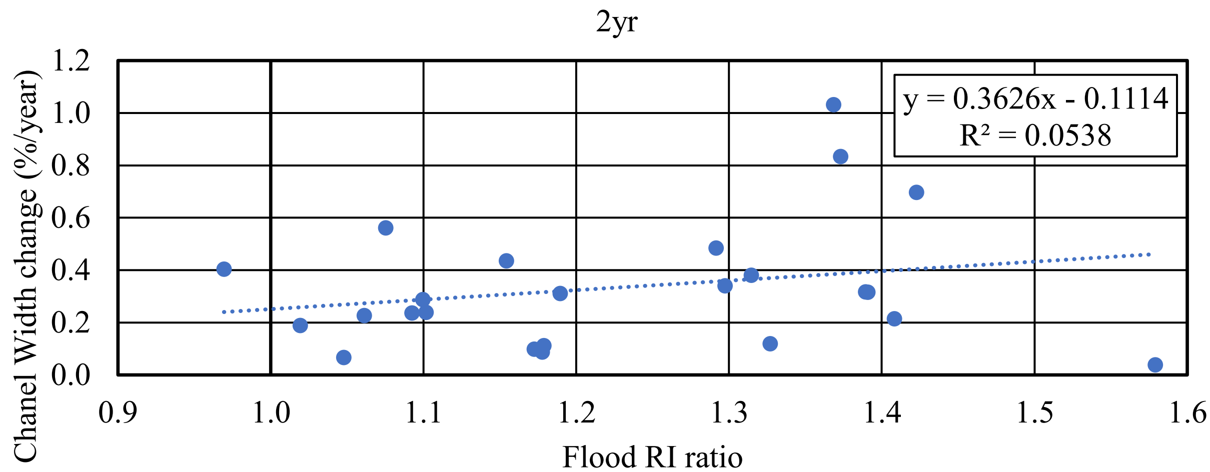


Figure 11. Large differences between the 10-year and 2-year event relates to the flood magnitude at different return intervals.



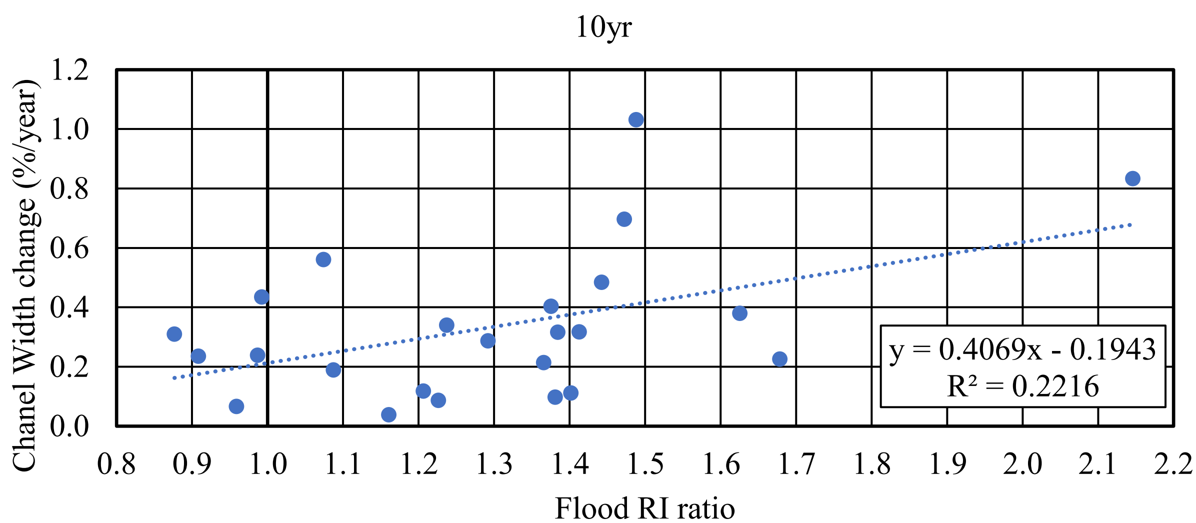


Figure 12. Regional Flood increase compared to width change percent.

CONCLUSION

It is well-documented that increased precipitation is occurring in the Ozark Highlands due to the rapidly changing climate (Dirmeyer and Kinter, 2010; Hayhoe et al., 2009; Pryor et al., 2014; Wuebbles and Hayhoe, 2004). Understanding the ways in which the rivers of this region are responding to this phenomenon is vital, as this knowledge can provide valuable information to policymakers that may be utilized to protect delicate native habitats, ensure desirable water quality, and protect existing infrastructure. Increased precipitation amount and intensity can be linked to larger floods and unstable channels, both of which can endanger the integrity of buildings and other infrastructures that were not previously at risk (Arnell and Gosling, 2016; Bernier et al., 2021; Palmer et al., 2008). Habitats can be destroyed through erosional processes and through increased sedimentation into channel systems (Lenhart et al., 2013; Moore, 2012; Palmer et al., 2009). Additionally, increased precipitation increases the likelihood that contaminated legacy mining sediments unique to the Big River watershed can be re-introduced to the channel system through bank erosion, and toxic sediment transport (Pavlowsky et al., 2017; Saha and Paul, 2016).

To determine how anthropogenic climate change has affected Big River, aerial photographs from 1937, 1954, the 1970s, 2007, and 2018 were analyzed to calculate channel width changes over time. Trends from these calculations were then compared to data from 24 USGS gage sites across the Ozark Highlands to verify whether the findings for Big River were generally representative of the entire Ozark Highlands region. Additionally, flood records were used to calculate changes in flood magnitude for both the 2- and 5-year floods during two time periods: 1941-1971 and 1990-2020.

Results of this study indicate: (1) magnitudes and frequencies of both the 2- and 5-year floods have increased since the 1970s; (2) from 1937 to 1970 the Big River channel went through a period of narrowing which may be attributed to watershed improvement due to soil conservation practices and mining activities which discharged large quantities of sand and fine gravel; (3) channel widening has occurred since the 1970s in all segments of Big River; (4) preliminary results support the hypothesis that bar density is increasing as channels are widening, but additional research is needed; and (5) channel widening trends seen along Big River are generally occurring throughout the Ozark Highlands. Specific conclusions based on these results are described below:

(1) Since the 1970s, the magnitude of 2- and 5-year floods increased by 1.6- and 1.4-times, respectively. Land use changes during this period were minimal with the area becoming slightly more urbanized during the 1970s and through 1992, but with urban growth remaining at a constant 9% of the watershed thereafter (Meneau, 1997). The largest changes in land use occurred from 1992 through 2019, where forest cover increased from 48% to 59%, and pastures decreased from 26% to 18% (Figure 4). Due to the minimal changes in urban or agricultural land use in the watershed, changes that are frequently associated with channel instability, it is likely that climate change induced increases in precipitation and storm intensity are the main contributing factors to channel width increases along Big River.

(2) A period of channel narrowing occurred along Big River from 1937 through 1970. From 1937 to 1954, 51% of 500-m channel cells narrowed, and 57% narrowed from 1954 to 1970. Upstream river segments narrowed more rapidly than downstream

segments, with a maximum narrowing rate of 0.8 meters per year. During this period, mining activities upstream likely contributed to increased sediment deposits into Big River, disrupting the natural flow and providing a plausible cause of channel narrowing (Fryirs, 2017; Pavlowsky et al., 2017). In addition, soil conservation practices introduced by government programs beginning in the1920s probably reduced runoff and soil erosion from agricultural areas.

(3) Analyses of aerial photographs reveal that channel widening has occurred in all segments of Big River since 1970, rates varying from 0.1 meters per year (downstream) to 0.5 meters per year (upstream). A strong trend in channel widening was indicated with 70% of channel cells indicating widening from 1970 to 1990, 66% from 1990 to 2007, and 65% from 2007 to 2018. Field observations in the study area revealed frequent signs of slumping and erosion along both sides of the channel indicating channel instability. The combination of aerial and field observations support the hypothesis that channel widening is occurring in Big River (Ahiablame et al., 2017b; Heimann et al., 2018; Downs and Thorne, 1996; Gilvear et al., 1999).

(4) During the aerial analyses, it was noted that the total number of sediment bars increased in Big River over time, from 125 in 1954 to 147 in 2018. The highest number of bars (172) occurred in 2007. Several factors, including water level at photography time and increased sedimentation from channel widening and erosional processes could be the cause of this increase over time. Research shows that increased sediment load can result in an increase in bar formation (Martin and Pavlowsky,

2011; Rashid, 2020; Simon, 1989; Wang et al., 2016). It is hypothesized that the sediment input from eroding banks may be the cause for the increased bar activity but more research is needed to verify this relationship.

(5) During this study, data from 24 USGS gages located throughout the Ozark Highlands were used to calculate changes in discharge for the 2- and 5-year floods. Of these, 58% showed an increase in magnitude of at least 5% for both 2- and 5-year flooding events. Overall averages within the region reflected increases in all flood magnitudes examined. Analyses of channel widths revealed that 28 of the 47 cell segments analyzed increased by at least 5%, with regional averages indicating increases throughout. These measurements support the hypothesis that Big River is not an exception to the changes occurring in river systems within the Ozark Highlands.

The results of this research indicate that climate change driven channel widening is probably occurring in Big River, and that this trend is likely reflected throughout the Ozark Highlands as a whole. Analyses of factors such as land-use changes, field observations, and USGS gage data imply that increased precipitation is the main contributing factor to increases in flood rates and geomorphological changes of the channel systems. These changes increase the potential of damage to native habitats, endanger the health of the ecosystem through the potential introduction of legacy mining sediments into the channel system, and may lead to damage of existing infrastructure (Hayhoe et al., 2009; Heimann et al., 2018; Lenhart et al., 2013; Pavlowsky et al., 2017; Wang et al., 2016). Therefore, it is imperative that further research be conducted. To evaluate channel change using aerial photographs from different watersheds throughout the region to locate and understand the processes causing the most rapid changes. Further, the combined relationship of land use and climate change as a cause of channel disturbances in the Ozark Highland needs to be investigated further.

