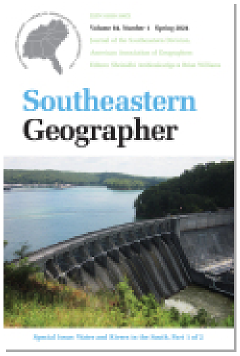
Spatial and Temporal Characteristics of Channel Disturbance Zones in Big River, Southeast Missouri (1937–2018)



Marc R. Owen, Robert T. Pavlowsky, Derek J. Martin

Southeastern Geographer, Volume 64, Number 1, Spring 2024, pp. 30-53 (Article)

Published by The University of North Carolina Press
DOI: *https://doi.org/10.1353/sgo.2024.a920706*

Spatial and Temporal Characteristics of Channel Disturbance Zones in Big River, Southeast Missouri (1937–2018)

MARC R. OWEN
Ozarks Environmental and Water Resources Institute, Missouri State University

ROBERT T. PAVLOWSKY
School of Earth, Environment, and Sustainability, Ozarks Environmental and Water Resources Institute, Missouri State University

DEREK J. MARTIN
Department of Geography and Planning, Appalachian State University

HIGHLIGHTS:

- Disturbance zones occur along 24% of the 182 km channel at intervals of one per 2.5 km.
- Over 80 percent of disturbance zones were formed before 1937.
- Disturbance zones and stable reaches exhibited both enlargement and contraction from 1937 to 1976.
- Since 1976, the active channel area has increased in all disturbance zones and stable reaches.
- Peak annual flood magnitude and frequency has increased after 1973 in Big River.

ABSTRACT: *Ozarks watersheds have responded to land clearing and settlement disturbances by transporting large amounts of gravel and sediment to main valleys of medium-large river systems. Historical gravel and sediment accumulate in disturbance zones, which are areas of excessive channel activity that can be detected over time using historical aerial photographs. This project uses a series of aerial photos from 1937–2018 to identify disturbance zones in the Big River of southeast Missouri, which has a history of lead mining and ore processing that has caused widespread contamination of the channel and floodplain deposits. Variations in active areas of the historical meander belt show that disturbance zones account for 24 percent of the channel length at an interval of one per 2.5 km of channel. Megabars and extensions are the most prominent types of disturbance zones, but translations and cutoffs are larger with higher potential for sediment storage. From 1937 to 1976, areas of channel activity have cycled between expansion and contraction. However, after a period of recovery prior to 1976, disturbance zone areas have been expanding over the last 40 years likely in response to an increase in flood magnitude and frequency from more high intensity rainfall events since 1973.*

KEYWORDS: historical channel change, aerial photo analysis, climate change

https://doi.org/10.1353/sgo.0.a913116

SOUTHEASTERN GEOGRAPHER, 64(1) 2024: pp. 30–53

INTRODUCTION

Historical landscape disturbances during Euro-American settlement and agricultural expansion beginning in the early 1800s substantially modified the form and behavior of stream channels and floodplains throughout North America including the Mississippi River and its Midwestern tributaries (Knox 1972, Knox 2006, Kemp et al. 2020). Soil and vegetation disturbances increased runoff and soil erosion thus producing larger floods, higher sediment yields, and increased sedimentation rates on floodplains in medium- to large-sized watersheds (Lecce and Pavlowsky 2001, Owen et al. 2011). With the emphasis on soil erosion and siltation due to concerns about soil conservation, most early studies focused on understanding increased rates of suspended sediment delivery and deposition as the result of accelerated soil and bank erosion (Knox 1972, Trimble and Lund 1982). Hence, research in fluvial geomorphology aimed at explaining the deposition rates, history, and spatial distribution of post-settlement overbank alluvium or legacy sediment on floodplains (James 2013). Historical land disturbances also caused lateral channel adjustments such as the formation of enlarged meander belts that contained larger floods, increased stream power, and optimized sediment transport capacity (Lecce 1997, Owen et al. 2011). However, much less attention was given to understanding the response of bed sediment loads and related channel adjustments to watershed disturbances in the Eastern USA.

Anthropogenic activities as a cause of increased sediment supply and adjustments in channel form and bed sediment were recognized early on in mountain streams in the Western USA (James 1989, Buffington 2012). A few studies in the Midwest described how channel systems were destabilized by increased supplies of coarser sediment caused by incision and the uneven balance of erosion/deposition along the channel bed. For example, lowering of base-level by channelization practices and dam construction resulted in bed incision, unstable banks, and downstream sedimentation in river systems within the Loess Hills region in the Missouri and Illinois River basins (Simon and Rinaldi 2000). Other studies also elaborated on the processes and form changes caused by channelization (Urban and Rhoads 2003, Jerin et al. 2023). However, these streams were primarily affected by direct manipulation of the channel itself by human activities, and not solely by the hydrological effects of vegetation and soil disturbances on uplands.

A good example from the Eastern USA describing how widespread land clearing and soil disturbance influenced river channel formation through coarse sediment inputs and bar deposition is found in the unglaciated Ozark Highlands of southern Missouri. River systems in this region were affected by hydrological change, excess gravel loads, and altered channel morphology due to land clearing and soil disturbances beginning more than 180 years ago (Jacobson and Primm 1994; Jacobson, 1995). Land use changes beginning in the early to middle 1800s including timber harvesting, row crop cultivation, and livestock grazing increased runoff and soil erosion rates causing headwater streams to incise and widen and release higher loads of gravelly sediment to downstream river segments (Jacobson and Primm 1994). Based on the interpretation of historical documents, channel instability in the Ozarks was related to the downstream migration of bed sediment pulses with maximum effect from 1890 to 1910 and generally ending by 1940 (Saucier 1983, Jacobson and Prim 1994, Jacobson 1995, Jacobson and Gran 1999, Panfil and Jacobson 2001). Historical and, to some degree, contemporary bed sediment transport in Ozark rivers has generally been described as large gravel bars slowly migrating downstream during large flood events in a wave-like process with bar size and mobility attenuating downstream or over time as tributary gravel inputs decrease (Jacobson 1995, Jacobson and Gran 1999). However, a recent study indicated a downstream shift in the locus of greatest gravel storage over a period of 30 years in two major Ozark River systems (Erwin et al. 2021).

While sediment wave translation suggests the progressive movement of peak bar deposition and channel aggradation downstream (James 2006), locations of channel instability and excess bar deposition are distributed non-uniformly in Ozark Rivers (Jacobson 1995, Panfil and Jacobson 2001, Martin and Pavlowsky 2011, Erwin et al. 2021). Thus, while the interpretation of gravel sediment waves as an indicator of bedload transport and the major driver of bar deposition and channel instability is plausible, the effects of other hydrological variables or local factors such as variable source inputs, valley width, and lateral channel adjustments on channel response is not clear (Martin and Pavlowsky 2011, Erwin et al. 2021). Ozark river channels tend to migrate laterally slowly, develop a sinuous planform with relatively straight stable segments, and concentrate geomorphic activity within discrete reaches identified by wider channels with active bank erosion and extensive bar deposits (Panfil and Jacobson 2001). These types of dynamic reaches have been previously described as active reaches, disturbance reaches, sedimentation zones, or disturbance zones (Saucier 1983, Church 1983, Jacobson 1995, Martin and Pavlowsky 2011). For this study, “disturbance zone” will refer to these features.

Disturbance zones are spatially persistent and can remain active in the same location for relatively long periods of up to 100 years or longer within an individual’s reach. Stratigraphic evidence indicates that some were present prior to settlement (Jacobson 1995, Jacobson and Gran 1999). However, both historical and present-day channel, bar, and floodplain deposits tend to contain more gravel than older, pre-settlement deposits (Saucier 1983). The size of a disturbance zone can vary over periods of several decades or longer due to the expansion and contraction of active channel deposits related to the passage of gravel pulses or bed waves and remobilization by large floods (Jacobson 1995, Erwin et al. 2021). In general, channel adjustments in Ozark rivers are limited vertically by shallow bedrock and laterally by bedrock bluffs, strath terraces, and narrow valleys in general (Saucier 1983, Shepherd et al. 2011). Disturbance zones tend to form in flow separation zones at channel bends near bedrock bluffs and below tributary confluences and where gravel supply is high in areas with chert-rich carbonate bedrock, more cleared land, and higher road density (Jacobson and Gran 1999, Panfil and Jacobson 2001).

The anthropogenic impacts on disturbance zones and their spatial distribution, geomorphic characteristics, and sediment pulse behavior are generally understood (Jacobson 1995, Jacobson and Gran 1999, Pavlowsky and Martin 2011, Erwin et al. 2021). However, the formation and spatial distribution of different forms and how their activity has changed from the settlement period to the present (2018) are poorly understood.

