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Historical Changes of Channel Width in a Headwater Stream System, Mark Twain National Forest, Missouri

Sierra N. Casagrand
Missouri State University, Sierra09@live.missouristate.edu

HISTORICAL CHANGES OF CHANNEL WIDTH IN A HEADWATER STREAM SYSTEM, MARK TWAIN NATIONAL FOREST, MISSOURI

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In Partial Fulfillment

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Master of Natural and Applied Sciences, Geology and Geography

By

Sierra Nicole Casagrand

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HISTORICAL CHANGES OF CHANNEL WIDTH IN A HEADWATER STREAM SYSTEM, MARK TWAIN NATIONAL FOREST, MISSOURI

Geology, Geography and Planning

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ABSTRACT

It is well known that watershed disturbances due to land clearing and agricultural settlement during the early 1800s changed the hydrology and geomorphology of stream systems in the Midwestern USA. However, little is known about the impacts of historical logging on stream systems in forested watersheds. This study evaluates channel width measurements from 38 General Land Office (GLO) surveys completed in 1821, aerial photographs from the 1930's to present, and LiDAR imagery from 2016/17 to evaluate changes in channel morphology in Big Barren Creek in Mark Twain National Forest in the Ozarks Highlands of southeast Missouri. The area was heavily logged for pine between 1880 and 1920 and today is being managed for both pine forest restoration and cyclical tree harvesting. Overall, modern channel widths have increased by an average of 2.6 times since 1821. The largest increases occurred in second order streams averaging a 3.4-fold increase, while no change in width occurred in a 2 km long 4th order confined bedrock-controlled segment. It is suggested that the primary cause of channel widening was the increase in runoff due to deceased canopy interception of rainfall after removal of short-leaf pine by exploitive logging and replacement by hardwoods. Apparently, recent climate change resulting in more intense rains and frequent floods has caused channel width to increase at some sites by an average of 1.6 times since 2007.

KEYWORDS: logging, land use change, LiDAR, General Land Office, Missouri Ozarks, fluvial geomorphology, aerial photography

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Approved:

Robert Pavlowsky, Ph.D., Committee Chair

Xiaomin Qiu, Ph.D., Committee Member

Marc Owen, M.S., Committee Member

Julie Masterson, Ph.D., Dean of the Graduate College

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INTRODUCTION

Human activities such as urbanization and agriculture can disturb river form by increasing runoff and soil erosion in watersheds leading to channel instability and higher bed and bank erosion rates (Anderson 1970; Field, Masters, and Singer 1982; Lazaro 1990; Jacobson and Pugh 1992; Harbor 1994; Moscrip and Montgomery 1997; Jacobson 2004; James and Lecce 2013). The removal of natural vegetation and soil disturbance tends to reduce rainfall infiltration rates, increase runoff, and cause floods to become flashier with higher peak flows (James and Lecce 2013). Land use changes in the watershed typically affect water and sediment delivery, leading to channel adjustments altering water quality, stream habitats, and channel morphology (Jacobson and Pugh 1992; Vitousek 1994; Rosgen 1995; James and Lecce 2013). Increased runoff is known to cause channel enlargement through channel incision and widening (Booth 1991). In steep headwater streams channel enlargement can occur by gullying or the transition of multi-threaded systems to a single channel form while downstream lower gradient streams can adjust to larger floods by a combination of cutbank erosion and channel widening, and overbank sedimentation (Luce 1995). Typically, channel area and bank height form to the size needed to contain the bankfull flood with a recurrence interval of about 1-2 years (Figure 1) (Wolman and Leopold 1957; Sherwood and Huitger 2005; Wohl 2014). Therefore, a chronic increase in flood depth and frequency is expected to cause channel area enlargement (Wolman and Leopold 1957; Wolman and Miller 1960; Dunne and Leopold 1978; Castro and Jackson 2001; Wohl 2014).