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APPENDICES

Appendix A. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
0.25	49.47	46.83	47.93	45.32	38.70	45.49
0.75	49.05	35.17	40.36	43.46	38.14	37.01
1.25	49.99	39.92	39.17	41.71	48.38	40.02
1.75	48.53	40.35	37.93	38.46	43.22	37.55
2.25	53.66	44.43	41.68	43.35	38.31	41.46
2.75	56.21	38.44	43.72	47.12	39.09	40.64
3.25	41.80	37.78	37.45	37.92	41.55	37.88
3.75	42.49	38.40	37.56	35.38	40.40	37.75
4.25	46.82	44.45	33.61	34.99	37.44	30.72
4.75	47.44	42.16	44.67	40.38	32.75	38.66
5.25	46.58	38.70	39.34	34.08	39.98	33.01
5.75	46.18	38.78	40.32	33.80	32.65	31.69
6.25	44.81	42.14	39.89	30.37	33.03	28.50
6.75	46.31	38.63	33.65	34.40	30.31	32.53
7.25	41.01	35.74	35.75	30.57	35.42	39.28
7.75	48.46	58.13	47.03	45.92	41.31	34.32
8.25	53.89	47.37	45.42	42.54	40.04	36.59
8.75	42.14	37.65	37.80	31.25	40.99	43.07
9.25	43.45	36.61	39.66	30.84	38.80	34.76
9.75	38.03	35.35	31.97	29.19	28.49	32.33

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
20.75	43.14	43.49	44.13	41.29	42.03	42.10
21.25	41.19	46.69	47.73	44.46	50.23	41.25
21.75	52.46	51.62	58.79	58.90	61.45	65.96
22.25	45.52	48.67	54.74	50.46	48.33	43.04
22.75	44.65	46.28	45.35	41.68	46.02	40.88
23.25	53.75	51.99	61.34	55.26	56.41	57.80
23.75	52.04	75.30	94.62	72.50	70.64	75.37
24.25	40.53	39.01	48.89	56.10	63.55	64.63
24.75	57.15	54.39	54.52	42.64	47.04	45.97
25.25	47.04	45.18	47.27	42.03	43.11	40.44
25.75	55.25	52.20	49.46	44.25	46.77	43.94
26.25	67.43	55.63	52.07	41.44	48.12	44.75
26.75	61.28	55.49	58.00	55.66	55.54	54.67
27.25	49.66	49.50	47.14	50.45	51.81	48.35
27.75	45.30	41.59	37.98	50.33	50.45	46.52
28.25	48.35	50.24	42.31	36.51	47.74	45.89
28.75	62.04	50.65	53.28	46.05	46.71	49.81
29.25	58.29	47.64	50.67	46.28	47.25	51.77
29.75	55.36	72.19	73.95	59.49	55.33	48.39
30.25	49.35	42.41	50.66	39.60	43.51	41.97
30.75	47.07	45.56	38.23	33.64	48.62	46.09

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
31.25	44.75	43.26	46.70	38.33	38.18	37.13
31.75	41.79	47.37	39.54	35.92	39.51	40.13
32.25	47.47	55.92	50.99	47.93	60.31	64.43
32.75	36.64	40.90	39.85	42.47	46.17	44.61
33.25	36.39	46.57	39.72	42.76	46.98	46.94
33.75	42.77	44.51	43.01	45.89	48.52	48.92
34.25	47.70	44.98	40.68	40.60	49.64	51.34
34.75	46.27	46.06	47.43	45.44	44.77	46.91
35.25	50.48	47.35	47.96	37.69	47.61	45.16
35.75	52.58	46.63	48.83	33.97	43.51	41.94
36.25	87.44	97.92	79.07	57.52	93.93	89.84
36.75	59.81	51.66	43.83	35.23	56.72	45.43
37.25	46.51	55.71	47.85	36.53	39.97	39.05
37.75	63.34	60.96	59.24	43.40	54.75	45.26
38.25	55.23	51.95	50.08	38.37	48.23	51.11
38.75	56.37	52.58	45.44	39.38	42.74	47.33
39.25	65.29	64.56	65.65	51.89	51.00	54.22
39.75	56.24	52.88	50.21	41.29	42.42	49.07
40.25	64.78	56.94	51.32	46.56	54.08	55.29
40.75	55.45	51.92	50.31	44.65	50.55	47.50
41.25	47.06	31.83	45.63	52.87	43.99	51.48

Appendix A-Continued. 500-meter cell widths for Big River.

	Average Width (m)					
River Km	2018	2007	1990	1970	1954	1937
41.75	59.59	55.99	55.58	51.52	57.48	52.08
42.25	53.84	49.79	49.95	45.15	54.40	49.83
42.75	67.26	62.18	59.08	51.87	42.15	57.86
43.25	51.98	48.20	47.48	40.20	41.87	50.69
43.75	48.95	41.94	41.50	33.92	38.80	42.19
44.25	42.17	39.74	39.08	37.96	39.90	39.22
44.75	47.78	47.73	38.55	31.11	37.91	40.01
45.25	54.06	49.91	43.30	38.29	41.08	38.13
45.75	47.93	45.59	44.05	40.67	44.47	40.14
46.25	46.87	44.19	36.02	33.35	38.38	37.61
46.75	45.77	44.13	33.86	32.49	43.05	37.94
47.25	43.93	45.29	34.92	34.55	35.93	38.12
47.75	60.00	49.14	46.67	54.13	74.52	75.84
48.25	60.42	52.74	47.31	46.09	53.78	57.97
48.75	41.15	33.12	32.78	33.75	37.56	36.36
49.25	39.57	42.01	51.52	49.97	40.48	45.57
49.75	46.39	39.04	41.03	46.80	50.87	49.83
50.25	45.45	39.53	40.30	38.90	41.46	41.95
50.75	44.85	43.19	49.50	46.17	46.09	41.72
51.25	55.44	52.94	67.96	54.33	55.72	40.95
51.75	77.04	83.35	69.39	43.45	38.56	41.79

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
52.25	50.67	54.42	43.33	43.82	44.55	54.26
52.75	68.30	69.72	59.95	47.31	40.76	36.35
53.25	65.23	70.80	61.97	40.16	35.10	34.39
53.75	59.06	49.11	58.78	51.25	48.52	40.17
54.25	48.96	50.76	43.77	39.03	32.88	34.17
54.75	46.14	40.91	45.10	31.23	39.42	38.85
55.25	52.17	48.77	46.32	43.47	42.94	37.02
55.75	85.12	95.15	64.80	43.46	50.93	46.19
56.25	45.09	50.43	40.08	35.89	42.46	47.80
56.75	47.24	56.58	41.92	40.68	38.78	104.15
57.25	28.33	54.34	180.14	110.27	48.76	55.00
57.75	45.03	105.59	90.24	102.14	81.30	81.40
58.25	77.86	68.53	67.68	54.31	62.44	62.88
58.75	66.57	56.63	53.61	50.81	57.52	59.90
59.25	99.11	70.84	57.52	52.63	56.81	60.16
59.75	61.40	52.41	46.44	47.38	46.64	50.65
60.25	58.01	55.94	44.71	32.59	40.46	43.31
60.75	48.36	65.35	60.81	49.93	58.57	66.55
61.25	47.08	40.32	40.26	34.90	37.89	31.28
61.75	39.61	53.96	43.02	38.52	50.44	47.57
62.25	63.95	78.56	57.53	45.27	51.72	68.16

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
62.75	55.26	50.66	47.01	33.12	46.96	50.05
63.25	52.97	49.97	41.10	33.81	32.67	45.15
63.75	53.32	48.73	41.50	37.14	46.04	49.14
64.25	51.90	50.50	41.65	35.46	30.22	41.16
64.75	50.58	43.32	38.56	39.43	33.20	42.72
65.25	46.10	53.62	55.87	38.32	36.44	50.43
65.75	50.20	43.02	38.15	36.67	47.09	42.41
66.25	56.35	53.23	40.75	34.85	51.53	64.68
66.75	41.05	43.08	33.95	31.37	32.32	34.67
67.25	41.46	37.82	36.28	31.02	27.71	25.34
67.75	42.44	37.61	35.97	35.58	34.11	31.04
68.25	42.28	38.97	37.58	40.00	40.20	34.27
68.75	47.43	54.14	41.03	43.66	44.43	43.75
69.25	63.40	88.17	43.34	41.27	38.93	46.44
69.75	54.37	102.20	63.80	39.38	41.11	44.23
70.25	56.52	47.93	53.73	41.98	46.90	32.70
70.75	55.94	50.76	48.73	45.49	43.68	33.18
71.25	63.67	58.91	51.15	52.71	69.76	34.25
71.75	74.66	63.60	53.37	41.40	131.19	82.24
72.25	63.18	86.83	52.70	55.34	58.92	47.31
72.75	62.90	55.23	48.46	38.43	47.10	49.73

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
73.25	60.23	52.31	46.19	36.77	46.62	57.75
73.75	69.04	56.90	49.80	44.46	42.35	58.80
74.25	62.20	54.56	44.06	44.69	39.40	38.79
74.75	76.71	68.41	60.14	33.70	49.21	40.06
75.25	48.66	47.56	36.64	31.92	36.33	41.67
75.75	43.84	46.64	40.73	43.90	36.17	34.40
76.25	46.82	41.00	36.44	40.73	34.46	36.40
76.75	42.24	41.96	42.24	46.10	36.62	39.23
77.25	51.46	49.73	46.14	45.61	37.66	40.08
77.75	54.90	48.59	42.83	42.73	33.48	34.73
78.25	53.07	46.01	29.76	25.58	26.83	39.66
78.75	74.13	70.57	55.37	39.23	30.53	39.20
79.25	43.31	37.54	37.58	25.16	24.29	30.49
79.75	42.23	38.94	35.89	36.04	29.88	30.25
80.25	42.67	40.77	34.45	33.03	33.38	35.39
80.75	53.06	108.31	80.61	68.90	32.92	58.11
81.25	51.37	64.78	50.84	62.12	60.20	51.40
81.75	55.53	46.84	45.82	36.08	39.07	43.86
82.25	65.28	78.96	54.37	50.66	49.22	42.11
82.75	56.41	45.69	33.84	37.31	41.55	42.77
83.25	62.04	56.79	36.52	27.71	39.71	39.74

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
83.75	47.35	50.47	41.07	28.31	30.09	44.13
84.25	72.37	64.89	33.34	44.49	38.88	38.84
84.75	54.45	47.17	41.24	47.64	41.63	43.11
85.25	54.52	46.80	39.17	28.29	37.47	41.95
85.75	39.94	58.28	47.43	46.09	69.29	65.38
86.25	58.34	51.60	47.20	41.45	51.22	40.84
86.75	46.36	41.26	32.51	24.82	54.43	44.32
87.25	46.70	48.60	35.95	38.56	31.19	32.89
87.75	53.00	55.76	37.85	41.80	45.16	50.74
88.25	45.85	70.03	44.44	37.85	56.87	49.57
88.75	68.10	81.85	62.62	39.80	32.99	36.33
89.25	42.57	47.59	48.43	45.42	53.22	45.72
89.75	57.11	48.40	42.05	31.03	30.76	37.42
90.25	63.74	54.56	46.49	39.96	35.03	36.35
90.75	49.40	45.77	41.44	36.39	42.13	43.27
91.25	37.94	51.69	36.57	36.46	35.88	44.43
91.75	73.44	65.31	63.46	50.53	61.06	38.78
92.25	52.72	47.24	39.87	37.05	37.33	40.74
92.75	42.71	51.99	43.09	44.07	33.06	38.87
93.25	55.06	50.50	43.23	32.70	33.83	35.20
93.75	60.48	61.67	42.43	31.09	38.65	48.21

Appendix A-Continued. 500-meter cell widths for Big River.