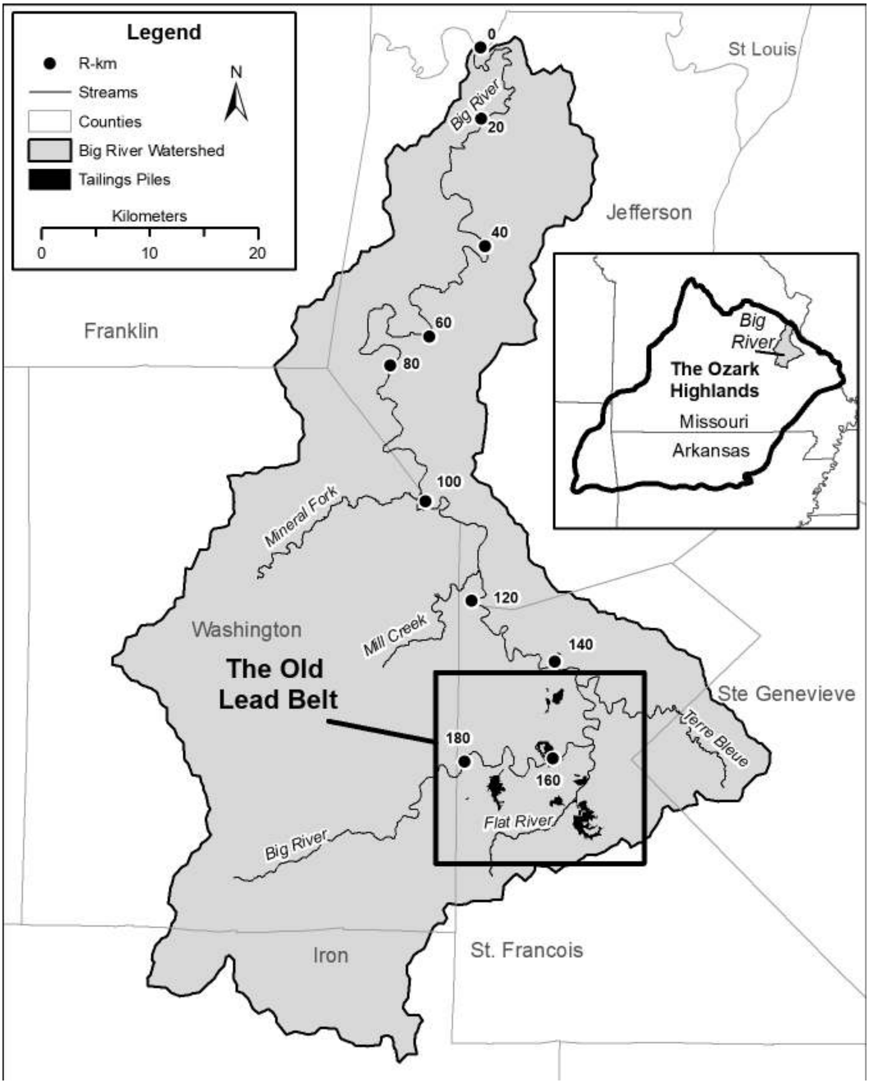


Figure 1. Big River Watershed in SE Missouri.

The purpose of this study is to assess, classify, and evaluate the spatial and temporal distribution of disturbance zone formation along the Big River draining into the eastern Ozark Highlands (Figure 1). Historical aerial photographs from the 1930s to present are used to identify historical stable reaches and disturbance zones for geomorphic analysis in Big River (Kondolf and Larson 2006). Quantifying the spatial and temporal patterns of disturbance zones will help to improve our understanding of the nature and importance of the fluvial processes that influence gravel bar formation and the role that sediment waves may play as a control on channel morphology in Big River.

Big River was affected by early settlement and agricultural land use peaking between 1870 and 1910 leading to large floods and increased gravel loads in tributaries and the main channel (Jacobson and Prim 1994). In addition, Big River drained the Old Lead Belt which was a global producer of lead (Pb) from six large mines generally located within the vicinity of the confluence of Big River with Flat River Creek in St. Francois County (Pavlowsky et al. 2017) (Figure 1). Between 1894 and 1972 large quantities of metalliferous sand- and fine gravel-sized mill waste were discharged into Big River until the early 1930s when froth flotation milling began and tailings ponds with dams were installed (Pavlowsky et al. 2017). Channel bed and floodplain deposits are currently contaminated with Pb for over 170 km extending from Leadwood, Missouri to the mouth at Eureka, Missouri south of St. Louis (Pavlowsky et al. 2017). It is not clear to what degree that the finer inputs of mining sediment have influenced disturbance zones (Jacobson 1995). Therefore, the Big River offers an opportunity to investigate the effects of two different types of historical bed sediment inputs on disturbance zone activity. Further, the results of this study can help understand variability in contaminated sediment storage and potential remobilization to guide remediation efforts.

The downstream migration of large sediment pulses can persist for decades to centuries due to remobilization during channel aggradation and incision cycles as well as augmentation by the reworking of stored sediment by periodic flood events (James 1989, James 2006). Understanding the spatial and temporal characteristics of historical channel change, gravel storage, and the future trajectory is critical to management efforts aimed at protecting aquatic resources in the Big River (Montgomery 1999, Bracken et al. 2014). Further, efforts to mitigate sediment contamination from past mining activities and restore endangered mussel habitat require a better understanding of sediment dynamics over a range of temporal and spatial scales (Roberts et al. 2022). The specific objectives of this study are to: (i) use the historical locations of the active channel to classify areas of stability versus disturbance based on abrupt changes in width; (ii) evaluate the downstream distribution and temporal variations in the location, size, and adjustment of the four different types of disturbance zones within the historical active belt; and (iii) compare temporal channel changes to historical land use, flood, and rainfall records for the area.

STUDY AREA

The Big River (2,512 km^2) is a low-gradient, riffle-pool Ozarks stream with a gravely bed and floodplains composed mainly of silt-loam overbank deposits of variable age and thickness over buried channel bar deposits (Pavlowsky et al. 2017). The watershed primarily drains the Salem Plateau of the Ozark Highlands before it flows into the Meramec River near Eureka, Missouri. The headwaters of the river begin in the St. Francois Mountains which are composed of Precambrian igneous rocks (Brown 1981). However, most of the drainage area of the Big River is underlain by Paleozoic dolomite with some limestone and shale units. Sandstones do outcrop locally in the southeastern and northern portions of the basin. In general, bed elevations of Ozark rivers are bedrock controlled as localized exposures occur on the channel bed in many reaches along the Big River and bedrock bluffs are commonly mapped along the valley margins that control meander wavelength amplitude (Brown 1981, Shepherd 2011).

The Delaware, Missouri, Osage, and Shawnee tribes inhabited the eastern Ozarks prior to European settlement. French explorers were the first to settle in the Big River watershed in the 1720s in Potosi, Missouri with the first town located along the main channel of Big River at Big River Mills near Flat River Creek in 1796 which constructed the first mill across the river in 1825. After the Louisiana Purchase in 1803, county governments under control by the US were organized by 1821 when Missouri gained statehood. Euro-American settlement accelerated after 1830 and major railroads moved into the region after the Civil War in the 1870s. While the areas first lead mining occurred in the early 1700s, large-scale industrial mining and processing mills operated from the 1890s to the early 1970s. Agricultural US Census records indicated that farmland as a percent of watershed area exceeded 50 percent between 1875 and 1950 with a peak period of 60 percent farmland between 1900–20. Urban populations began to increase after 1950. The land use distribution in the Big River watershed in 2019 was 71 percent forest/woodland, 18 percent pasture, 9 percent urban/developed, 1 percent row-crops, and 1 percent other/water.

METHODS

The primary method used to identify disturbance zones in the Big River was channel change analysis of the available historical aerial photography following rectification and interpretation protocol methods outlined by Martin and Pavlowsky (2011). However, instead of using a channel centerline for interpretation, active channel polygons were created for each photo year that included the wetted channel and bar areas. This allows for analysis of both downstream active channel width changes and changes in active width between photo years, not just changes in channel planform. Specific methods for photo rectification, interpretation, and channel change analysis are detailed below.

Historical aerial photography

A total of 222 aerial photographs were used for this project ranging in age from 1937 to 2018 and were categorized into seven sets for historical channel change analysis with average dates as follows: 1937, 1954, 1976, 1991, 2007, 2013, and 2018 (Table 1). The 1937, 1954, 1976 and portions of the 1991 photo series sets were acquired from the United States Geological Survey (USGS). The 1992 photos from the 1991 photo set were acquired through the Missouri Spatial Data Information Service (MSDIS) and came pre-rectified. The 2007 photographs were used as the base map for this study and were also acquired through MSDIS and came pre-rectified. The 2013 aerials were flown in 2013 and 2014 and were acquired from Google Earth as unrectified images. The 2018 aerials were acquired from the U.S. Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP) and were flown in November 2018. The 1937, 1954, and 2007 photo sets were all collected within a month apart and likely minimal channel

Table 1. Summary of Aerial Photographs and Rectification Errors.