Human effects on channel morphology typically increase channel width (Knox 1977; Hession et al. 2003; Rose and Basher 2010; Lecce 2013). Knox (1977) found that since Euro-American settlement of the Platte River watershed in southwestern Wisconsin (drainage area,

A_d=440 km^2), headwater and tributary channels have become wider and deeper as a response to an increase of frequency of channel-forming discharge from every 1.58 years before settlement to every 1.1 years in the 1970s. An urbanized stream in Ontario, Canada (A_d=14.8 km^2) showed a 75% increase in channel width due to increased flow caused by urbanization of the surrounding environment (Bevan et al. 2018). In a northern Wisconsin stream (A_d=122 km^2), bankfull discharge is estimated to have increased up to 2.5 times since 1946 due to logging and agriculture on clear cut land (Fitzpatrick, Knox, and Whitman 1999). In cropland and rangeland settings with poor soil management practices, absence of cover vegetation, and soil compaction by livestock increases runoff and bank erosion causing channel enlargement, especially in headwater streams where stream power can increase by three times after disturbances (Gifford, Faust, and Coltharp 1997; Poesen, Vandaele, and Wesemael 1996; James and Lecce 2013). Besides runoff-related disturbances, direct change by artificial means can affect channel form such as channelization. The aim of channelization is to protect agricultural fields from flooding by straightening, deepening, and widening the channel. However, these channel manipulations increase stream power and sediment transport capacity thus destabilizing channel form (Hupp 1992; Landwehr and Rhoads 2003; Franklin et al. 2009; Wohl 2014).

Forest Harvesting Influence on Channels

Forest hydrology differs from urban, cropland, and rangeland hydrology because of the presence of dense vegetation that limits runoff by canopy interception, organic soil infiltration, and detention storage (Stuart and Edwards 2006). In general, surface runoff is uncommon in forested watersheds because rainfall intensity rarely exceeds the infiltration capacity of the soil (Horton 1933; Sloan and Moore 1984; Luce 1995). In forests predominantly composed of tree species that create a dense overstory canopy and do not shed their leaves, the effective rainfall rate is lower as these species intercept precipitations throughout the year (Figure 2) (Luce 1995). For instance, the average pine rainfall interception rate was 0.36 cm per rainfall event, however, hardwoods intercept only 0.25 cm per rainfall event during the leaf on period (30 % less) and 0.13 cm per rainfall event during the leaf off period (64 % less) (Luce, 1995). A study of urban trees ability to reduce runoff concluded that pine trees intercepted 47% of throughfall and stemflow of total yearly rainfall (Zabret and Sraj 2019). In addition, forest soils frequently have high hydraulic conductivity because of a relatively thick layer of organic material that increases porosity and protects root systems that increase soil pore space (Stuart and Edwards 2006). For example, a summary of global comparisons showed saturated hydraulic conductivity at a depth of 12.5 cm averaged 73.8 cm/h in forest soils. However, in pastureland the average was only 1.4 cm/h and, moreover, young fallow fields averaged 0.7 cm/h (Zimmerman and Elsenbeer 2008).

Forest clearing and timber harvesting has also been shown to affect watershed processes affecting stream hydrology (Harr and McCorison 1979; Wright et al. 1990; Douglas et al. 1992), stream temperature (Brown and Krygier 1970), water quality (Douglas et al. 1992; Gökbulak et al. 2007), and sediment production (Brown and Krygier 1971; Douglas et al. 1992). Studies in the Pacific Northwest showed that clear-cut forests and logging roads could double sediment production due to increased mass movements of sediment on steep slopes where more runoff and seepage causes instability (Mersereau and Dyrness 1972; Beschta 1978; Grant and Wolff 1991; Luce 1995). Forest clearing is also known to increase erosion due to the loss of vegetation and root systems that hold unstable soil in place, which usually prevents soil loss due to sheet flow, rain drop impact, and rilling processes (Luce 1995; Leigh 2016). In the Missouri Ozarks, timber harvesting was shown to increase water yield, storm flows, and sediment yields (Jacobson 2004).

When stream banks are cleared of trees or fallen trees are removed from the channel, there is often an increase in stream velocity which increases bank erosion rates and can affect the channel morphology (Douglas et al. 1992).