	Average Width (m)					
River Km	2018	2007	1990	1970	1954	1937
94.25	48.46	46.49	34.97	33.53	41.88	38.93
94.75	51.06	44.12	34.21	35.36	33.15	29.44
95.25	52.10	47.29	37.83	29.50	40.99	45.06
95.75	42.82	55.71	37.93	31.38	32.06	29.82
96.25	71.98	63.32	45.09	43.30	48.70	45.69
96.75	56.95	49.13	67.42	55.81	45.48	35.70
97.25	52.59	45.89	38.94	32.28	36.54	30.43
97.75	53.51	53.32	41.77	32.87	39.06	38.70
98.25	54.34	50.85	57.93	42.91	40.49	42.70
98.75	44.79	53.91	54.08	49.68	29.15	54.34
99.25	46.99	44.51	38.33	30.03	31.31	26.98
99.75	37.91	34.15	31.79	23.25	27.02	26.52
100.25	31.72	31.03	29.97	24.91	29.25	25.03
100.75	38.11	40.71	27.42	32.73	32.04	25.63
101.25	35.53	38.62	36.38	29.96	38.91	27.29
101.75	42.65	45.76	32.82	34.87	30.19	25.18
102.25	41.17	35.61	34.24	34.70	29.77	27.69
102.75	39.95	61.56	56.79	58.87	56.38	28.76
103.25	53.05	55.64	39.47	36.05	37.18	30.52
103.75	33.77	42.39	39.25	33.42	64.80	43.84
104.25	52.03	37.49	39.38	31.21	45.44	31.99

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
104.75	45.08	41.63	32.85	28.40	33.30	35.28
105.25	42.99	37.52	30.16	27.02	27.32	28.93
105.75	37.40	36.93	29.77	25.09	30.97	30.26
106.25	54.37	50.88	39.15	32.35	35.68	50.13
106.75	48.61	45.19	37.64	38.55	38.90	44.14
107.25	40.06	38.60	31.90	24.22	27.92	28.33
107.75	42.15	41.42	35.99	27.80	29.82	28.59
108.25	42.00	36.73	35.40	33.43	30.02	37.77
108.75	49.62	42.91	35.88	32.84	32.10	32.24
109.25	43.38	40.94	34.65	31.92	43.08	33.82
109.75	43.93	53.93	39.24	27.57	33.85	44.20
110.25	50.09	55.27	37.02	31.80	31.36	41.39
110.75	39.86	39.63	32.79	29.76	37.68	35.20
111.25	35.30	38.12	28.83	28.86	36.85	35.35
111.75	49.39	40.36	36.31	33.90	30.10	34.27
112.25	40.70	39.92	32.45	27.50	35.58	39.57
112.75	48.60	43.10	52.94	40.11	43.60	51.44
113.25	45.18	41.17	34.61	36.08	34.77	41.70
113.75	45.60	43.01	36.91	28.82	44.75	46.85
114.25	49.36	46.84	44.70	32.50	41.40	41.12
114.75	47.12	44.76	41.98	29.83	35.90	38.52

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m)					
	2018	2007	1990	1970	1954	1937
115.25	48.14	40.60	32.96	27.67	29.87	33.86
115.75	47.42	41.33	34.26	31.49	35.93	34.53
116.25	52.90	49.45	39.71	27.76	39.84	40.70
116.75	47.34	46.66	40.46	34.19	48.93	45.68
117.25	42.48	43.24	40.64	30.35	34.02	33.12
117.75	42.89	42.52	36.03	28.71	45.50	35.39
118.25	51.07	49.01	40.87	35.25	48.65	46.33
118.75	42.33	41.40	43.46	36.98	31.21	44.93
119.25	46.46	44.87	41.26	36.22	44.28	33.27
119.75	47.34	47.70	33.11	38.93	36.64	38.29
120.25	42.42	41.93	34.59	24.65	36.24	29.97
120.75	55.21	58.62	48.72	39.08	51.01	49.16
121.25	47.86	48.13	43.77	40.85	40.40	39.72
121.75	43.91	42.32	35.52	28.75	38.95	41.08
122.25	65.97	53.01	56.13	35.46	43.18	59.05
122.75	47.20	49.98	36.51	35.14	36.69	40.94
123.25	54.15	60.75	54.74	29.11	34.35	41.15
123.75	46.64	43.69	40.09	31.51	34.43	33.20
124.25	45.84	48.22	35.20	29.98	33.58	39.61
124.75	43.58	36.39	37.57	22.30	34.69	26.29
125.25	57.96	46.48	44.33	32.57	44.27	47.34

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
125.75	48.85	46.26	36.66	29.31	32.19	33.76
126.25	51.94	44.78	47.12	32.47	37.06	39.06
126.75	46.13	41.86	36.51	26.43	35.36	35.15
127.25	45.07	43.82	36.28	27.21	40.05	38.09
127.75	48.33	40.19	34.70	30.48	37.29	34.66
128.25	48.15	37.87	35.62	29.97	31.73	27.60
128.75	53.55	40.23	39.44	33.45	32.00	34.66
129.25	38.08	35.60	23.61	21.95	31.80	30.31
129.75	37.44	34.40	21.41	21.90	24.98	29.83
130.25	48.12	37.64	36.54	26.29	35.34	34.74
130.75	40.98	40.67	33.32	31.66	49.28	32.44
131.25	32.61	30.61	29.92	26.96	29.38	33.16
131.75	41.98	32.10	32.89	36.78	31.27	32.35
132.25	46.56	40.77	43.60	17.83	26.07	42.09
132.75	34.63	31.33	23.64	18.84	19.90	29.11
133.25	49.06	51.87	32.28	23.04	26.78	28.15
133.75	105.08	46.75	91.02	25.86	25.71	32.56
134.25	75.36	73.68	69.15	35.83	40.16	52.66
134.75	39.22	48.50	34.16	27.20	33.42	42.54
135.25	39.17	34.95	32.30	24.89	27.01	42.69
135.75	39.33	35.54	34.48	18.66	30.26	32.10

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
136.25	45.57	43.25	41.99	29.36	36.60	36.53
136.75	38.34	32.45	32.34	19.65	29.01	33.47
137.25	49.19	45.04	32.78	21.56	24.08	24.82
137.75	37.04	34.86	27.34	17.49	23.15	33.27
138.25	44.30	37.85	41.66	25.61	36.43	32.18
138.75	41.92	34.65	34.42	23.85	30.21	23.74
139.25	43.96	38.82	30.60	23.79	21.83	26.75
139.75	39.43	33.09	31.69	18.20	35.49	35.47
140.25	44.22	35.13	43.84	26.53	36.77	37.54
140.75	37.73	28.55	37.56	29.04	45.47	34.78
141.25	46.26	39.32	30.60	19.79	31.20	40.36
141.75	38.46	28.09	33.15	20.86	30.67	43.87
142.25	50.70	50.99	40.81	19.03	45.30	55.37
142.75	43.29	40.03	39.61	17.05	39.40	43.63
143.25	42.70	42.49	34.69	32.86	34.52	42.47
143.75	39.52	31.70	26.12	30.54	26.68	29.75
144.25	40.48	40.03	37.77	33.30	33.20	40.42
144.75	42.31	34.93	38.55	21.55	24.45	29.81
145.25	36.66	33.05	27.48	21.41	23.83	30.47
145.75	33.32	29.52	30.16	22.74	24.01	27.92
146.25	31.29	33.15	30.59	22.06	28.10	29.75

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
146.75	38.19	34.03	27.68	22.63	25.62	27.56
147.25	31.97	28.58	28.48	24.59	22.10	7.95
147.75	33.29	36.35	38.28	18.55	31.31	14.29
148.25	33.55	31.40	25.80	18.61	32.47	29.08
148.75	39.87	35.72	32.04	16.23	28.04	40.97
149.25	32.85	31.31	30.21	31.02	24.99	41.29
149.75	42.55	32.80	24.28	16.96	25.33	38.00
150.25	49.05	45.42	32.77	26.56	27.50	20.27
150.75	34.70	31.12	28.94	24.55	23.15	N/A
151.25	34.70	36.17	35.40	45.63	46.18	N/A
151.75	42.57	38.65	40.13	32.30	33.24	N/A
152.25	34.19	30.11	24.70	15.73	21.15	10.85
152.75	42.22	37.23	28.34	26.39	28.06	43.73
153.25	41.79	41.48	32.28	26.17	26.27	40.96
153.75	34.50	26.76	30.31	20.83	26.77	36.20
154.25	33.46	29.89	27.80	24.09	22.16	36.61
154.75	37.26	34.07	33.30	28.07	39.06	30.22
155.25	50.27	45.15	46.12	29.13	58.26	2.47
155.75	41.44	40.50	32.48	29.36	33.00	29.96
156.25	39.01	37.11	33.56	33.84	25.00	30.52
156.75	41.17	40.57	37.82	31.31	26.34	41.75

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
157.25	38.35	34.22	27.55	27.45	30.49	48.58
157.75	39.77	35.96	33.53	27.50	31.94	46.16
158.25	38.96	36.66	27.83	31.23	35.08	44.00
158.75	41.76	32.58	28.53	32.16	30.37	46.88
159.25	41.50	38.33	37.88	41.19	32.90	41.32
159.75	56.95	58.58	54.00	52.95	36.57	66.78
160.25	35.77	32.95	35.24	26.44	43.01	40.57
160.75	37.82	31.69	34.74	31.72	35.87	38.78
161.25	66.50	61.20	65.95	29.22	32.22	37.50
161.75	72.51	66.43	60.05	43.34	39.40	45.75
162.25	38.31	37.68	32.41	28.01	35.26	35.58
162.75	33.77	33.79	28.62	17.40	27.68	29.57
163.25	40.21	39.56	34.94	26.61	35.82	38.68
163.75	39.60	41.07	39.25	20.78	37.67	36.54
164.25	50.06	37.87	31.23	31.03	33.89	32.75
164.75	37.43	34.03	28.45	34.17	39.34	41.82
165.25	52.69	49.73	40.66	41.67	48.30	52.81
165.75	42.47	47.14	40.77	33.06	46.54	40.84
166.25	60.65	64.65	58.20	40.86	92.06	44.11
166.75	40.31	40.13	39.00	23.54	42.14	34.24
167.25	36.41	37.35	35.40	23.58	32.72	42.55

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
167.75	36.83	33.16	31.10	26.22	32.50	41.02
168.25	34.87	39.36	31.22	21.56	31.01	40.46
168.75	33.86	34.70	23.55	33.07	27.31	33.87
169.25	35.07	37.26	30.87	36.52	32.35	45.76
169.75	34.42	38.08	29.03	22.33	28.31	35.93
170.25	34.81	35.65	28.80	27.37	35.22	45.21
170.75	43.73	45.19	38.31	30.77	40.46	50.10
171.25	50.60	52.15	49.66	45.19	44.86	48.40
171.75	42.03	41.97	34.48	32.90	27.59	38.28
172.25	78.55	61.27	56.84	37.65	53.16	46.42
172.75	175.07	41.08	171.27	46.23	45.35	53.18
173.25	56.23	55.94	44.31	20.52	22.66	39.33
173.75	50.47	41.28	36.55	31.68	34.06	51.53
174.25	82.86	34.73	32.96	30.71	32.09	50.23
174.75	49.65	44.65	42.66	38.82	45.22	55.77
175.25	41.36	37.31	30.81	37.31	32.62	39.57
175.75	76.22	40.58	34.84	24.44	37.56	71.65
176.25	39.10	41.19	30.35	29.81	35.03	39.30
176.75	37.32	30.56	27.03	20.13	22.91	37.99
177.25	70.47	60.03	44.47	22.78	29.72	63.42
177.75	31.85	33.22	30.29	24.75	27.04	42.72

Appendix A-Continued. 500-meter cell widths for Big River.