Photo Year/Date	Number of Photos	Source	Notes	Resolution (m)	RMSE Range (m)	Max P2P Error (m)	Mean P2P Error (m)
July 23-Aug. 24, 1937	57	USGS	B&W	0.91	0.2-4.5	0.9-18.4	4.1-6.4
Oct. 17-Nov. 16, 1954	41	USGS	B&W	1.02	0.3-2.7	4.4-27.5	2.8-5.0
May 12, 1974-Dec. 2, 1979	19	USGS	B&W	0.75-2.11	0.7-3.08	4.3-6.4	3.7-4.5
Feb. 20,1990-April 5,1992	16	USGS MSDIS	B&W	1.00	0.6-1.1 Pre-rectified	1.9-9.8	3.3-5.8
Mar. 8-12, 2007	15	MSDIS	Color	0.61	Pre-rectified	n/a	n/a
Nov. 29, 2013-Oct. 21, 2014	48	Google Earth	Color	0.58-1.12	0.41-4.35	7.6-8.6	4.0-4.4
Nov. 16-21, 2018	26	USDA	Color	0.60	Pre-rectified	9.1	1.7

changes occurred between specific collection dates. The 1976 and 1991 sets however were collected over several years and therefore represent an average Channel position between 1974–1979 and 1990–1992. Photo years 1937, 1954, 1974, 1976, 1978, 1979, and 1990 were scanned at a resolution ranging from 0.75-2.11 m. Spatial resolution of the 2013–2014 Google Earth images ranged from 0.58-1.12 m. Resolution of the 2018 NAIP images is 0.6 m.

Aerial photos were rectified with a minimum of eight ground control points (GCP) using a second-order polynomial transformation (Hughes et al. 2006). Root-mean-square (RMS) errors ranged from 0.2-4.5 m for all aerials but were generally 3 m or less. In addition, this study also used independent test points (point-to-point) to evaluate rectification error (Hughes et al. 2006). Individual maximum test point error varied greatly in the 1954 and 1937 photos sets ranging from 0.9-27.5 m. The photo sets collected after 1954 had less variability in the maximum test point error ranging from 1.9-9.8 m. The average test point error for all photos sets ranged from 2.8-6.4 m and is the best representation of total photographic error for this method.

Historical channel layers

The visible active channel was digitized from each photo set along both bank lines to create a historical channel planform position for each year. Potential sources of error in the digitization process include vegetation obstructions and photo distortion, particularly along bedrock bluffs. Most of the aerial photos used for this project were collected during leaf-off conditions and tree canopy cover was usually not a problem for most photo years. Tree canopy cover was present in the 1937 aerials that were collected in the summer. However, at that time the majority of the valley was being farmed and the riparian corridor was generally a very thin strip along the banks and did not significantly

Table 2. Data layers created.

Geospatial Layers	Type	Description
Centerline	Line	Line representing the average channel position from 1937-2018
River kms	Points	Points calculated every 100 m along the centerline increasing upstream
Active Channel	Polygon	Entire channel including bars and the wetted channel digitized from historical aerials 1937-2018
Historical Active Belt	Polygon	Combined layer of all the active channel polygons from each year
Valley Width	Line	Valley width measured every 500 m along the centerline interpreted from 1-m DEM
Variables		
Length (m)		Distance from the upstream to downstream points of the disturbance zone or stable reach along the centerline
Area (m^2)		Area of the historical meander belt of individual disturbance zones and stable reaches.
Mean Width (m)		Disturbance zone and stable reach area divided by the length
Max Width (m)		Widest part of the disturbance zone or stable reach
Valley Width (m)		Valley width at the disturbance zone or stable reach interpreted from 1-m DEM

hide the channel. The exception is along bedrock bluffs, which could be 30 m high or more, that were generally vegetated and where the camera angle could create significant distortion. Fortunately, several overlapping photos were available from the older aerial sets and the channels along these bedrock bluffs were carefully digitized by finding the photos that had minimal distortion of the channel position.

The active channel layers from each of the photo years were combined to create a single historical active belt layer by combining areas of both exposed channel gravel or sand deposits and the wetted channel to form one continuous polygon layer for each set of years. The active channel indicates the total area of bed sediment transport and storage within the river channel including sub-aerial and underwater channel areas in the photographs. The historical active belt layer then was created by combining the active channel layers from each set of years into one layer representing the combined positions of all the active channel locations from 1937 to 2018. A description of the layers created from digitizing aerial photos and parameters calculated for the historical meander belt layer are summarized in Table 2. A channel centerline file was created by collapsing the historical active belt layer into a line that represents the average central position of the active channel from 1937 to 2013 (Table 2). A river kilometer (R-km) layer was then derived from the centerline representing every 100 m of stream channel in the study area increasing in an upstream direction. Each disturbance zone and stable reach were attributed with an R-km value representing the central location of the feature from 1937–2018. Finally, valley width was measured every 500 m along the channel centerline.

Disturbance zone identification

Disturbance zones were identified by analyzing width changes in the historical active belt based on the average width of the upstream reach. The width of gravel-bed rivers has been used to indicate bed load transport (Brenna et al. 2022) and overall reach storage of bed sediment (Erwin et al. 2021). The historical active belt was classified into disturbance zones by locating abrupt increases in the width of the active belt immediately downstream of stable reaches indicated by long segments with little change in width. For this study, disturbance zones were identified as channel reaches where the active belt width (i) increased by >1.5 times that of the upstream reach and (ii) maintained the larger width for a minimum of 100 m of channel length (about 2-3 channel stable channel widths). The magnitude of the width factor was based on the combination of experience with planform changes in the Big River by the authors and the limits of photographic errors to allow the resolution of change rather than background noise in width measurements. The area of each stable reach and disturbance zone was calculated using ESRI's ArcGIS 10.8.1 software. Each stable reach and disturbance zone was compared to the centerline layer to determine length. Mean width of each reach was then calculated by dividing the area by the length. The maximum width of the disturbance zone was measured at the widest portion of the historical active belt layer. After the initial analysis, each disturbance zone was verified visually. Some classified disturbance zones were not accepted because one, or occasionally more than one, digitized channel was off-set due to photograph or rectification errors. Errors occurred most frequently near bluffs due to the angle of the camera, visual obstruction by shadows, and subsequent rectification errors.

Disturbance zone classification

Disturbance zones were classified based on four disturbance types described by Martin and Pavlowsky (2011). An extension is formed when a channel meander grows laterally across the valley floor increasing the length of the channel. It typically forms a cut bank on the outside bend and point bar along the inside bend. A translation forms when a meander bend maintains its shape, but migrates longitudinally either up or downstream with no net change in channel length. This disturbance type typically forms where lateral channel erosion is limited by a narrow valley segment, bedrock bluffs, strath terraces, or other channel obstructions. A cutoff occurs when a new channel forms by incision across the neck of a large bend usually in a chute or backswamp area and thus bypasses the bend. Logically, a translation or extension may progress into a cutoff. However, cutoffs may switch back and forth over time reoccupying the previous channel location without eroding the material in-between. Finally, a megabar describes a reach where large accumulations of gravel are deposited in an overly wide area in the channel as center or point bar complexes. The presence of a megabar probably indicates an interruption in gravel transport routing where more sediment is being supplied to the reach than exported from it. Excessive bar deposition or bed aggradation can deflect the thalweg to increase local bank erosion rates or increase channel slope and the erosive energy during floods. In some cases, there was more than one disturbance type in the active zone. In these instances, the dominant type was used for classification based on year-to-year photo set analysis.

Rainfall and flood datasets

Daily rainfall records were obtained from the Midwestern Regional Climate Center's (MRCC) cli-MATE (https://mrcc.purdue.edu/CLIMATE/) database. For analysis of long-term rainfall patterns in the Big River watershed, the weather station at De Soto, Missouri in Jefferson County was used and operated since 1901. However, for several periods within the record there were missing data. Records were augmented with records from the nearby stations Potosi, Festus, Richwoods, Arcadia, and Fredericktown. Temporal changes in flood frequency were calculated from peak annual discharge values from the United States Geological Survey (USGS) gage, Big River at Byrnesville, Missouri (#07018500) that has a record going back to 1921. Flood recurrence intervals were calculated from the 30-year "moving window" partial duration series flood records using HEC-SSP 2.2 software starting in 1923 moving in five-year increments.

RESULTS AND DISCUSSION

Disturbance zone identification

There were 79 disturbance zones and 80 stable reaches identified along the 182 km historical active belt layer for Big River with 43.3 km (23.8 percent) of the length classified as disturbance zones and 138.7 km (76.2 percent) classified as stable reaches (Table 3). This percentage of disturbance is similar to the 21 percent reported in the Finley River of southwest Missouri using similar methods (Martin and Pavlowsky 2011). However, when considering the total area of the main channel, 35.9 percent of the channel is disturbed while 64.1 percent is classified as stable. Of the 79 disturbance zones identified, five were determined to be due to human modification of the channel, such as around bridges that have been replaced or moved over time and in proximity to mill dams and will be referred to as "anthropogenic" disturbance zones (Table 3). The remaining 74 disturbance zones are considered "self-adjusted" or formed by river channel adjustments to discharge and sediment interactions. There is approximately one disturbance zone for every 2.5 km of channel length based on a total of 74 self-adjusted disturbance zones along the lower 182 km of the Big River.