Fewer studies have been completed on the effects of logging practices on stream channel form in forested watersheds compared to agricultural and urban watersheds. The studies that have been conducted in forested areas are primarily in the Pacific Northwest and upper Midwest regions of the United States. A study in North Fish Creek, Wisconsin (A_d=122 km^2) estimated bankfull discharge has increased 15 m^3/s (40 %) upstream where reaches have degraded and incised while downstream reaches have increased 5-10 m^3/s and transitioned from multi-threaded channels to single threaded channels due to the effects of logging and land use change (Fitzpatrick, Knox, and Whitman 1999). Jacobson (2004) found that watersheds located on the Ozark Plateau show increased in soil disturbance and bed and bank erosion due to increased runoff from logging. In the Caspar Creek watershed in northern California (A_d=21.7 km^2), increased channel erosion due to higher flows was found to also be caused by logging in the watershed (Cafferata and Reid 2013).

Ozarks Logging History and Channel Response

The Ozark Highlands Region, known locally as the Ozarks, has endured Euro-American land use changes since the late 1700s with extreme land use changes, such as logging, road construction, channelization, and increased agriculture in the mid-1800s which led to changes in channel form and coarse sediment supply (Jacobson and Pugh 1992; Jacobson and Primm 1997; Owen and Pavlowsky 2011; Bradley 2017). Large scale logging on forested ridges began with the introduction of the railroad to the Ozarks in the mid to late 1800s while the fertile valley bottoms of the Ozarks were clear cut for agriculture practices (Jacobson and Primm 1997; Cunningham 2006). Jacobson (2004) concluded that timber harvest can increase sediment yields, water yields, cause baseflows to become higher, and increase storm flows in Ozark Rivers. However, one question that remained unanswered was how low-order streams in the Ozarks have been affected by human induced disturbances (Jacobson 2004). The channelization of Big Barren Creek (BBC), a fourth order stream that flows into the Current River, has been prevalent since at least the 1960s making channels deeper and narrower than the pre-settlement bankfull channels (Bradley 2017). Reminga (2019) suggested that upper and middle Big Barren Creek (BBC) was primarily drained by multi-threaded channels before Euro-American settlement, which later transitioned to single channel forms because of anthropogenic land disturbances. These studies did not address how channel size has changed throughout the watershed since early settlement.

General Land Office Surveys

General Land Office (GLO) surveys from the 1820s provide information on the pre-settlement landscape prior to logging (General Land Office 1855). GLO surveys have been used previously to assess historical vegetation changes (Table 1) (Bourdo 1956; Bragg and Hulbert 1976; Friedman and Reich 2005; Powell 2008; Peacock et al. 2008; Hanberry, Palik, and He 2012; Hanberry, Dey, and He 2012; Baas 2018) and reconstruct land cover at the time of settlement (Dilts et al. 2012). A few studies have used information from GLO surveys to analyze how a channel has changed overtime, generally finding higher discharge in current channels than in historical GLO surveyed channels (Huckleberry 1994; O'Connor, Jones, and Haluska 2002; Lecce 2013; White et al. 2017). Lecce (2013) used GLO surveys found that cross-sectional area increased up to three times which increases the movement of sediment during channel forming floods.

Purpose, Hypothesis, and Research Questions

The purpose of this study is to investigate the impacts of historical land use change and its effects on forest hydrology and channel form in the Big Barren Creek watershed in southeast Missouri by comparing channel measurements from government surveys in the early 1800s with present-day channel surveys. Previous studies in the United States generally found that bankfull channel area has increased overtime due to land use changes (Riedel, Verry, and Brooks 2005; O'Driscoll, Soban, and Lecce 2009; Bevan et al. 2018). These findings suggest that the Big Barren Creek watershed may have experienced similar increases in channel size that can be evaluated by width measurements provided by GLO surveys in comparison to other historical and present-day surveys. It is hypothesized that more intensive land uses in the Ozarks, such as logging, over the past 200 years has increased runoff rates from the watershed, causing larger floods and the erosional enlargement of stream channels over time. The findings from this study can provide insights into understanding how present-day drainage networks and channel forms have evolved in Big Barren Creek watershed due to the influence of Euro-American settlement and economic growth in the Ozark Highlands. The following three questions will be addressed by this thesis: 1) How has forest hydrology and channel form changed since the pre-settlement conditions documented in the GLO survey notes; 2) Can LiDAR be used to accurately measure channel widths in Mark Twain National Forest; and 3) What spatial and temporal trends are indicated by historical channel width change in BBC?