River Km	Average Width (m) 2018	2007	1990	1970	1954	1937
178.25	41.01	42.68	40.20	19.38	30.13	37.54
178.75	65.22	36.81	25.89	19.62	35.34	27.20
179.25	55.21	51.86	24.53	26.13	50.48	49.25
179.75	46.16	44.48	27.00	31.81	33.30	47.00
180.25	62.93	57.58	40.62	23.36	43.53	41.92
180.75	69.40	74.85	64.74	27.05	77.29	108.41
181.25	56.23	60.14	57.26	37.82	52.23	79.29
181.75	36.30	35.49	37.33	33.64	36.16	49.57
182.25	36.55	34.44	33.47	29.26	32.56	151.08
182.75	40.60	42.21	42.63	48.09	47.87	187.98
183.25	40.36	38.12	36.03	30.38	25.53	58.39
183.75	37.63	34.15	29.69	29.30		82.33
184.25	62.60	63.70	54.09	31.74		125.12
184.75	34.98	35.09	28.31	28.14		39.31
185.25	36.42	36.63	71.65	59.42		36.07
185.75	44.29	22.29	37.47	40.23		6.08
186.25	83.01		50.09	62.69		

Appendix B. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
0.5	-0.40	0.33	0.16	-0.06	0.24
1	0.07	0.27	-0.19	-0.31	1.26
1.5	0.49	-0.33	-0.16	0.04	0.92
2	0.33	-0.24	-0.03	0.14	0.74
2.5	-0.19	0.25	-0.10	0.16	0.84
3	-0.09	0.40	-0.21	-0.31	1.62
3.5	0.22	-0.18	-0.03	0.02	0.37
4	0.16	-0.25	0.14	0.05	0.37
4.5	0.40	-0.12	-0.09	0.64	0.22
5	-0.35	0.38	0.27	-0.15	0.48
5.5	0.41	-0.29	0.33	-0.04	0.72
6	0.06	0.06	0.41	-0.09	0.67
6.5	0.27	-0.13	0.60	0.13	0.24
7	-0.13	0.20	-0.05	0.29	0.70
7.5	-0.23	-0.24	0.32	0.00	0.48
8	0.41	0.23	0.07	0.65	-0.88
8.5	0.20	0.13	0.18	0.11	0.59
9	-0.12	-0.49	0.41	-0.01	0.41
9.5	0.24	-0.40	0.55	-0.18	0.62
10	-0.23	0.03	0.17	0.20	0.24

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
21	0.00	-0.04	0.18	-0.04	-0.03
21.5	0.53	-0.29	0.20	-0.06	-0.50
22	-0.26	-0.13	-0.01	-0.42	0.08
22.5	0.31	0.11	0.27	-0.36	-0.29
23	0.30	-0.22	0.23	0.05	-0.15
23.5	-0.08	-0.06	0.38	-0.55	0.16
24	-0.28	0.09	1.38	-1.14	-2.12
24.5	-0.06	-0.37	-0.45	-0.58	0.14
25	0.06	-0.22	0.74	-0.01	0.25
25.5	0.16	-0.05	0.33	-0.12	0.17
26	0.17	-0.13	0.33	0.16	0.28
26.5	0.20	-0.33	0.66	0.21	1.07
27	0.05	0.01	0.15	-0.15	0.53
27.5	0.20	-0.07	-0.21	0.14	0.01
28	0.23	-0.01	-0.77	0.21	0.34
28.5	0.11	-0.56	0.36	0.47	-0.17
29	-0.18	-0.03	0.45	-0.15	1.04
29.5	-0.27	-0.05	0.27	-0.18	0.97
30	0.41	0.21	0.90	-0.10	-1.53
30.5	0.09	-0.20	0.69	-0.49	0.63
31	0.15	-0.75	0.29	0.43	0.14

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
31.5	0.06	0.01	0.52	-0.20	0.14
32	-0.04	-0.18	0.23	0.46	-0.51
32.5	-0.24	-0.62	0.19	0.29	-0.77
33	0.09	-0.18	-0.16	0.06	-0.39
33.5	0.00	-0.21	-0.19	0.40	-0.93
34	-0.02	-0.13	-0.18	0.09	-0.16
34.5	-0.10	-0.45	0.01	0.25	0.25
35	-0.13	0.03	0.12	-0.08	0.02
35.5	0.14	-0.50	0.64	-0.04	0.29
36	0.09	-0.48	0.93	-0.13	0.54
36.5	0.24	-1.82	1.35	1.11	-0.95
37	0.66	-1.07	0.54	0.46	0.74
37.5	0.05	-0.17	0.71	0.46	-0.84
38	0.56	-0.57	0.99	0.10	0.22
38.5	-0.17	-0.49	0.73	0.11	0.30
39	-0.27	-0.17	0.38	0.42	0.34
39.5	-0.19	0.04	0.86	-0.06	0.07
40	-0.39	-0.06	0.56	0.16	0.31
40.5	-0.07	-0.38	0.30	0.33	0.71
41	0.18	-0.29	0.35	0.09	0.32
41.5	-0.44	0.44	-0.45	-0.81	1.38

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
42	0.32	-0.30	0.25	0.02	0.33
42.5	0.27	-0.46	0.30	-0.01	0.37
43	-0.92	0.49	0.45	0.18	0.46
43.5	-0.52	-0.08	0.45	0.04	0.34
44	-0.20	-0.24	0.47	0.03	0.64
44.5	0.04	-0.10	0.07	0.04	0.22
45	-0.12	-0.34	0.46	0.54	0.00
45.5	0.17	-0.14	0.31	0.39	0.38
46	0.25	-0.19	0.21	0.09	0.21
46.5	0.05	-0.25	0.17	0.48	0.24
47	0.30	-0.53	0.09	0.60	0.15
47.5	-0.13	-0.07	0.02	0.61	-0.12
48	-0.08	-1.02	-0.47	0.15	0.99
48.5	-0.25	-0.38	0.08	0.32	0.70
49	0.07	-0.19	-0.06	0.02	0.73
49.5	-0.30	0.47	0.10	-0.56	-0.22
50	0.06	-0.20	-0.36	-0.12	0.67
50.5	-0.03	-0.13	0.09	-0.05	0.54
51	0.26	0.00	0.21	-0.37	0.15
51.5	0.87	-0.07	0.85	-0.88	0.23
52	-0.19	0.24	1.62	0.82	-0.57

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
52.5	-0.57	-0.04	-0.03	0.65	-0.34
53	0.26	0.33	0.79	0.57	-0.13
53.5	0.04	0.25	1.36	0.52	-0.51
54	0.49	0.14	0.47	-0.57	0.90
54.5	-0.08	0.31	0.30	0.41	-0.16
55	0.03	-0.41	0.87	-0.25	0.48
55.5	0.35	0.03	0.18	0.14	0.31
56	0.28	-0.37	1.33	1.79	-0.91
56.5	-0.31	-0.33	0.26	0.61	-0.49
57	-3.85	0.10	0.08	0.86	-0.85
57.5	-0.37	3.08	4.37	-7.40	-2.37
58	-0.01	1.04	-0.74	0.90	-5.51
58.5	-0.03	-0.41	0.84	0.05	0.85
59	-0.14	-0.34	0.18	0.18	0.90
59.5	-0.20	-0.21	0.31	0.78	2.57
60	-0.24	0.04	-0.06	0.35	0.82
60.5	-0.17	-0.39	0.76	0.66	0.19
61	-0.47	-0.43	0.68	0.27	-1.54
61.5	0.39	-0.15	0.34	0.00	0.61
62	0.17	-0.60	0.28	0.64	-1.30
62.5	-0.97	-0.29	0.88	1.24	-1.33

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
63	-0.18	-0.63	0.99	0.21	0.42
63.5	-0.73	0.05	0.52	0.52	0.27
64	-0.18	-0.40	0.31	0.43	0.42
64.5	-0.64	0.24	0.44	0.52	0.13
65	-0.56	0.28	-0.06	0.28	0.66
65.5	-0.82	0.09	1.25	-0.13	-0.68
66	0.28	-0.47	0.11	0.29	0.65
66.5	-0.77	-0.76	0.42	0.73	0.28
67	-0.14	-0.04	0.18	0.54	-0.18
67.5	0.14	0.15	0.38	0.09	0.33
68	0.18	0.07	0.03	0.10	0.44
68.5	0.35	-0.01	-0.17	0.08	0.30
69	0.04	-0.03	-0.19	0.77	-0.61
69.5	-0.44	0.11	0.15	2.64	-2.25
70	-0.18	-0.08	1.74	2.26	-4.35
70.5	0.84	-0.22	0.84	-0.34	0.78
71	0.62	0.08	0.23	0.12	0.47
71.5	2.09	-0.77	-0.11	0.46	0.43
72	2.88	-4.08	0.86	0.60	1.01
72.5	0.68	-0.16	-0.19	2.01	-2.15
73	-0.16	-0.39	0.72	0.40	0.70

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
73.5	-0.65	-0.45	0.67	0.36	0.72
74	-0.97	0.10	0.38	0.42	1.10
74.5	0.04	0.24	-0.05	0.62	0.70
75	0.54	-0.70	1.89	0.49	0.75
75.5	-0.31	-0.20	0.34	0.64	0.10
76	0.10	0.35	-0.23	0.35	-0.25
76.5	-0.11	0.28	-0.31	0.27	0.53
77	-0.15	0.43	-0.28	-0.02	0.03
77.5	-0.14	0.36	0.04	0.21	0.16
78	-0.07	0.42	0.01	0.34	0.57
78.5	-0.75	-0.06	0.30	0.96	0.64
79	-0.51	0.40	1.15	0.89	0.32
79.5	-0.36	0.04	0.89	0.00	0.52
80	-0.02	0.28	-0.01	0.18	0.30
80.5	-0.12	-0.02	0.10	0.37	0.17
81	-1.48	1.64	0.84	1.63	-5.02
81.5	0.52	0.09	-0.81	0.82	-1.22
82	-0.28	-0.14	0.70	0.06	0.79
82.5	0.42	0.07	0.27	1.45	-1.24
83	-0.07	-0.19	-0.25	0.70	0.97
83.5	0.00	-0.55	0.63	1.19	0.48