Megabars and extensions were the most common disturbance zone type and made up the majority of total disturbance zone length and area, but cutoffs and translations tend to be relatively large on average. Out of 74 self-adjusted disturbance zones, 31 were classified as megabars, 30 extensions, 9 translations, and only 4 were cutoffs (Table 3). While megabars represent 41.9 percent of the total number of disturbance zones, they only represent about 24-27 percent of the total length and area of all disturbance zones. In contrast, translations are only 12.2 percent of the total number of disturbance zones but represent roughly 20-21 percent of the total length and area of all

Table 3. Summary of historical active belt layer classification and disturbance zone types.

Feature	#	Percent	Length (km)	Percent	Area (m^2)	Percent
Main Channel			182.0		12,772,789	
↓						
Stable Reach	80	50.3	138.7	76.2	8,187,789	64.1
Disturbance Zone	79	49.7	43.3	23.8	4,585,000	35.9
↓						
Anthropogenic	5	6.3	1.2	2.8	99,885	2.2
Self-Adjusted	74	93.7	42.1	97.2	4,485,115	97.8
↓						
Cutoff	4	5.4	3.1	7.4	581,005	13.0
Extension	30	40.5	19.3	45.9	1,868,604	41.7
Megabar	31	41.9	11.2	26.5	1,096,357	24.4
Translation	9	12.2	8.5	20.2	939,149	20.9

disturbance zones. When considering individual disturbance zone types by total length and area of disturbance, megabars on average tend to be relatively small, extensions are moderate in size, and cutoffs and translations tend to be large. This suggests that while megabars and extensions are common in the Big River, translations and cutoffs represent areas where the active channel is larger, more active, has a wider historical active belt, and therefore has the potential for higher rates of storage and possible remobilization of legacy sediment.

Disturbance zone distribution

Longitudinally, the density of disturbance zones tends to fluctuate from segment to segment, but disturbance zone types may be controlled by valley morphology to some degree. Upstream of Eaton Branch, the uppermost mining tributary at R-km 171, the density of disturbance zones is relatively high (Figure 2). This suggests disturbance zones have formed or are forming in the Big River independent of mining inputs. From the upper mining tributary to the confluence of Mineral Fork at R-km 99, disturbance zones vary from 1-3 per 5 km segment. However, downstream of Mineral Fork, the largest tributary to Big River, to R-km 50, the number of disturbance zones fluctuates from 1-4 per 5 km segment, suggesting one or a combination of three things: (i) a historical sediment wave from initial land clearing has migrated into this segment (Jacobson 1995), (ii) water and sediment inputs from Mineral Fork have differentially affected the main channel, or (iii) changes in valley morphology and sediment routing promote increased disturbance zone formation (Jacobson and Gran 1999). Megabars and extensions appear in all segments of the river, but are the only types identified in the relatively narrow valley sections between R-km 140 and R-km 90 (Pavlowsky et. al 2017). However, translations and cutoffs are more common downstream of Mineral Fork where the valley gets wider suggesting valley morphology may control the extent of lateral migration and disturbance zone formation to some degree.

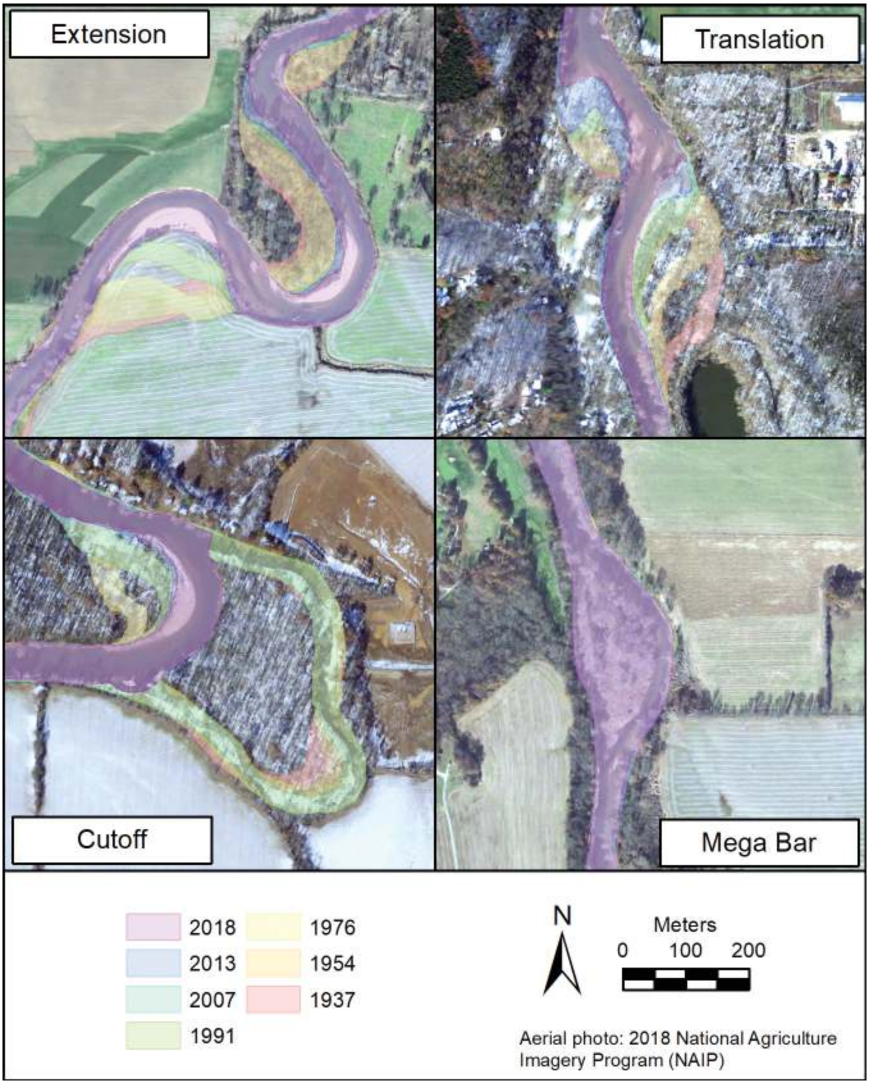


Figure 2. Examples of the four disturbance zone types in Big River.

Most disturbance zones along the Big River have been in place since 1937, but some disturbance zones are no longer active in 2018 suggesting that geomorphic recovery may be occurring. Over 80 percent of the disturbance zones identified for this study were observed in 1937 (Table 4). Previous work in the Ozarks also found that disturbance zones were persistent and tended to remain in the same location even after settlement (Jacobson and Gran, 1999). Of the remaining, 6.8 percent were first detected

Table 4. Temporal changes in active disturbance zones.

Year	Active in 2018	Percent of year	Non-active in 2018	Percent of year	Total	Percent of total
1937	46	76.7	14	23.3	60	81.1
1954	4	80.0	1	20.0	5	6.8
1970	5	83.3	1	16.7	6	8.1
1990	3	100	0	0.0	3	4.0
2007	0	0.0	0	0.0	0	0.0
2013	0	0.0	0	0.0	0	0.0
2018	0	0.0	0	0.0	0	0.0
Total	58	78.4	16	21.6	74	100

in 1954, 8.1 percent in 1970, and 4.0 percent in 1990. No new disturbance zones were observed in the 2007, 2013, and 2018 aerial photo series. This suggests disturbance zone formation is not controlled by recent phenomena and, if related to human modifications of the watershed, likely resulted from land disturbances prior to 1937. Locations of disturbance zones are known to be persistent over time and they can expand and contract due to the passage of gravel waves or remobilization of sediment during large floods (Jacobson 1995; Erwin et al., 2021). Of the 60 disturbance zones identified in the 1937 aerial photos, 46 (76.7 percent) are still active in 2018. Also, of the 14 post-1937 disturbance zones identified for this study, two are no longer active in the 2018 aerials again suggesting that local recovery of some previously unstable channel areas has occurred. While most disturbance zones are persistent, some may be more prone to disturbance than others so that channel activity can vary through time and at different locations longitudinally.