The use of GLO surveys to show the effects of logging on channel form has not yet been completed in the Mark Twain National Forest. Jacobson generally describes regional effects of logging but does not focus on smaller watersheds (Jacobson and Pugh 1992; Jacobson and Primm 1997; Jacobson 1995; Jacobson 2004). Reminga (2019) evaluated historical channel sedimentation in BBC but did not specifically evaluate channel changes due to historical logging disturbances. This research will improve our understanding of how anthropogenic disturbances have affected forested watersheds in the Ozark Highlands and add to our knowledge about how past forest disturbances have affected present day channel conditions. The continuous research on how historical and current land uses affect forested watersheds is important with the growing need for better management practices to improve stream health and stability and sustain our forested lands (Arthur, Paratley, and Blankenship 1998). Additionally, as the climate change progresses, it is expected that rainfall events and flooding will continue to increase, increasing runoff and erosion rates which may negatively affect Ozark watersheds (Pryor et al. 2014; Heimann, Holmes, and Harris 2018). With the knowledge of how land use changes affect watersheds, best management practices can be planned for in Ozark's forests, and mitigating the effects of climate change.

Table 1. Location of GLO vegetation and channel studies.

Reference	Year	Study Topic	Location
Bourdo	1956	Vegetation	Upper Peninsula of Michigan
Bragg and Hulbert	1976	Vegetation	Geary County, Kansas
Friedman and Reich	2005	Vegetation	Northeast Minnesota
Powell	2008	Vegetation	Umatilla National Forest
Peacock et al.	2008	Vegetation	Tombigbee National Forest
Hanberry et al.	2012	Vegetation	Missouri Ozarks
Hanberry et al.	2012	Vegetation	Laurentian Mixed Forest Province and Eastern Broadleaf Forest Province, Minnesota
Baas	2018	Vegetation	Delaware County, Indiana
Dilts et al.	2012	Land Cover Change	Walker River Basin, Nevada and California
Huckleberry	1994	Channel	Gila River, Arizona
Knox	1977	Channel	Platte River watershed, Wisconsin
O'Connor et al.	2002	Channel	Quinault River and Queets River
Lecce	2013	Channel	Blue River, Wisconsin
White et al.	2017	Channel	Northeast Oregon