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
84	-0.83	-0.08	0.91	0.55	-0.28
84.5	0.00	0.25	-0.80	1.86	0.68
85	-0.09	0.27	-0.46	0.35	0.66
85.5	-0.26	-0.42	0.78	0.45	0.70
86	0.23	-1.05	0.10	0.64	-1.67
86.5	0.61	-0.44	0.41	0.26	0.61
87	0.59	-1.35	0.55	0.51	0.46
87.5	-0.10	0.33	-0.19	0.74	-0.17
88	-0.33	-0.15	-0.28	1.05	-0.25
88.5	0.43	-0.86	0.47	1.51	-2.20
89	-0.20	0.31	1.63	1.13	-1.25
89.5	0.44	-0.35	0.22	-0.05	-0.46
90	-0.39	0.01	0.79	0.37	0.79
90.5	-0.08	0.22	0.47	0.47	0.83
91	-0.07	-0.26	0.36	0.25	0.33
91.5	-0.50	0.03	0.01	0.89	-1.25
92	1.31	-0.48	0.92	0.11	0.74
92.5	-0.20	-0.01	0.20	0.43	0.50
93	-0.34	0.50	-0.07	0.52	-0.84
93.5	-0.08	-0.05	0.75	0.43	0.41
94	-0.56	-0.34	0.81	1.13	-0.11

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
94.5	0.17	-0.38	0.10	0.68	0.18
95	0.22	0.10	-0.08	0.58	0.63
95.5	-0.24	-0.52	0.59	0.56	0.44
96	0.13	-0.03	0.47	1.05	-1.17
96.5	0.18	-0.25	0.13	1.07	0.79
97	0.58	0.47	0.83	-1.08	0.71
97.5	0.36	-0.19	0.48	0.41	0.61
98	0.02	-0.28	0.64	0.68	0.02
98.5	-0.13	0.11	1.07	-0.42	0.32
99	-1.48	0.93	0.31	-0.01	-0.83
99.5	0.25	-0.06	0.59	0.36	0.23
100	0.03	-0.17	0.61	0.14	0.34
100.5	0.25	-0.20	0.36	0.06	0.06
101	0.38	0.03	-0.38	0.78	-0.24
101.5	0.68	-0.41	0.46	0.13	-0.28
102	0.29	0.21	-0.15	0.76	-0.28
102.5	0.12	0.22	-0.03	0.08	0.51
103	1.62	0.11	-0.15	0.28	-1.96
103.5	0.39	-0.05	0.24	0.95	-0.24
104	1.23	-1.43	0.42	0.18	-0.78
104.5	0.79	-0.65	0.58	-0.11	1.32

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
105	-0.12	-0.22	0.32	0.52	0.31
105.5	-0.09	-0.01	0.22	0.43	0.50
106	0.04	-0.27	0.33	0.42	0.04
106.5	-0.85	-0.15	0.49	0.69	0.32
107	-0.31	-0.02	-0.06	0.44	0.31
107.5	-0.02	-0.17	0.55	0.39	0.13
108	0.07	-0.09	0.59	0.32	0.07
108.5	-0.46	0.15	0.14	0.08	0.48
109	-0.01	0.03	0.22	0.41	0.61
109.5	0.54	-0.51	0.20	0.37	0.22
110	-0.61	-0.29	0.83	0.86	-0.91
110.5	-0.59	0.02	0.37	1.07	-0.47
111	0.15	-0.36	0.22	0.40	0.02
111.5	0.09	-0.36	0.00	0.55	-0.26
112	-0.25	0.17	0.17	0.24	0.82
112.5	-0.23	-0.37	0.35	0.44	0.07
113	-0.46	-0.16	0.92	-0.58	0.50
113.5	-0.41	0.06	-0.10	0.39	0.36
114	-0.12	-0.72	0.58	0.36	0.24
114.5	0.02	-0.40	0.87	0.13	0.23
115	-0.15	-0.28	0.87	0.16	0.21

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
115.5	-0.23	-0.10	0.38	0.45	0.69
116	0.08	-0.20	0.20	0.42	0.55
116.5	-0.05	-0.55	0.85	0.57	0.31
117	0.19	-0.67	0.45	0.36	0.06
117.5	0.05	-0.17	0.73	0.15	-0.07
118	0.59	-0.76	0.52	0.38	0.03
118.5	0.14	-0.61	0.40	0.48	0.19
119	-0.81	0.26	0.46	-0.12	0.09
119.5	0.65	-0.37	0.36	0.21	0.14
120	-0.10	0.10	-0.42	0.86	-0.03
120.5	0.37	-0.53	0.71	0.43	0.04
121	0.11	-0.54	0.69	0.58	-0.31
121.5	0.04	0.02	0.21	0.26	-0.02
122	-0.13	-0.46	0.48	0.40	0.14
122.5	-0.93	-0.35	1.48	-0.18	1.18
123	-0.25	-0.07	0.10	0.79	-0.25
123.5	-0.40	-0.22	2.14	0.35	-0.60
124	0.07	-0.12	0.71	0.21	0.27
124.5	-0.35	-0.15	0.44	0.77	-0.22
125	0.49	-0.52	1.27	-0.07	0.65
125.5	-0.18	-0.49	0.98	0.13	1.04

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
126	-0.09	-0.12	0.61	0.56	0.24
126.5	-0.12	-0.19	1.22	-0.14	0.65
127	0.01	-0.37	0.84	0.31	0.39
127.5	0.12	-0.54	0.76	0.44	0.11
128	0.15	-0.28	0.35	0.32	0.74
128.5	0.24	-0.07	0.47	0.13	0.94
129	-0.16	0.06	0.50	0.05	1.21
129.5	0.09	-0.41	0.14	0.71	0.23
130	-0.29	-0.13	-0.04	0.76	0.28
130.5	0.04	-0.38	0.85	0.06	0.95
131	0.99	-0.73	0.14	0.43	0.03
131.5	-0.22	-0.10	0.25	0.04	0.18
132	-0.06	0.23	-0.32	-0.05	0.90
132.5	-0.94	-0.34	2.15	-0.17	0.53
133	-0.54	-0.04	0.40	0.45	0.30
133.5	-0.08	-0.16	0.77	1.15	-0.26
134	-0.40	0.01	5.43	-2.60	5.30
134.5	-0.74	-0.18	2.78	0.27	0.15
135	-0.54	-0.26	0.58	0.84	-0.84
135.5	-0.92	-0.09	0.62	0.16	0.38
136	-0.11	-0.48	1.32	0.06	0.34

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
136.5	0.00	-0.30	1.05	0.07	0.21
137	-0.26	-0.39	1.06	0.01	0.54
137.5	-0.04	-0.11	0.93	0.72	0.38
138	-0.60	-0.24	0.82	0.44	0.20
138.5	0.25	-0.45	1.34	-0.22	0.59
139	0.38	-0.27	0.88	0.01	0.66
139.5	-0.29	0.08	0.57	0.48	0.47
140	0.00	-0.72	1.12	0.08	0.58
140.5	-0.04	-0.43	1.44	-0.51	0.83
141	0.63	-0.68	0.71	-0.53	0.83
141.5	-0.54	-0.48	0.90	0.51	0.63
142	-0.78	-0.41	1.02	-0.30	0.94
142.5	-0.59	-1.09	1.82	0.60	-0.03
143	-0.25	-0.93	1.88	0.03	0.30
143.5	-0.47	-0.07	0.15	0.46	0.02
144	-0.18	0.16	-0.37	0.33	0.71
144.5	-0.42	0.00	0.37	0.13	0.04
145	-0.32	-0.12	1.42	-0.21	0.67
145.5	-0.39	-0.10	0.51	0.33	0.33
146	-0.23	-0.05	0.62	-0.04	0.35
146.5	-0.10	-0.25	0.71	0.15	-0.17

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
147	-0.11	-0.12	0.42	0.37	0.38
147.5	0.83	0.10	0.32	0.01	0.31
148	1.00	-0.53	1.64	-0.11	-0.28
148.5	0.20	-0.58	0.60	0.33	0.20
149	-0.76	-0.49	1.32	0.22	0.38
149.5	-0.96	0.25	-0.07	0.06	0.14
150	-0.75	-0.35	0.61	0.50	0.89
150.5	0.43	-0.04	0.52	0.74	0.33
151	N/A	0.06	0.37	0.13	0.33
151.5	N/A	-0.02	-0.85	0.05	-0.13
152	N/A	-0.04	0.65	-0.09	0.36
152.5	0.61	-0.23	0.75	0.32	0.37
153	-0.92	-0.07	0.16	0.52	0.45
153.5	-0.86	0.00	0.51	0.54	0.03
154	-0.56	-0.25	0.79	-0.21	0.70
154.5	-0.85	0.08	0.31	0.12	0.32
155	0.52	-0.46	0.44	0.05	0.29
155.5	3.28	-1.21	1.42	-0.06	0.47
156	0.18	-0.15	0.26	0.47	0.09
156.5	-0.32	0.37	-0.02	0.21	0.17
157	-0.91	0.21	0.54	0.16	0.05

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
157.5	-1.06	-0.13	0.01	0.39	0.38
158	-0.84	-0.18	0.50	0.14	0.35
158.5	-0.52	-0.16	-0.28	0.52	0.21
159	-0.97	0.07	-0.30	0.24	0.84
159.5	-0.49	0.35	-0.28	0.03	0.29
160	-1.78	0.68	0.09	0.27	-0.15
160.5	0.14	-0.69	0.73	-0.13	0.26
161	-0.17	-0.17	0.25	-0.18	0.56
161.5	-0.31	-0.13	3.06	-0.28	0.48
162	-0.37	0.16	1.39	0.38	0.55
162.5	-0.02	-0.30	0.37	0.31	0.06
163	-0.11	-0.43	0.94	0.30	0.00
163.5	-0.17	-0.38	0.69	0.27	0.06
164	0.07	-0.70	1.54	0.11	-0.13
164.5	0.07	-0.12	0.02	0.39	1.11
165	-0.15	-0.22	-0.48	0.33	0.31
165.5	-0.27	-0.28	-0.08	0.53	0.27
166	0.34	-0.56	0.64	0.37	-0.42
166.5	2.82	-2.13	1.45	0.38	-0.36
167	0.46	-0.77	1.29	0.07	0.02
167.5	-0.58	-0.38	0.98	0.11	-0.09

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
168	-0.50	-0.26	0.41	0.12	0.33
168.5	-0.56	-0.39	0.81	0.48	-0.41
169	-0.39	0.24	-0.79	0.66	-0.08
169.5	-0.79	0.17	-0.47	0.38	-0.20
170	-0.45	-0.25	0.56	0.53	-0.33
170.5	-0.59	-0.33	0.12	0.40	-0.08
171	-0.57	-0.40	0.63	0.40	-0.13
171.5	-0.21	0.01	0.37	0.15	-0.14
172	-0.63	0.22	0.13	0.44	0.01
172.5	0.40	-0.65	1.60	0.26	1.57
173	-0.46	0.04	10.42	-7.66	12.18
173.5	-0.98	-0.09	1.98	0.68	0.03
174	-1.03	-0.10	0.41	0.28	0.84
174.5	-1.07	-0.06	0.19	0.10	4.38
175	-0.62	-0.27	0.32	0.12	0.45
175.5	-0.41	0.20	-0.54	0.38	0.37
176	-2.01	-0.55	0.87	0.34	3.24
176.5	-0.25	-0.22	0.04	0.64	-0.19
177	-0.89	-0.12	0.58	0.21	0.61
177.5	-1.98	-0.29	1.81	0.92	0.95
178	-0.92	-0.10	0.46	0.17	-0.12

Appendix B-Continued. Rate of width change per 500 meter cell.