The spatial distribution of disturbance zones in the Big River is mainly influenced by bluff obstruction and valley width, with proximity to tributary confluences as a secondary variable. Disturbance zones are known to form near high flow separation zones at channel bends along bedrock bluffs and near tributary confluences (Jacobson and Gran 1999, Panfil and Jacobson 2001). In the Big River nearly 85 percent of disturbance zones were associated with bluff lines but over half were >2 km downstream of a major tributary confluence (Figure 4). However, about 24 percent of the disturbance zones were within 0.5 km of a confluence suggesting gravel and coarse sediment from tributary inputs may contribute locally to disturbance zones. Valley width is also an important variable in the distribution of disturbance zones in the Big River as over 70 percent are in valleys between <400 m wide (Figure 3). This is relatively high compared to the variability in valley width for the Big River. Roughly 72 percent of the total number of disturbance zones are found in valleys 100-400 m wide. When considering the entire 182 km of river evaluated, about 55 percent of the river has a valley length between 100-400 m when measured every 0.5 R-km. Overall, most disturbance zones in the Big River

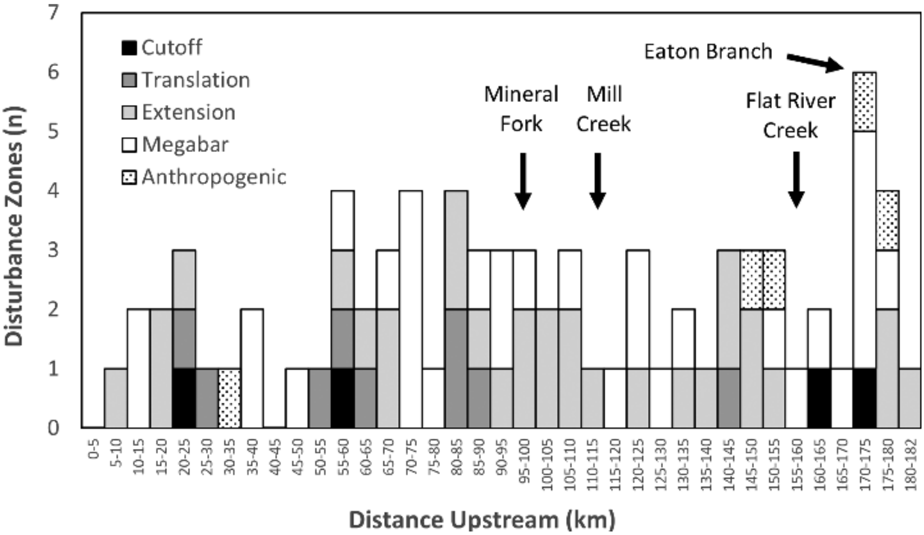


Figure 3. Downstream distribution of disturbance zone types.

are primarily found along bluffs in valleys <400 m wide and secondarily within 0.5 km of a major tributary confluence.

Active channel area change ratio

Changes in active channel area in both disturbance zones and stable reaches were used to identify the timing and how much the historical active belt was changing since 1937. To compare the timing of channel changes an active channel area change ratio was calculated by dividing the active channel area of the newest photo by the active channel area of the older photo within the historical active belt in disturbance zones and stable reaches. This was done over three periods, 1937–1976, 1976–2018, and 1937–2018 with a three-point moving average line used to show trends. A change ratio of 1 represents no change, <1 a reduction in area, and >1 an increase in area compared to the previous photo year. Additionally, valley width trends were also compared to patterns of channel changes to evaluate the influence of valley confinement on disturbance zone activity.

Changes in active channel areas for disturbance zones and stable reaches between 1937 and 1976 showed both enlargement and contraction, that may indicate sediment wave movement downstream, tributary inputs, or pulses from large floods. Between 1937 and 1976 active channel area ratios for disturbance zones vary from <1 to >2, particularly below the mining area at R-km 171 to R-km 50 (Figure 5). Below R-km 50, active channel areas in disturbance zones remained similar between 1937–1976. Upstream of the mining area (R-km 171), disturbance zones appear to have gotten smaller between 1937 and 1976 suggesting some recovery occurred over that period. Stable

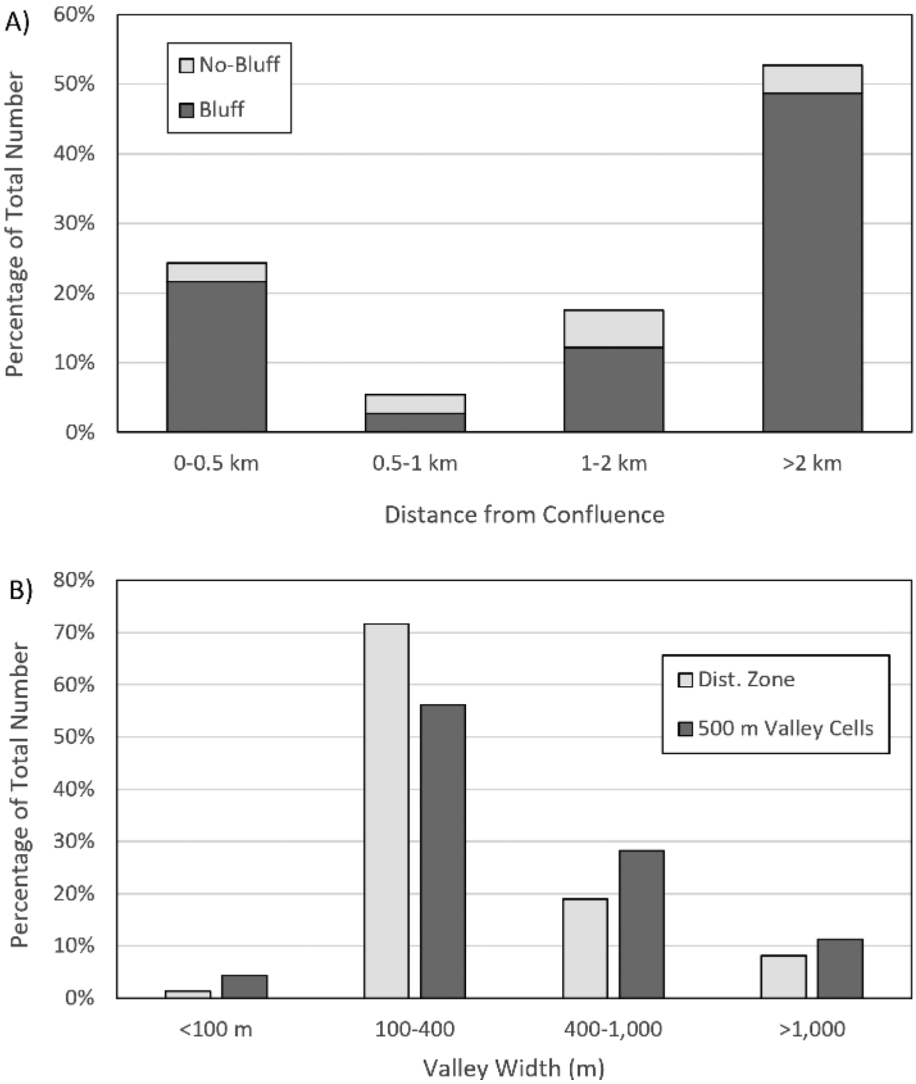


Figure 4. Distribution (by percent) of disturbance zones by A) bluff influence and distance from major tributary confluence and B) valley width.

reaches have a similar pattern, but do not increase in size as much as disturbance zones with active channel area change ratios mostly <1.5 except for the reach between R-km 100 and R-km 50 where some ratios are >1.5. This may indicate the passage of an attenuated sediment wave over that period that is a response to watershed disturbances from initial land clearing (Jacobson and Gran 1999, Erwin et al. 2021). Historical map analysis of the Bella Coola River, British Columbia indicated a pattern of sedimentation (disturbance) zones and transport (stable) reaches like Big River and other Ozark rivers (Church 1983). Overall, the river had become more stable over the past century with the locus of lateral instability and active gravel bars shifting downstream over 25 km. Two mechanisms were hypothesized to explain the effects: (i) High sediment loads from older natural or anthropogenic sediment sources may have become exhausted (i.e., attenuated sediment wave); or (ii) an upstream alluvial fan may have obstructed the channel and reduced downstream sediment delivery (local reduction in sediment supply). Further, these trends were interrupted occasionally by tributaries inputs from extreme floods (Church 1983). Similarly, the locus of gravel deposition has shifted downstream in the Current River, Missouri over the past 35 years exhibiting a non-uniform distribution related to local factors such as variations in valley geometry, tributary inputs, and lithology influencing sediment supply (Erwin et al. 2021).

Active channel areas in both disturbance zones and stable reaches had relatively high rates of change between 1976 and 2018 that may indicate a major reactivation of channel response to a contemporary disturbance, such as watershed-scale land cover changes or climate change. Between 1976 and 2018, active channel area increased in all disturbance zones and stable reaches along the Big River (Figure 4). Disturbance zone change ratios varied from 1.0 to 5.6, and stable reaches from 1.1 to 4.2 with both generally decreasing downstream. Most of the highest change ratios for both disturbance zones and stable reaches occur in the mining affected area between R-km 171 and R-km 120 where the valley width is less than 400 m. Channel beds can become unstable and increase bar deposition in river segments located in narrow valleys where bed roughness increases due to higher relief riffle-pool structures and bedrock obstacles, particularly if bed sediment loads are relatively high initially (Kasai et al. 2004, Fotherby 2009). Banks and floodplains within narrow valley segments will also be more susceptible to flow turbulence and erosional processes compared to wider valley locations along the same river (Magilligan 1985). Below R-km 120, channel change ratios are lower than in upstream areas but are still significantly higher than in 1976. While upland soil erosion rates have decreased dramatically due to improved soil conservation and land management practices, modern channels continue to adjust to variable sediment loads from tributary inputs and the remobilization of stored legacy sediments by ongoing bed and bank erosion (Simon and Rinaldi 2000, James 2013). Channel systems may potentially be responding to numerous contemporary disturbances such as urban development, channelization, road and infrastructure construction, and climate change (Knox 1985, Knox 2006, James et al. 2022, Hess et al. 2023).