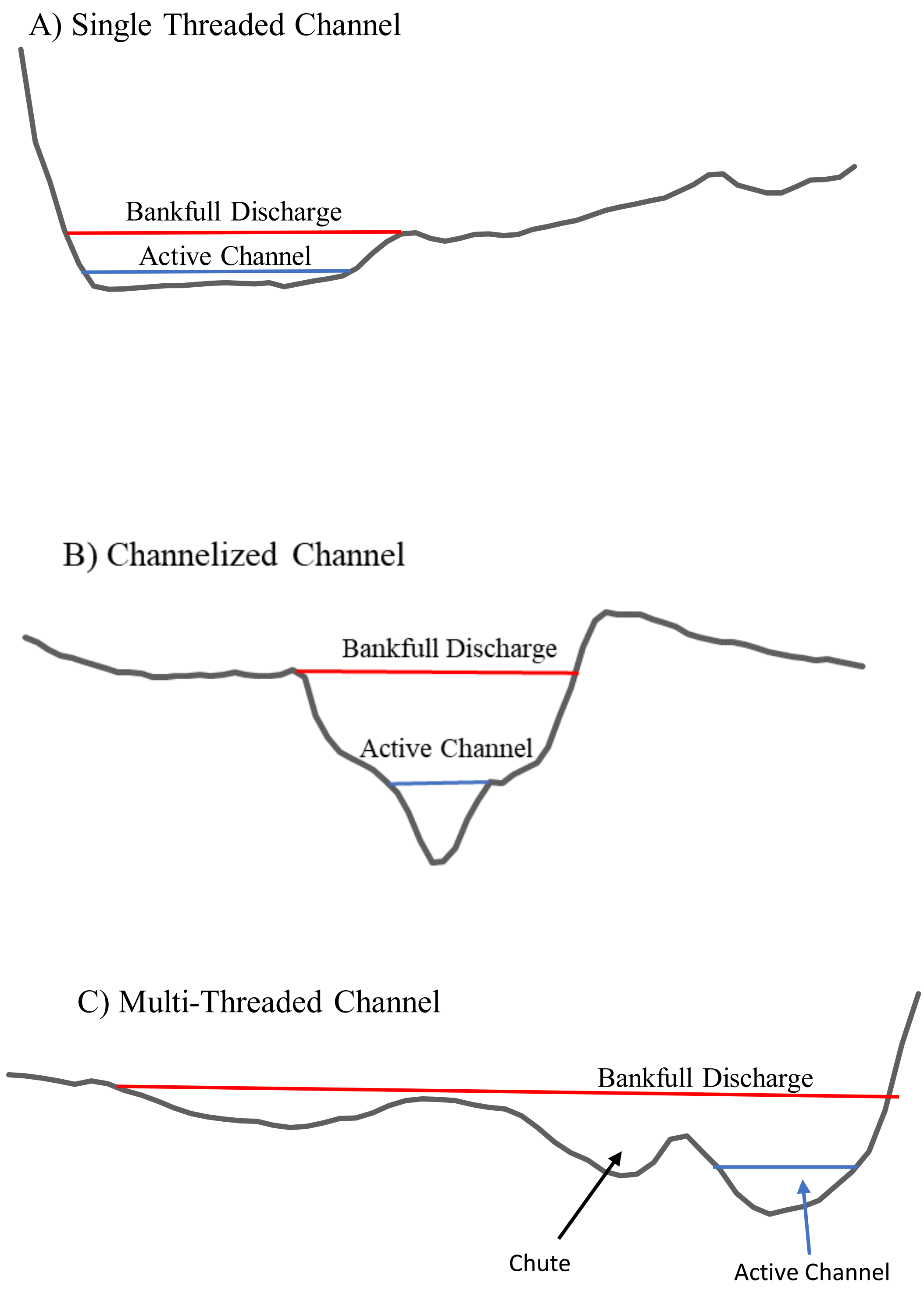


Figure 1. Bankfull discharge for multiple channel types found in the study area.

Figure 2. Pine tree snow interception in the Big Barren Creek watershed in December 2020.

STUDY AREA

Regional Location

Big Barren Creek (BBC) watershed drains 191 km^2 of Carter, Oregon, and Ripley Counties in southeast Missouri (Figure 3). The towns of Van Buren, Winona, Grandin, Alton, Hunter, and Doniphan surround the watershed with all having populations less than 2,100 residents. The BBC watershed lies almost entirely within Carter County, which had an estimated population of 5,982 in 2019 (U.S. Census Bureau 2020). The main channel flows 40 km from an elevation of 314 m to 109 m where it flows into the Current River about 24 km south of Van Buren, MO. About 150 km^2 of the Eleven Point Ranger District of the Mark Twain National Forest is drained by BBC. The study area is in the Current River Hills sub region of the Salem Plateau, a physiographic region of the Ozark Highlands, which is characterized by extensive rolling highlands, dolomite and limestone bedrock, and areas of karst topography (Panfil and Jacobson 2001; Nigh and Schroeder 2002).

Geology and Soils

The BBC watershed is composed of mostly weathered residuum formed from underlying dolomite and sandstone bedrock which can be more than 30 m thick (Figure 4) (Miller and Vandike 1997; Panfil and Jacobson 2001). The watershed contains losing and gaining streams, caves, sinkholes, and springs commonly associated with karst topography formed by the solution of carbonate rocks over long periods of time (Nigh and Schroeder 2002; Weary et al. 2014). The BBC watershed is located along the Wilderness-Handy fault zone that trends northeast forming the bedrock bluff formation in the lower half of the watershed (Weary et al. 2014).