	Change in width (m/yr)				
R-Km	1937-1954	1954-1970	1970-1990	1990-2007	2007-2018
178.5	-0.44	-0.45	1.73	0.15	-0.15
179	0.48	-0.65	0.52	0.64	2.58
179.5	0.07	-1.01	-0.13	1.61	0.30
180	-0.81	-0.06	-0.40	1.03	0.15
180.5	0.09	-0.84	1.44	1.00	0.49
181	-1.83	-2.09	3.14	0.60	-0.50
181.5	-1.59	-0.60	1.62	0.17	-0.35
182	-0.79	-0.10	0.31	-0.11	0.07
182.5	-6.97	-0.14	0.35	0.06	0.19
183	-8.24	0.01	-0.45	-0.02	-0.15
183.5	-1.93	0.20	0.47	0.12	0.20
184	-4.84	1.22	0.03	0.26	0.32
184.5	-7.36	1.32	1.86	0.57	-0.10
185	-2.31	1.17	0.01	0.40	-0.01
185.5	-2.12	2.48	1.02	-2.06	-0.02
186	-0.36	1.68	-0.23	-0.89	2.00
186.5	0.00	2.61	-1.05	-2.95	7.55
Percent of wider cells	30.65%	20.64%	70.40%	66.04%	65.24%
Sd.Dev	0.94	0.53	0.84	0.75	1.07

Appendix C. Big River average reach width.

2018												
Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	55.83	26.46	39.73	49.65	64.08	82.94	175.07	31.85	47.40
1	171	16	42.73	9.48	36.72	39.68	42.78	63.28	72.51	33.77	22.19
2	155	10.5	37.16	4.61	33.46	34.70	41.79	42.57	49.05	31.29	12.41
3	144.5	12	46.04	14.56	39.21	42.31	45.74	71.66	105.08	34.63	31.62
4	132.5	17	47.02	6.12	43.06	46.92	48.72	56.17	65.97	32.61	13.01
5	115.5	16.5	43.55	5.69	39.93	43.18	48.60	52.49	54.37	31.72	13.07
6	99	26.5	54.13	9.59	46.70	53.06	60.23	72.80	76.71	37.94	17.72
7	72.5	20.5	55.28	12.96	47.08	52.97	63.18	77.86	99.11	28.33	23.45
8	52	17	54.15	10.13	46.60	53.21	59.76	70.68	87.44	39.57	18.70
9	35	18	49.56	6.87	45.16	48.85	54.10	61.47	67.43	36.39	13.85
10	17	17	49.46	8.66	44.78	47.13	52.25	69.18	73.44	36.15	17.51

Appendix C-Continued. Big River average reach width.

				2007							
Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	44.22	11.60	35.77	41.23	52.08	62.61	74.85	22.29	26.23
1	171	16	41.20	9.18	35.41	37.98	42.09	62.75	66.43	31.69	22.29
2	155	10.5	33.89	4.32	31.12	33.15	36.17	41.48	45.42	26.76	12.74
3	144.5	12	39.96	9.59	34.26	38.33	43.69	51.74	73.68	28.09	24.01
4	132.5	17	43.60	6.48	40.34	42.88	47.44	54.97	60.75	30.61	14.86
5	115.5	16.5	42.63	6.58	38.48	41.29	44.87	55.44	61.56	31.03	15.44
6	99	26.5	53.76	12.11	46.80	50.50	56.79	73.93	108.31	37.54	22.52
7	72.5	20.5	58.35	16.89	48.77	53.62	65.35	95.15	105.59	37.61	28.95
8	52	17	50.96	12.46	44.15	49.47	52.92	71.14	97.92	31.83	24.45
9	35	18	49.49	7.22	45.37	48.15	51.71	59.98	75.30	39.01	14.58
10	17	17	42.29	6.87	37.62	40.13	44.45	55.41	62.45	33.83	16.25

Appendix C-Continued. Big River average reach width.

1990

Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	44.11	25.92	30.58	37.33	47.07	68.20	171.27	24.53	58.76
1	171	16	36.78	9.92	30.41	34.15	39.06	59.04	65.95	23.55	26.97
2	155	10.5	30.84	4.30	27.80	30.21	32.77	38.55	40.13	24.28	13.95
3	144.5	12	38.08	13.94	32.13	34.29	39.91	65.35	91.02	23.64	36.61
4	132.5	17	38.37	7.01	34.82	36.60	41.16	50.83	56.13	21.41	18.26
5	115.5	16.5	36.51	6.14	32.71	35.94	39.17	48.41	56.79	27.42	16.82
6	99	26.5	44.32	9.72	37.58	42.24	47.43	62.96	80.61	29.76	21.93
7	72.5	20.5	52.30	22.99	41.10	46.32	57.52	67.68	180.14	33.95	43.96
8	52	17	48.68	10.29	41.95	47.67	51.07	68.46	79.07	32.78	21.14
9	35	18	49.67	10.43	43.79	47.58	51.52	64.49	94.62	37.98	20.99
10	17	17	42.08	7.54	37.62	40.11	44.56	54.36	68.75	31.53	17.92

Appendix C-Continued. Big River average reach width.

					1970						
Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	32.93	10.57	25.44	30.71	37.74	53.76	59.42	19.38	32.11
1	171	16	30.79	7.27	26.57	30.06	33.26	42.42	52.95	17.40	23.60
2	155	10.5	24.13	6.50	20.83	22.74	26.39	32.30	45.63	15.73	26.94
3	144.5	12	24.28	5.33	19.49	23.82	27.66	33.23	35.83	17.05	21.93
4	132.5	17	30.65	5.29	27.35	30.41	34.90	38.98	40.85	17.83	17.27
5	115.5	16.5	31.82	6.27	28.25	31.51	33.55	39.25	58.87	23.25	19.69
6	99	26.5	39.27	8.78	32.87	38.43	44.46	52.72	68.90	24.82	22.36
7	72.5	20.5	44.46	15.48	35.89	40.68	47.31	55.34	110.27	31.02	34.81
8	52	17	42.47	7.27	36.82	40.98	46.74	54.20	57.52	31.11	17.11
9	35	18	46.01	7.50	41.94	44.36	48.53	59.05	72.50	33.64	16.30
10	17	17	39.34	7.80	33.60	38.19	43.43	52.20	63.54	29.19	19.82

Appendix C-Continued. Big River average reach width.

1954											
Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	38.17	11.90	30.13	35.03	45.22	52.97	77.29	22.66	31.18
1	171	16	37.16	11.97	31.71	34.48	39.35	52.78	92.06	25.00	32.23
2	155	10.5	27.80	5.86	24.01	26.27	28.10	39.06	46.18	21.15	21.10
3	144.5	12	31.80	6.75	26.76	30.93	36.47	44.53	49.28	19.90	21.22
4	132.5	17	37.25	6.44	32.53	36.08	40.31	49.05	51.01	24.98	17.29
5	115.5	16.5	36.16	8.16	30.17	34.31	38.90	50.36	64.80	27.02	22.56
6	99	26.5	40.09	9.15	33.38	38.65	45.16	58.20	69.29	24.29	22.83
7	72.5	20.5	47.37	17.08	38.78	44.43	50.93	69.76	131.19	27.71	36.05
8	52	17	47.76	11.28	42.15	43.75	53.09	63.45	93.93	35.93	23.61
9	35	18	48.93	6.86	45.71	47.54	50.28	61.98	70.64	37.89	14.02
10	17	17	40.19	5.95	37.52	40.01	42.44	52.14	54.47	28.49	14.81

Appendix C-Continued. Big River average reach width.

1937											
Segment	R-km	length (km)	Average width (m)	Standard Deviation	25%	50%	75%	95%	Max	Min	CV
0	186.5	15.5	60.14	37.22	39.31	48.83	62.17	139.39	187.98	6.08	61.89
1	171	16	40.09	9.96	35.84	40.74	45.34	51.32	66.78	2.47	24.84
2	155	10.5	29.77	10.29	27.65	30.02	37.65	41.66	43.73	7.95	34.58
3	144.5	12	36.43	7.92	31.51	35.13	42.49	51.34	55.37	23.74	21.74
4	132.5	17	37.58	6.76	33.17	35.27	41.05	47.97	59.05	26.29	17.98
5	115.5	16.5	34.95	7.51	28.52	34.05	41.19	48.33	51.44	25.03	21.49
6	99	26.5	41.75	7.66	36.40	40.08	44.43	57.89	65.38	29.44	18.36
7	72.5	20.5	48.18	15.72	36.35	45.15	54.26	81.40	104.15	25.34	32.62
8	52	17	47.60	10.78	41.11	45.35	51.01	64.22	89.84	36.36	22.64
9	35	18	47.78	8.33	42.07	45.93	49.14	64.96	75.37	37.13	17.43
10	17	17	40.11	6.93	35.46	38.27	44.88	53.15	58.28	28.50	17.28

Appendix D. Averge bar width for the reaches of Big River.

				2018							
Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	19.98	26.26	4.08	13.72	25.75	41.67	138.34	0.35	131.45
1	171	16	8.35	8.89	3.14	4.41	9.31	28.76	31.84	0.16	106.48
2	155	10.5	5.53	3.86	2.59	4.68	7.24	12.12	14.04	0.71	69.72
3	144.5	12	10.48	14.46	4.12	4.60	8.54	38.80	60.15	0.24	137.92
4	132.5	17	4.48	3.84	1.53	3.22	6.58	12.58	15.61	0.50	85.78
5	115.5	16.5	5.40	4.10	2.21	4.64	8.40	11.09	16.88	1.02	75.90
6	99	26.5	15.60	17.94	3.75	10.15	20.62	61.59	78.63	1.22	114.95
7	72.5	20.5	16.43	21.64	2.68	7.73	15.91	65.24	94.74	0.53	131.76
8	52	17	11.09	8.29	4.37	9.36	16.21	27.02	29.37	0.52	74.78
9	35	18	7.29	10.31	2.40	3.72	8.32	18.61	47.03	0.97	141.47
10	17	17	7.28	7.02	1.48	5.79	10.70	16.88	28.74	0.10	96.42

Appendix D-Continued. Averge bar width for the reaches of Big River.