Overall, active channel area change ratios have increased 2-3 times in the Big River from 1937–2018 with the highest rates of change occurring in relatively narrow valleys. Ratios for disturbance zones varied from 1.0-7.4 with an average of 3.2 from 1937–2018 (Figure 4). Stable reach ratios averaged 2.0, ranging from 1.0-3.8 over the same period. However, the majority of these changes have occurred during the last 40 years. The magnitude of channel change has a negative relationship with valley width for both disturbance zones and stable reaches since 1937. For example, the mining-effected segment between R-km 171 and 130 had the highest ratios for both disturbance zones and stable

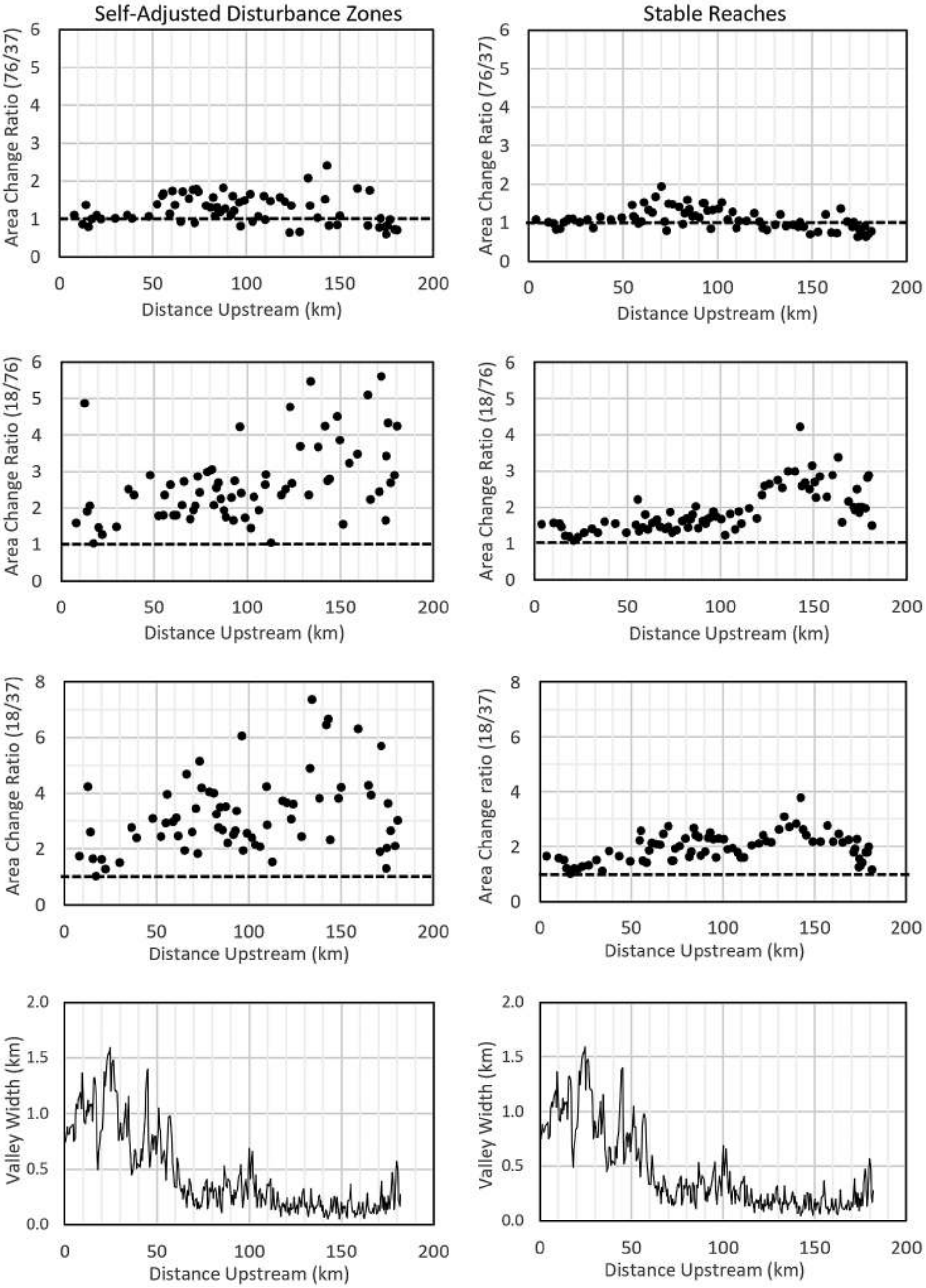


Figure 5. Downstream changes in active channel area ratio for disturbance zones and stable reaches from 1937-1976, 1976-2018, 1937-2018, and valley width at 0.5 km increments.

reaches while also having the lowest valley width. In contrast, the lowest ratios for both disturbance zones and stable reaches occurred in the wider valley segment below Mineral Fork with the lowest ratios in the lower segment near the confluence.

The increase in magnitude of contemporary channel changes likely indicates a major shift in hydrologic regime rather than just the downstream passage of historical gravel waves since the rate of downstream sediment transport may be limited. Pavlowsky et al. (2017) reported that fine gravel (<16 mm) tailings from the Old Lead Belt discharged a century ago has only reached R-km 115 with a maximum transport rate of 250 mm/yr. Median bed material sizes in Ozark rivers are twice that size (Panfil and Jacobson 2001). Moreover, modeling studies in the Big River indicated that median bed material sizes exhibit limited mobility even at flow conditions associated with the 2-yr flood (Roberts et al. 2022; Pavlowsky et al 2023). Further, the volume of gravel bar deposits was better correlated with the occurrence of bedrock outcrops rich in chert gravel nearby in Buffalo River, Arkansas and Current River, Missouri in the Ozarks than tributary inputs (Panfil and Jacobson 2001). Moreover, gravel volumes in the channel were related to locations and thickness of buried gravel deposits in cutbanks in the Neosho River, Kansas (Juracek and Perry 2005). Thus, disturbance zone activity can currently be responding to the overall reduction of upland gravel inputs due to soil conservation, downstream gravel wave migration and attenuation, and local erosion related to hydrological disturbances from increased flooding related to recent climate change (Heimann et al. 2018, Pavlowsky et al 2023, Hess et al. 2023).

Increased Rainfall and Flooding

The contemporary increase in disturbance zone size is probably not related directly to land use management but more likely caused by channel and sediment adjustments to increased floods associated with changes in rainfall patterns since the 1970s. Annual maximum peak records from the Byrnesville gage show an increase in the magnitude and frequency of floods since the early 1990s (Figure 6). This seems to follow the active channel area change ratio analysis discussed above where there appears to be an abrupt change in the size of both disturbance zones and stable reach areas between 1976 and 2018. These results coincide with historical flood record analysis across the region that shows increases in the magnitude of floods at reoccurrence intervals (RI) between the 2-100 yr flood events in other Ozarks watersheds (Foreman 2014; Heimann et al., 2018).

Not only has there been a change in annual peak flood magnitude along the Big River, but the frequency of flooding has also increased since the 1970s. Mean daily discharge records were compared to the mean annual flood discharge (RI = 2.33 yrs) at the Byrnesville gage. The mean annual flood discharge (RI = 2.33 yrs) was chosen since it would be larger than the channel forming discharge (RI = 1.5 yrs) and that high magnitude floods are known to be important in the formation and maintenance of disturbance zones (Rosgen 1996, Jacobson and Gran 1999). Prior to 1970, the number of days the mean daily discharge exceeded the average mean annual flood discharge of 538 m^3/s was 23 days over the 50 years from 1923–1972 (Figure 5). Over the 50-year period from 1973 to 2022, the mean daily discharge exceeded the annual mean flood discharge for 59 days, or about twice that during the period before 1973.