Upland soils in the BBC watershed are generally formed in parent materials consisting of a thin layer of silty Pleistocene loess of glacial origin over clayey residuum from the weathering of cherty limestone and dolomite (Gott 1975; U.S. Department of Agriculture, Natural Resource Conservation Service 2006). Loess deposits are located on broad ridgetops and gentle slopes. However, most of the loess deposits have been eroded producing upland soils formed in a mixture of loess and residuum (Gott 1975). Three soil associations cover the BBC watershed, including: the Scholten-Coulstone association, the Rueter-Relfe-Poynor-Alred association, and the Scholten-Clarksville association (Figure 5) (Web Soil Survey 2019). Where loess is absent leached, acidic forests soils known as ultisols occur over 86% of BBC (Web Soil Survey 2019) (Figure 6). Without fertilizer and lime, ultisols are usually not suitable for productive agriculture and must be supplemented for continuous production (Web Soil Survey 2019). Alfisols and entisols cover 13% of the watershed and are commonly located on floodplains where soil fertility is higher and more suitable for continuous agriculture (Web Soil Survey 2019).

Alluvial soils in the BBC watershed vary from silt loams to very gravelly depending on location in the stream network and flooding frequency. There are 21 different soil series in the BBC watershed with seven soil series described as soils deposited by streams in alluvium (Table 2) (U.S. Department of Agriculture, Natural Resource Conservation Service 2006). Midco, Secesh, and the Tilk-Secesh complex are the most common alluvial soil series making up about 57% of the alluvial soils in the watershed. Frequently flooded alluvial soils are found along the tributaries of BBC with a silt and sand soil texture (Figure 7). Occasionally flooded alluvial soils with a gravelly texture occur along the main stem of BBC. The soils that are rarely flooded have a silty texture, typically being found on the floodplain of the main stem of BBC. Alluvial soils that contain large amounts of sand and gravel make up about 12% of the soils in the watershed, which are transported to the drainage network through incision (Jacobson 2004).

Climate and Hydrology

The climate in BBC is continental with hot, humid summers. There are occasional episodes of severe weather in winter, though only an average of seven inches of snowfall annually (Gott 1975). Precipitation amounts generally exceed 116 cm/yr and are frequently a result of thunderstorms which are most common in spring (Gott 1975; Pavlowsky, Owen, and Bradley 2016). These thunderstorms often produce damaging hail, wind, and lightening (Gott 1975). Over the past 30 years, rainfall totals and frequency of intense rainfall events are shown to be increasing in the BBC watershed (Pavlowsky, Owen, and Bradley 2016). On April 30, 2017, the Current River at Van Buren, Missouri experienced its largest flood within the last 100 years with a peak storm flow of 5,069 m^3/s and maximum stage of 11.4 m (Heimann, Holmes, and Harris 2018). The recent increase in larger floods could increase flood frequency and cause changes to stream channels in BBC (Pavlowsky, Owen and Bradley 2016). Over the past 30 years, the magnitude and frequency of flooding has been increasing, suggesting that channel systems may respond by channel erosion and widening (Heimann, Holmes, and Harris 2018).

Most headwater streams in the area are losing or dry streams caused by karst topography that underlies much of the Ozarks' region (Gott 1975; Panfil and Jacobson 2001; Nigh and Schroeder 2002). Therefore, much of the study area has no perennial flow and precipitation infiltrates and travels through the karst aquifer system and reemerges from springs (Panfil and Jacobson, 2001; Jacobson 2004). The Ozarks Environmental and Water Resources Institute at Missouri State University maintains multiple discharge gaging stations throughout the BBC watershed (Owen, Ahmed, and Pavlowsky 2017; Owen, Ahmed, and Pavlowksy 2018). Monthly discharge records for four locations in the watershed show peak discharge in April with almost no runoff from June to December (Figure 8). Baseflow in the Current River drainage basin is largely spring fed with some of the largest springs in the United States found within the Mark Twain National Forest (Gott 1975; Panfil and Jacobson 2001).