2007

Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	11.44	11.31	2.64	5.97	18.86	28.32	44.88	0.32	98.84
1	171	16	9.36	9.37	2.71	6.12	12.03	29.07	40.90	0.05	100.10
2	155	10.5	5.64	4.07	2.79	4.58	7.16	13.18	18.61	0.79	72.12
3	144.5	12	10.66	10.26	3.35	8.90	14.05	24.70	43.04	0.28	96.21
4	132.5	17	7.35	6.41	2.68	5.95	9.18	22.00	27.32	0.95	87.14
5	115.5	16.5	7.58	7.30	2.35	4.62	11.00	22.01	27.59	0.49	96.29
6	99	26.5	14.73	14.83	4.30	8.54	18.00	42.79	65.48	0.16	100.69
7	72.5	20.5	16.31	16.68	4.47	10.44	21.65	48.91	63.57	0.30	102.27
8	52	17	11.57	10.46	4.45	10.17	12.90	31.89	42.18	0.90	90.37
9	35	18	7.63	7.61	2.70	5.98	8.36	19.91	35.44	0.79	99.77
10	17	17	7.10	6.52	3.82	4.46	10.46	17.77	24.67	0.04	91.82

Appendix D-Continued. Averge bar width for the reaches of Big River.

1990

Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	16.35	27.18	3.62	6.52	16.09	44.64	133.20	133.20	166.28
1	171	16	8.88	10.50	2.15	4.69	8.44	28.20	41.60	0.36	118.28
2	155	10.5	6.08	4.24	3.04	5.80	7.94	13.03	14.32	0.06	69.74
3	144.5	12	11.40	16.59	3.24	4.75	9.44	47.49	60.33	0.06	145.56
4	132.5	17	5.30	5.70	1.78	3.10	6.37	18.26	22.52	0.04	107.61
5	115.5	16.5	5.85	7.59	1.79	2.63	6.21	21.22	27.74	0.19	129.71
6	99	26.5	10.74	10.10	2.41	4.77	10.49	28.37	45.63	0.00	94.04
7	72.5	20.5	18.53	25.89	2.98	13.82	21.63	44.64	121.28	0.31	139.76
8	52	17	9.20	8.36	4.87	6.55	9.94	25.99	33.11	0.95	90.88
9	35	18	25.44	33.70	5.39	7.69	31.99	86.13	110.06	0.85	132.46
10	17	17	8.52	8.27	2.00	7.25	10.29	25.04	25.20	0.07	97.12

Appendix D-Continued. Averge bar width for the reaches of Big River.

1970											
Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	10.58	10.19	1.57	8.84	15.12	31.76	34.04	0.23	0.96
1	171	16	10.80	7.58	5.75	9.56	12.65	26.03	35.50	0.51	0.70
2	155	10.5	6.26	4.96	2.73	4.36	7.89	16.01	20.30	0.39	0.79
3	144.5	12	7.19	4.08	4.51	6.28	9.36	12.95	18.38	0.95	0.57
4	132.5	17	5.20	3.66	2.53	4.47	7.20	13.51	15.16	0.64	0.70
5	115.5	16.5	4.87	6.00	1.94	2.51	4.79	14.15	25.38	0.51	1.23
6	99	26.5	8.58	8.82	2.27	4.65	11.25	25.32	35.89	0.25	1.03
7	72.5	20.5	9.54	12.89	2.94	6.13	10.52	39.85	54.64	0.71	1.35
8	52	17	6.84	5.16	2.61	4.95	10.92	13.16	19.53	0.78	0.75
9	35	18	16.10	28.39	2.69	6.86	12.77	65.67	121.58	0.07	1.76
10	17	17	7.69	7.55	2.68	5.66	9.39	19.61	31.21	0.95	0.98

Appendix D-Continued. Averge bar width for the reaches of Big River.

1954

Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	10.74	7.95	9.20	17.20	22.96	24.92	25.41	0.02	0.74
1	171	16	9.99	11.69	2.24	6.75	13.10	27.17	60.00	0.56	1.17
2	155	10.5	3.74	3.45	1.20	3.52	4.25	8.34	14.94	0.13	0.92
3	144.5	12	6.39	4.65	1.49	5.85	9.47	12.49	18.27	0.95	0.73
4	132.5	17	6.93	6.32	2.71	4.29	11.22	19.32	21.49	0.23	0.91
5	115.5	16.5	5.42	7.44	1.08	3.03	5.73	23.02	30.43	0.00	1.37
6	99	26.5	9.72	8.82	3.56	5.30	13.31	29.18	31.16	0.95	0.91
7	72.5	20.5	14.74	16.50	3.98	11.59	18.32	41.92	79.16	79.16	1.12
8	52	17	9.64	10.12	2.26	7.13	11.63	33.50	34.84	34.84	1.05
9	35	18	5.49	4.32	2.33	3.84	9.38	12.33	13.34	13.34	0.79
10	17	17	3.95	4.47	1.82	2.53	3.69	11.83	17.18	17.18	1.13

Appendix D-Continued. Averge bar width for the reaches of Big River.

1937											
Segment	R-km	length (km)	Average width	Standard Deviation	25%	50%	75%	95%	Max	Min	CV%
0	186.5	15.5	25.66	21.40	11.04	21.55	33.21	65.71	86.88	0.54	0.83
1	171	16	13.22	9.35	7.15	11.17	17.31	26.43	40.50	0.15	0.71
2	155	10.5	4.45	2.79	2.09	4.21	6.00	8.72	11.22	0.95	0.63
3	144.5	12	7.73	16.70	2.07	5.08	12.33	23.41	29.73	0.35	2.16
4	132.5	17	7.50	9.47	2.31	5.30	8.96	16.21	46.48	0.18	1.26
5	115.5	16.5	8.96	6.68	3.59	6.78	12.14	22.26	23.77	0.00	0.75
6	99	26.5	11.30	9.29	3.79	8.56	15.66	30.03	33.87	0.10	0.82
7	72.5	20.5	19.11	19.05	3.72	11.88	26.30	54.52	80.44	0.95	1.00
8	52	17	11.25	12.83	1.91	9.75	12.79	37.66	50.09	0.01	1.14
9	35	18	5.49	4.13	3.24	4.63	6.32	13.84	14.43	0.15	0.75
10	17	17	5.11	4.84	1.89	4.42	5.51	13.24	19.62	0.49	0.95

Appendix E-1. Change in flow of the Ozark Gages.

Region	Gage	Gage #	Ad (km^2)	Elev (m)	Flood Freq Change Ratio			
					2yr	10yr	50yr	100yr
Arkansas River Basin	Big Cabin Creek near Big Cabin, OK	07191000	1165	190	1.19	0.88	0.75	0.71
	Illinois River near Tahlequah, OK	07196500	2460	203	1.15	0.99	0.98	0.99
	Spring River near Quapaw, OK	07188000	6516	227	1.42	1.47	1.43	1.40
Mississippi River Basin-Arkansas River	Elk River near Tiff City, MO	07189000	2204	229	1.33	1.21	1.09	1.05
	Shoal Creek above Joplin, MO	07187000	1106	270	1.10	0.99	0.91	0.88
	Spring River near Waco, MO	07186000	3015	254	1.39	1.38	1.40	1.41
Mississippi River Basin-Meramec River	Big River at Byrnesville, MO	07018500	2375	132	1.37	1.49	1.48	1.46
	Big River near Richwoods, MO	07018100	1904	159	1.39	1.41	1.24	1.16

Appendix E-1-Continued. Change in flow of the Ozark Gages.

Region	Gage	Gage #	Ad (km^2)	Elev (m)	Flood Freq Change Ratio			
					2yr	10yr	50yr	100yr
Mississippi River Basin-Meramec River	Meramec River near Eureka, MO	07019000	9811	123	1.41	1.37	1.41	1.44
	Meramec River near Steelville, MO	07013000	2023	208	1.18	1.23	1.29	1.31
Mississippi River Basin-St. Francis River	St. Francis River near Patterson, MO	07037500	2476	113	1.10	1.29	1.80	1.98
Mississippi River Basin-White River	Bryant Creek near Tecumseh, MO	07058000	1476	175	1.37	2.15	2.78	3.04
	Current River at Doniphan, MO	07068000	5278	98	1.18	1.40	1.66	1.78
	Current River at Van Buren, MO	07067000	4318	135	1.02	1.09	1.19	1.24
	Eleven Point River near Bardley, MO	07071500	2054	125	0.97	1.38	1.94	2.23

Appendix E-1-Continued. Change in flow of the Ozark Gages.

Region	Gage	Gage #	Ad (km^2)	Elev (m)	Flood Freq Change Ratio			
					2yr	10yr	50yr	100yr
Mississippi River Basin-White River	Jacks Fork at Eminence, MO	07066000	1031	188	1.17	1.38	1.77	1.98
	James River at Galena, MO	07052500	2556	281	1.29	1.44	1.68	1.79
Missouri River Basin-Gasconade River	Gasconade River at Jerome, MO	06933500	7356	201	1.31	1.63	1.68	1.67
	Little Piney Creek at Newburg, MO	06932000	518	211	1.58	1.16	0.88	0.78
Missouri River Basin-Osage River	Cedar Creek near Pleasant View, MO	06919500	1088	225	1.30	1.24	1.08	1.02
White River Basin	Eleven Point River near Ravenden Springs, AR	07072000	2927	89	1.06	1.68	2.57	3.08
	Kings River near Berryville, AR	07050500	1365	294	1.05	0.96	1.02	1.06

Appendix E-1-Continued. Change in flow of the Ozark Gages.

Region	Gage	Gage #	Ad (km^2)	Elev (m)	Flood Freq Change Ratio			
					2yr	10yr	50yr	100yr
White River Basin	Spring River at Imboden, AR	07069500	3056	80	1.08	1.07	1.21	1.29
	Strawberry River near Poughkeepsie, AR	07074000	1225	91	1.09	0.91	0.83	0.80

Appendix E-2. Ozark gage image river width analysis.

Gage #	Reach	Pre - Channel Width			Post - Channel Width			Width Change				
		Date	Mean (m)	Cv%	Date	Mean (m)	Cv%	(m)	Cv%	% change	% change/ year	m/year
07191000	1	Feb-95	36.3	16.0	Mar-15	40.4	10.6	4.1	123.8	13.6	0.67	0.21
	2		42.9	14.2		44.8	12.0	1.9	67.6	4.8	0.24	0.09
07196500	1	Mar-95	89.4	17.9	Mar-17	95.6	20.7	6.2	116.8	6.6	0.30	0.28
	2		68.5	16.2		71.3	17.1	2.8	153.6	4.2	0.19	0.13
07188000	1	Mar-95	87.6	8.8	Mar-15	88.7	8.7	1.1	253.1	1.3	0.07	0.06
	2		97.2	29.6		103.2	29.1	6.0	61.1	6.6	0.33	0.30
07189000	1	Feb-96	57.9	17.9	Mar-16	64.9	22.6	7.1	97.7	11.7	0.58	0.35
	2		74.8	21.0		86.0	18.3	11.3	104.7	16.7	0.83	0.56
07187000	1	Mar-96	42.7	16.8	Mar-16	46.8	14.8	4.1	100.6	10.3	0.51	0.20
	2		52.5	13.3		53.7	13.2	1.2	126.4	2.4	0.12	0.06
07186000	1	Feb-96	44.6	11.7	Mar-16	48.2	9.6	3.6	51.3	8.4	0.42	0.18
	2		47.3	20.5		50.9	21.4	3.6	71.6	7.6	0.38	0.18
07018500	1	Apr-92	49.2	13.6	Apr-16	50.7	11.5	1.2	437.9	3.8	0.16	0.05
	2	Mar-96	51.1	9.4		52.4	12.0	1.2	260.8	2.3	0.11	0.06

Appendix E-2-Continued. Ozark gage image river width analysis.