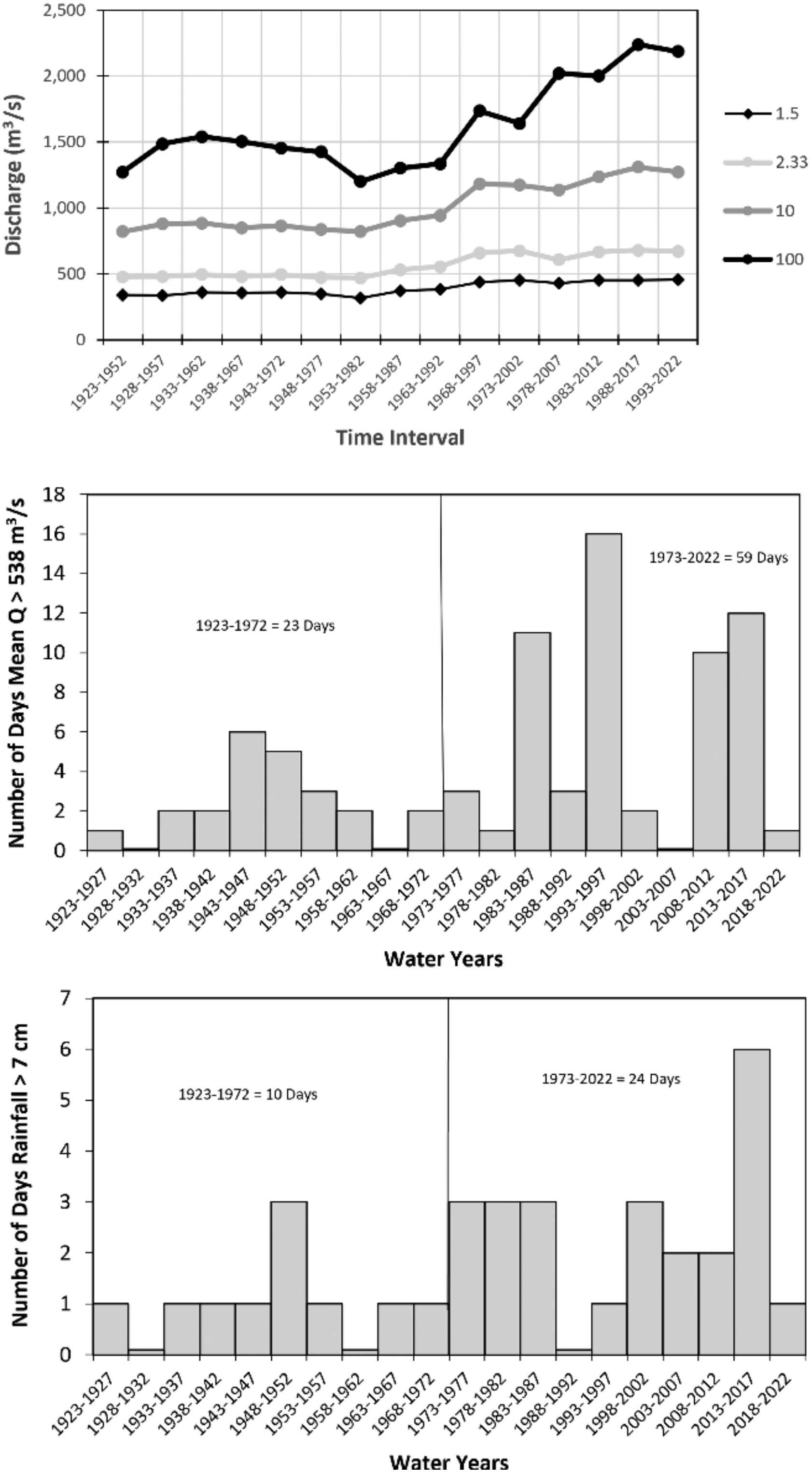


Figure 6. Changes in flood magnitude, flood frequency, and rainfall intensity for the Big River since 1923.

Table 5. Urban Land Use Changes since 1992.

Land Use	Percent				Percent Diff
	1992	2001	2011	2019	2019-1992
Urban	2.87	6.83	7.12	8.64	5.78
Pasture	20.15	18.11	18.37	18.24	-1.92
Forest	73.57	73.42	72.86	71.03	-2.54
Cropland	2.29	0.99	0.98	1.18	-1.11
Other	1.12	0.65	0.67	0.91	-0.21

Rainfall records indicate the changes in flood frequency and magnitude at the Byrnesville gage can be attributed to increased rainfall intensity since 1973. Rainfall records from nearby weather stations show that between 1923–1972 the number of days the 24-hour rainfall total exceeded 7 cm was 10 days in 50 years. From 1973–2022, the number of days the 24-hour rainfall total exceeded 7 cm has been 24 days in 50 years. These data suggest that the higher frequency and magnitude of floods in the Big River are linked to increased rainfall intensity in the region. These findings support both published historical data and future climate change prediction models that indicate the Midwest will likely be subjected to increased high intensity rainfall patterns that will elevate the flood risk for that part of the country (Slater and Villarini 2016). With this as a backdrop, managers working on the Big River can expect more flooding, bank erosion, and sediment transport as the river adjusts to this new climatic regime (Knox 1985).

Since the 1970s there has been a significant increase in the size of the active channel and an increase in magnitude and frequency of high intensity rainfall and flooding, however land use has not changed drastically since the 1990s. While there has been an increase in urban land use within the Big River watershed, the total area of developed land remains relatively small. Analysis of land use changes from 1992 to 2019 shows urban area increased from 2.9 percent to 8.6 percent over the entire watershed (Table 5). The largest increase in urban area occurred between 1992 and 2001, when urban area increased from 2.9 percent to 6.8 percent. Increases in urban area have been more gradual since 2001. Over the same period, all other land use categories decreased including pasture, cropland, and forest land. While the increase in urban area is notable, the distribution of urban area throughout the watershed and relative size of the watershed would suggest the hydrological and geomorphic response is not due to significant changes in land cover.

CONCLUSIONS

This study uses a series of historical aerial photographs from 1937–2018 to describe temporal channel disturbance along 182 km of the main channel of the Big River in southeast Missouri. The active channel was digitized for seven sets of photograph years and these layers were combined to create one historical active belt layer. Disturbance zones were then identified and classified based on abrupt changes in the historical meander belt width. Changes in the active channel area for each photo year was used to understand how disturbance zones were changing over time and relate that to increases in floods and rainfall intensity in the watershed.

Approximately 24 percent of the main channel of the Big River is classified as disturbance zones, with a density of approximately one every 2.5 km of channel length, which is like other published studies in the Ozarks using similar methods (Martin and Pavlowsky 2011). When comparing individual disturbance zones by type, translations and cutoffs are generally larger than extensions and megabars, but channel migration appears to be controlled as width characteristics are similar for all types except for the cutoffs. Longitudinally, the density of disturbance zones tends to fluctuate from segment to segment, but disturbance zone types appear to be evenly distributed downstream. Average disturbance zone lengths and widths vary downstream, but the largest and most closely spaced tend to occur between R-km 50 and R-km 100 just below the Mineral Fork confluence. Spatial distribution of disturbance zones in the Big River is mainly influenced by the presence of a bluff and valley width, with 84% influenced by a bluff and 73% found in valleys <400 m wide. Proximity to a tributary confluence would be considered a secondary variable, with about 24% within 0.5 km downstream of a majority tributary. Around 80 percent of disturbance zones along the Big River were formed before 1937, but at least some disturbance zones were no longer active in 2018. This suggests some geomorphic recovery has occurred in the Big River but, for the most part, disturbance zone locations have been persistent for over 80 years.

Analysis of area changes over time for disturbance zones and stable reaches reveals that channel activity varied along the main channel from 1937–1976. Change ratios were relatively low but exhibited an alternating pattern of increasing and decreasing size possibly indicating the ongoing passage of an attenuated historical sediment wave or discrete pulses related to flood occurrences. However, areas of both disturbance zones and stable reaches increased from 1976 to 2018 showing significant channel changes over that timeframe. This was evident within the portion of the channel directly below the mining area, in an area with a relatively narrow valley, suggesting the river in this reach is particularly sensitive to hydrologic changes. Analysis of the flood record for the oldest gaging stations along the Big River suggests a dramatic increase in the peak annual flood and flood frequency after 1973. Rainfall records indicate that this is likely due to increased high intensity rainfall being more common over that time and not watershed-scale changes in land cover. These results suggest that contaminated sediments associated with historical mining activities currently stored in gravel bar and floodplain deposits have been and will continue to be remobilized as the channel responds to future floods and possibly a new climatic regime.

REFERENCES CITED

Bracken L.J., Turnbull, L., Wainwright, J., and Bogaart, P. 2015. Sediment Connectivity: A Framework for Understanding Sediment Transfer at Multiple Scales. *Earth Surface Processes and Landforms*, 40: 177–188.

Brenna, A., Bizzi, S., and Surian N. 2022. A Width-Based Approach to Estimating Historical Changes in Coarse Sediment Fluxes at River Reach and Network Scales. *Earth Surface Processes and Landforms,* 47: 2560–2579.

Brown, B.L., 1981. Soil Survey of St. Francois County, Missouri. United States Department of Agriculture, Soil Conservation Service and Forest Service in cooperation with the Missouri Agricultural Experiment Station.

Buffington, J.M., 2012. Changes in Channel Morphology Over Human Timescales. In *Gravel-Bed Rivers: Processes, Tools, Environments,* edited by M. Church, P.M. Biron, A.G. Roy, Chapter 32. John Wiley and Sons. DOI:10.1002/9781119952497

Church, M., 1983. Pattern of Instability in a Wandering Gravel Bed Channel. In *Modern and Ancient Fluvial Systems*, edited by B. Collinson and J. Lewin, v. 6. Oxford, United kingdom, Blackwell.