Land Use History

Pre-Settlement Vegetation. Before Euro-American settlement, 70 percent of Missouri was covered by forest with the most extensive forest being the pine forests in the Ozarks (Cunningham 2006). The Missouri Ozarks was estimated to have 6.6 million acres of pine with about 4,000 to 25,000 board feet per acre before logging began in the area in 1887 (Liming 1946; Hill 1949; Cunningham 2006). The dominant pine species in the BBC watershed was short-leaf pine (Pinus echinata), with dominant hardwoods including, black oak (Quercus velutina), white oak (Quercus alba), and post oak (Quercus stellate) (Cunningham and Hauser 1989). Shortleaf pine was the dominant tree species recorded during GLO surveys in the Current River Hills with 3,849 recorded trees while total oak trees totaled 2,218 (Hanberry, Palik, and He 2012). USDA Forest Inventory and Assessment surveys completed between 2004 and 2008 recorded a decrease in shortleaf pines found on survey lines to 1,292 trees (-66%) while oak species increased to 4,581 trees (+107%) (Hanberry, Palik, and He 2012). A study of shortleaf pine abundance in the Pike Creek watershed, located just north of the study area, estimated the 1890 pine tree inventory (17,143 trees) was almost three times greater than the pine population in 1997 (5,744 trees) (Guyette and Dey 1997). The established pine and pine-oak forests did not allow for much undergrowth and limited vegetation left the understory relatively open (Martin and Presley

1958). Open forests, located on higher ground and gentle slopes, were covered with oaks, shortleaf pine, and bluestem grass (Andropogon gerardi), while the rough and dissected lands were covered in oak, pine, and other mixed deciduous tree species (Nigh and Schroeder 2002). The lack of transportation routes and limited farmland availability slowed population growth in the region allowing relatively undisturbed conditions to generally last until exploitative logging began in the 1880s (Galloway 1961).

Settlement. Prior to Euro-American settlement, the Osage controlled most of the land south of the Missouri River, including the Current River and BBC, but they had little effect on the physical landscape (Stevens 1991; Rafferty 2001). The Spaniard Hernando de Soto and his army were the first Europeans to record encounters with Native Americans in the Ozarks in the 1540s, though they did not settle the area (Stevens 1991; Rafferty 2001). French trappers in the late 1600s and early 1700s also contacted the Osage, but like the Spanish, they did not settle in the Ozarks, but had strong relationships with the Osage through trade and eventually settled in Potosi, north of BBC in the mid-1700s (Stevens 1991). In 1818, Henry Schoolcraft recorded his travels through the Missouri Ozarks noting the tall pines, savannah, and open forest floors in the Current River valley in the first recorded survey of the Ozarks (Schoolcraft 1821; Jacobson and Primm 1997).

The General Land Office was responsible for conducting surveys of public lands from 1785-1946 (Hanberry, Palik, and He 2012). Surveys including the BBC watershed were conducted in 1821. Settlement was sparse before the surveys were conducted but started to increase in the late 1800s. The early settlers of the Ozarks were Scots Irish descendants who migrated from Tennessee and Kentucky (Stevens 1991; Cunningham 2006). Van Buren was established in 1833 as a small village along the Current River and by the early 1840's Van Buren included a store, mill and courthouse with several residents (Stevens 1991). The towns of Grandin and Hunter, located in the Johnson township, about 14 kilometers east of the BBC watershed, and the town of Fremont, located in the Pike township, about 16 kilometers northwest of the BBC watershed, were incorporated in 1923 (U.S. Census Bureau 1930).