Gage #	Reach	Pre - Channel Width			Post - Channel Width			Width Change				
		Date	Mean (m)	Cv%	Date	Mean (m)	Cv%	(m)	Cv%	% change	% change/ year	m/year
07018100	1	Mar-96	51.7	35.9	Nov-13	55.1	37.0	3.4	121.9	6.3	0.36	0.19
	2	Mar-96	55.7	11.9	Nov-13	58.2	18.5	2.5	211.8	3.8	0.21	0.14
07019000	1	Mar-96	99.4	7.1	Apr-16	104.0	8.0	4.6	148.3	4.7	0.24	0.23
	2		94.5	6.5		95.9	6.4	1.4	175.7	1.5	0.08	0.07
07013000	1	Apr-96	48.2	11.1	Oct-14	47.6	10.0	-0.6	-1063.7	-0.3	-0.02	-0.03
	2		43.5	9.3		44.1	8.5	0.6	499.1	1.6	0.09	0.03
07037500	1	Mar-96	51.5	17.1	Nov-15	53.2	16.2	1.7	197.6	3.5	0.18	0.08
	2		78.7	5.1		84.6	4.9	5.9	94.8	8.0	0.40	0.30
07058000	1	Mar-95	59.3	18.8	Apr-15	63.5	17.4	4.2	69.7	7.7	0.38	0.21
	2		54.6	9.8		57.8	8.2	3.3	118.9	6.4	0.32	0.16
07068000	1	Apr-95	93.2	12.3	Sep-16	97.5	11.6	4.3	113.1	4.8	0.23	0.20
	2		85.5	10.7		94.1	10.9	8.6	107.1	10.7	0.50	0.40
07067000	1	Apr-95	92.9	23.5	Sep-16	99.3	23.1	6.4	121.3	7.3	0.34	0.30
	2	Feb-95	92.4	26.0		95.4	29.8	3.0	302.0	2.2	0.10	0.14

Appendix E-2-Continued. Ozark gage image river width analysis.

Gage #	Reach	Pre - Channel Width			Post - Channel Width			Width Change				
		Date	Mean (m)	Cv%	Date	Mean (m)	Cv%	(m)	Cv%	% change	% change/ year	m/year
07071500	1	Mar-96	82.6	39.9	Mar-16	91.2	36.9	8.6	71.7	12.1	0.60	0.43
	2	Apr-95	50.9	25.1		54.1	27.5	3.2	118.1	6.0	0.29	0.15
07066000	1	Feb-95	56.8	15.0	Oct-14	54.7	13.4	-2.1	-344.1	-2.8	-0.14	-0.11
	2	Mar-96	44.6	28.6		47.7	24.6	3.1	100.2	8.1	0.43	0.17
07052500	1	Mar-97	66.6	9.5	Feb-17	71.2	10.5	4.5	99.9	6.9	0.35	0.23
	2		78.1	32.8		80.3	36.1	2.2	203.5	2.0	0.10	0.11
06933500	1	Apr-95	122.1	20.3	Oct-16	136.2	17.7	14.1	25.7	12.1	0.56	0.65
	2		90.5	22.0		91.6	22.2	1.1	496.3	1.5	0.07	0.05
06932000	1	Feb-95	24.9	13.1	Oct-16	26.4	13.8	1.6	171.2	6.7	0.31	0.07
06919500	1	Mar-96	26.0	9.3	Nov-13	29.4	12.6	3.4	66.5	12.8	0.72	0.19
	2		29.9	12.3		33.5	11.8	3.6	64.7	12.3	0.70	0.20
07072000	1	Feb-94	51.7	16.4	May-13	54.9	16.1	3.1	96.8	6.1	0.32	0.16
	2		55.2	24.1		60.0	23.6	4.8	134.1	9.3	0.48	0.25
07050500	1	Mar-94	54.6	11.0	Apr-19	63.9	11.4	9.3	98.5	18.1	0.72	0.37

Appendix E-2-Continued. Ozark gage image river width analysis.

Gage #	Reach	Pre - Channel Width			Post - Channel Width			Width Change				
		Date	Mean (m)	Cv%	Date	Mean (m)	Cv%	(m)	Cv%	% change	% change/ year	m/year
07050501	2		62.7	23.3		78.4	22.2	15.7	59.3	25.9	1.03	0.62
07069500	1	Feb-94	57.9	21.6	Mar-16	59.7	20.5	1.8	138.2	3.4	0.15	0.08
	2		62.1	19.4		62.9	22.1	0.8	333.8	0.9	0.04	0.04
07074000	1	Feb-94	44.3	25.3	Nov-20	47.2	19.3	2.9	113.8	8.0	0.30	0.11
	2		38.7	10.2		42.0	12.9	3.3	105.5	8.5	0.32	0.12

Appendix F. Google Earth pro image proofing.

Site	Object	Image 1	Image 2	Difference (m)	Mean (m)	CV%
		Mar-96	Apr-16			
Meramec River near Eureka, MO	building	26.66	25.44	-1.22		
	bridge width	34.36	34.73	0.37		
	building	89.23	89.61	0.38	-0.16	-479.94
		Mar-95	Apr-15			
Byrant Creek-Tecumseh	building	9.83	9.31	-0.52		
	building	11.87	11.1	-0.77		
	building	19.09	19.16	0.07	-0.41	-86.60
		Apr-95	Oct-16			
Gasconade River at Jerome, MO	building	24.03	23.53	-0.50		
	building	19.61	18.7	-0.91		
	building	20.29	20.3	0.01	-0.47	-80.64
		Feb-94	May-13			
Eleven Point River near Ravenden Springs, AR	bridge width	9.53	8.92	-0.61		
	building	24.04	23.72	-0.32		
	building	26.08	26.21	0.13	-0.27	-114.17
		Feb-95	Oct-16			
Little Piney Creek at Newburg, MO	building	20.13	20.65	0.52		
	building	18.17	17.8	-0.37		
	building	23.93	22.8	-1.13	-0.33	-206.42
		Mar-95	Mar-17			
Illinois River near Tahlequah, OK	building	14.33	13.85	-0.48		
	building	17.34	17.69	0.35		
	building	16.66	16.95	0.29	0.05	708.60

Appendix F-Continued. Google Earth pro image proofing.

Site	Object	Image 1	Image 2	Difference (m)	Mean (m)	CV%
		Mar-96	Mar-16			
Shoal Creek above Joplin, MO	bridge width	7.94	8.18	0.24		
	building	28.04	27.87	-0.17		
	building	28.67	28.65	-0.02	0.02	1016.27
		Feb-94	Nov-20			
Strawberry River near Poughkeepsie, AR	bridge	9.83	9.46	-0.37		
	building	30.46	30.9	0.44		
	building	15.24	15.54	0.3	0.12	286.61
		Apr-95	Sep-16			
Current River at Van Buren, MO	building	25.95	26.28	0.33		
	building	18.15	18.86	0.71		
	building	39.16	38.68	-0.48	0.19	265.86
		Mar-94	Apr-19			
Kings River near Berryville, AR	building	44.03	44.02	-0.01		
	building	17.63	17.13	-0.50		
	pond	64.75	64.44	-0.31	-0.27	-73.80
		Mar-96	Nov-13			
Cedar Creek near Pleasant View, MO	building	9.29	8.59	-0.7		
	building	17.83	17.26	-0.57		
	building	11.53	11.9	0.37	-0.30	-158.91
		Mar-95	Mar-15			
Spring River near Quapaw, OK	bridge	10.16	10.44	0.28		
	building	17.98	17.72	-0.26		
	building	16.35	15.95	-0.4	-0.13	-231.46

Appendix F-Continued. Google Earth pro image proofing.

Site	Object	Image 1	Image 2	Difference (m)	Mean (m)	CV%
		Apr-95	Sep-16			
Current River at Doniphan, MO	building	149.15	148.36	-0.79		
	building	32.13	32.63	0.50		
	bridge	14.45	14.09	-0.36	-0.22	-247.53
		Feb-96	Mar-16			
Spring River near Waco, MO	building	23.2	23.71	0.51		
	building	18.89	18.29	-0.60		
	building	19.47	19.46	-0.01	-0.03	-1360.37
		Mar-97	Feb-17			
James River at Galena, MO	building	18.99	18.78	-0.21		
	bridge	7.95	7.52	-0.43		
	building	14.41	14.2	-0.21	-0.28	-36.60
		Mar-96	Nov-15			
St. Francis River near Patterson, MO	bridge	9.25	8.89	-0.36		
	building	18.24	18.57	0.33		
	building	23	22.66	-0.34	-0.12	-259.99
		Mar-96	Mar-16			
Eleven Point River near Bardley, MO	bridge	8.04	7.48	-0.56		
	building	14.16	13.86	-0.30		
	building	13.18	13.15	-0.03	-0.30	-72.94
		Feb-96	Mar-16			
Elk River near Tiff City, MO	building	65.99	66.25	0.26		
	building	18.92	18.38	-0.54		
	building	11.35	11.38	0.03	-0.08	-403.54

Appendix F-Continued. Google Earth pro image proofing.

Site	Object	Image 1	Image 2	Difference (m)	Mean (m)	CV%
Meramec River near Steelville, MO		Apr-96	Oct-14			
	building	23.89	24.78	0.89		
	building	14.82	14.42	-0.40		
	building	44.96	45.25	0.29	0.26	202.72
Jacks Fork at Eminence, MO		Feb-95	Oct-14			
	baseball field	110.25	109.44	-0.81		
	building	17.29	17.63	0.34		
	building	57.09	57.87	0.78	0.10	648.72
Spring River at Imboden, AR		Feb-94	Mar-16			
	building	43.33	43.32	-0.01		
	building	61.88	62.19	0.31		
	building	59.5	58.63	-0.87	-0.19	-262.24
Big Cabin Creek near Big Cabin, OK		Feb-95	Mar-15			
	bridge	8.65	8.99	0.34		
	building	17.16	16.93	-0.23		
	building	12.81	12.57	-0.24	-0.04	-625.59
Big River at Byrnesville, MO		Apr-92	Apr-16			
	building	31.09	31.44	0.35		
	building	23.66	23.3	-0.36		
	building	18.3	17.88	-0.42	-0.14	-243.98
Big River near Richwoods, MO		Mar-96	Nov-13			
	bridge	7.32	7.46	0.14		
	pond	143.53	143.58	0.05		
	pond	32.97	32.51	-0.46	-0.09	-293.55