Erwin, S.O., Jacobson, R.B., and Jones, J.C. 2021. Stream Classification and Gravel-Bed Inventory for Buffalo National River and Ozark National Scenic Riverways. USGS Scientific Investigations Report 2020–5122.

Foreman, A.T. 2014. Climate change influence on historical flood variability in Ozark Highland rivers. M.S. thesis. Missouri State University, Springfield.

Fotherby, L.M. 2009. Valley confinement as a factor of braided river patterns for the Platte River. *Geomorphology,* 103 (4): 562–576.

Heimann, D.C., Holmes Jr., R.R., Harris, T.E. 2018. Flooding in the Southern Midwestern United States, April-May 2017. USGS Open-File Report 2018–1004.

Hess, J.W., Pavlowsky, R.T., and Lecce, S.A. 2023. Climate-driven flood effects on channel stability, sedimentation, and freshwater mussel habitat in rivers draining the Ozark Highlands. *SEDHYD 2023 Conference Proceedings*. https://www.sedhyd.org/past/2023Proceedings/SEDHYD2023-Proceedings-Draft-060523.pdf.

Hughes, M. L., McDowell, P. F., Marcus, A.W. 2006. Accuracy Assessment of Georectified Aerial Photographs: Implications for Measuring Lateral Channel Movement in a GIS. *Geomorphology,* Vol. 74: 1–16.

Jacobson, R. B., and Primm, A. T. 1994. Historical Land-Use Changes and Potential Effects on Stream Disturbance in the Ozark Plateaus, Missouri. USGS Water-Supply Paper 2484.

Jacobson, R. B. 1995. Spatial Controls on Patterns of Land-Use Induced Stream Disturbance at the Drainage-Basin Scale – An Example from Gravel-Bed Streams of the Ozark Plateaus, Missouri. *Geophysical Monograph,* Vol. 89: 219–239.

Jacobson, R. B., and Gran, K. B. 1999. Gravel Sediment Routing from Widespread, Low-Intensity Landscape Disturbance, Current River Basin, Missouri. *Earth Surface Processes and Landforms*, Vol. 24: 897–917.

James, L.A. 1989. Sustained Storage and Transport of Hydraulic Gold Mining Sediment in the Bear River, California. *Annuals of the Association of American Geographers*, 79 (4): 570–592.

James, L.A. 2006. Bed Waves at the Basin Scale: Implications for River Management and Restoration. *Earth Surface Processes and Landforms* 31: 1,692–1,706.

James, L.A. 2013. Legacy Sediment: Definitions and Processes of Episodically Produced Anthropogenic Sediment. *Anthropocene* 2: 16–26.

James, A., Lecce, S.A., Pavlowsky, R.T. 2022. Impacts of Land-Use and Land-Cover Change on River Systems. In *Treatise on Geomorphology 2nd Edition*, edited by J.F. Shroder, 1,191–1,236. Elsevier, Academic Press. (on-line) https://doi.org/10.1016/B978-0-12-818234-5.00089-4

Jerin, T., Pavlowsky, R.T., Owen, M.R., Hess, J.W., Alkier, H.N., Grong, K.A. 2023. Anthropogenic Channel Network Development in Forested Watersheds by Recent Stream Channelization Practices in Mark Twain National Forest, Missouri Ozarks. *Geomorphology* 426: 108601. doi: org/10.1016/j.geomorph.2023.108601

Juracek, K.E., and Perry, C.A. 2005. Gravel Sources for the Neosho River in Kansas, 2004. USGS Scientific Investigations Report 2005–5282.

Kasai, M., Marutani, T., and Brierley, G.J. 2004. Patterns of sediment slug translation and dispersion following typhoon-induced disturbance, Oyabu Creek. *Earth Surface Processes and Landforms*. 29 (1): 59–76.

Kemp, D.B., Sadler, P.M., and Vanacker, V. 2020. The Human Impact on North America Erosion, Sediment Transfer, and Storage in a Geologic Context. *Nature Communications*, 11(1), 6012. https://doi.org/10.1038/s41467-020-19744-3

Kondolf, G.M., and Larson, M. 2006. Historical Channel Analysis and its Application to Riparian and Aquatic Habitat Restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5(2): 109–126

Knox, J.C. 1972. Valley Alluviation in Southwestern Wisconsin. *Annals of the Association of American Geographers* 62: 401–410.

Knox, J.C. 1985. Responses of Floods to Holocene Climatic Change in the Upper Mississippi Valley. *Quaternary Research* 23 (3): 287–300.

Knox, J.C. 2006. Floodplain Sedimentation in the Upper Mississippi Valley: Natural Versus Human Accelerated. *Geomorphology* 79: 286–310.

Lecce, S.A. 1997. Spatial Patterns of Historical Overbank Sedimentation and Floodplain Evolution, Blue River, Wisconsin. *Geomorphology* 18: 265–277.

Lecce, S.A., and Pavlowsky, R.T. 2001. Use of Mining-Contaminated Sediment Tracers to Investigate the Timing and Rates of Historical Flood Plain Sedimentation. *Geomorphology* 38: 85–108.

Martin D. J., and Pavlowsky, R.T. 2011. Spatial Patterns of Channel Instability along an Ozark River, Southwest Missouri. *Physical Geography* 32 (5): 445–468.

Magilligan, F.J. 1985. Historical floodplain sedimentation in the Galena River Basin, Wisconsin and Illinois. *Annals of the Association of American Geographers.* 75 (4): 583–594.

Montgomery, D.R. 1999. Process Domains and the River Continuum. *Journal of the American Water Resources Association*. 35 (2): 397–410.

Owen, M.R., Pavlowsky, R.T., and Womble, P.J. 2011. Historical Disturbance and Contemporary Floodplain Development along an Ozark River, Southwest Missouri. *Physical Geography.* 32 (5): 423–444.

Panfil, M.S., and Jacobson, R.B. 2001. Relations Among Geology, Physiography, Land Use, and Stream Habitat Conditions in the Buffalo and Current River Systems, Missouri and Arkansas. Biological Sciences Report USGS BRD/BSR-2001-0005.

Pavlowsky, R.T., Lecce, S.A., Owen, M.R., and Martin, D.J. 2017. Legacy Sediment, Lead, and Zinc Storage in Channel and Floodplain Deposits of the Big River, Old Lead Belt Mining District, Missouri, USA. *Geomorphology* 299: 54–75.

Pavlowsky, R.T., Owen, M.R., Lecce, S.A., and Pace-Witt, J. 2023. Sand and gravel dispersal rates using mine tailings tracers in Big River, Ozark Highlands. *SEDHYD 2023 Conference Proceedings*. https://www.sedhyd.org/past/2023Proceedings/SEDHYD2023-Proceedings-Draft-060523.pdf.

Roberts, M.O., Jacobson, R.B., and Erwin, S.O. 2022. Hydraulics of Freshwater Mussel Habitat in Select Reaches of the Big River, Missouri. USGS Scientific Investigations Report 2022–5002. https://doi.org/10.3133/sir20225002.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, Colorado.

Saucier, R.T. 1983. Historic changes in the Current River meander regime. *Rivers '83 Conference Proceedings*, American Society of Civil Engineers: 180–190.

Shepherd, S.L., Dixon, J.C., and Davis, R.K. 2011. Are Ozarks Streams Underfit? Using GIS to Re-Examine Dury's Theory of Underfit Streams. *Physical Geography* 32 (2): 179–194.

Slater, L.J., and Villarini, G. 2016. Recent Trends in U.S. Flood Risk. *Geophysical Research Letters* 43: 12,428–12,436.

Simon A., and Rinaldi, M. 2000. Channel Instability in the Loess Area of the Midwestern United States. *Journal of the American Water Resources Association* 36 (1): 133–150.

Trimble, S.W., and Lund, S.W. 1982. Soil Conservation and the Reduction of Erosion and Sedimentation in the Coon Creek Basin, Wisconsin. USGS Professional Paper 1234.

Urban, M.A., and Rhoads, B.L. 2003. Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA. *Annals of the Association of American Geographers* 9(4): 783–796.

MARC OWEN (mowen@missouristate.edu) is the Assistant Director of the Ozarks Environmental and Water Resources Institute at Missouri State University in Springfield, Missouri. He specializes in field investigations in fluvial geomorphology, soils/sedimentation, and water quality along with the application of geospatial technology to watershed science.

ROBERT PAVLOWSKY (BobPavlowsky@missouristate.edu) is a Distinguished Professor in the Department of Geography, Geology, and Planning and the Director of Ozarks Environmental and Water Resources Institute at Missouri State University in in Springfield, Missouri. His research interests include fluvial geomorphology and sedimentology, environmental geochemistry, and climate change and human impacts on watersheds and river systems.

DEREK MARTIN (martindj1@appstate.edu) is an Associate Professor in the Department of Geography and Planning at Appalachian State University in Boone, North Carolina. His research interests include fluvial geomorphology, and field applications of geospatial technologies.