Historical Logging. The early logging history in Missouri was exploitative with a growing need for timber as the United States was developing. Small scale logging in the Ozarks was noted by Schoolcraft in 1818 but was limited to mills that provided lumber for small, local communities (Jacobson and Primm 1997). Large-scale timber operations began in the 1880s with the introduction of railroads to the area and the depletion of timber in the eastern states (Table 3) (Hill 1949; Jacobson and Primm 1997). Large logging companies constructed logging trams throughout forested areas to collect and deliver logs to the mill (Figure 9) (Stevens 1991; Rafferty 2001). The pine production period in Carter County began in 1887 when the Missouri Lumber and Mining Company, the largest lumber company in the area, began operations in Grandin, Missouri (Cunningham and Hauser 1989; Cunningham 2006). The mill was in operation from 1887 to 1909 in Grandin, Missouri (Cunningham 2006). In 1901, the Missouri Lumber and Mining Company had recorded more than 213,017 acres of cut land, in Carter County with peak production at 70 acres per day by logging suitable pines greater than 12 inches in diameter (Galloway 1961; Jacobson and Primm 1997; Cunningham 2006). In 1905, the Missouri Lumber and Mining Company expanded logging operations to Reynolds County and then Shannon County in 1907 (Stevens 1991). The mill at Grandin was relocated to West Eminence where it operated from 1909-1919 (Cunningham 2006). Oaks were often cut by smaller logging companies and commonly used for railroad ties once the pine was cleared (Jacobson and Primm 1997). The timber boom period brought an increase in population as larger towns started to develop with the arrival of loggers and their families (Cunningham and Hauser 1989). Overall, timber boom, in the Ozarks, lasted until the 1920s and population started to decline as the large mills left the area (Cunningham and Hauser 1989). Smaller logging companies continued operations until 1930 (Stevens 1991). After the logging period ended in BBC, clear-cut lands were abandoned or used for small-scale farming including open grazing (Galloway 1961; Jacobson and Primm 1997; Cunningham 2006).

Agriculture. While the Ozarks were initially settled in the early 1800's the most intensive land use changes occurred in the mid to late 1800's with the spread of row-crop agriculture, period of exploitative logging, and expanded railroads after the civil war (Jacobson and Pugh 1992). Free ranging hogs were abundant on forest lands prior to logging and decreased following the peak logging period while free ranging cattle increased after peak logging (Jacobson and Pugh 1992). Most of the land used for agriculture was located on the valley bottoms and scattered along flat uplands where adequate soil could be found, while the more profitable logging was taking place on the steeper slopes and along valleys of headwater drainages like BBC (Jacobson and Primm 1997). From 1890 to 1900, population increased 1.4 times, the number of farms increased 2.7 times and corn production increased 1.5 times corresponding with the arrival of the railroad and peak logging in Carter County (Table 4, Figure 10). Corn production peaked during 1900 to 1910 with over 480,000 bushels of corn harvested for those years before a sudden decrease of corn production in 1935 with 26,416 bushels harvested. Hog farming saw a peak in 1900 with 11,487 hogs with a peak in cattle farming in 1910 with 6,663 cattle. More recently, lands that are not forested are being used for cattle and forage crops (Jacobson and Pugh 1992).

Cyclical Logging and Management. After the period of exploitative logging, forest management was needed for logging to continue to be a source of income for residents. In 1922, the Missouri Forestry Association (MFA) was formed to help start conservation practices in Missouri's forests however, they did not yet approve the establishment of a national forest in Missouri (Cunningham 2006). The position of state forester was created within the Department of Agriculture in 1925 with a focus on fire control and reforestation until 1931 when the office was eliminated (Keefe 1987; Cunningham 2006). Early opposition to the government buying land for a National Forest was overturned by the economic hardship that came during the Great Depression, which led to many landowners selling their land to the government in the early 1930s (Halpern 2012). President Franklin D. Roosevelt proclaimed the Mark Twain National Forest and the Clark National Forest on September 11th, 1939. The two Forest units were later combined into the Mark Twain National Forest system on February 17th, 1976 (Halpern 2012). Today the Mark Twain National Forest system totals about 1.5 million acres with about half of the land within the boundaries under private ownership (U.S. Department of Agriculture, Forest Service 1999).

In 2011, a multi-million-dollar project began to restore the Missouri pine-oak woodlands by uniting multiple organizations and landowners. This restoration project focused on restoring the pine and pine-oak bluestem woodlands because of their resiliency to predicted climate change by being more adapted to fires (Missouri Pine-Oak Woodlands Restoration Project 2011). The project's goal is to restore up to seven percent of the fire-adapted forest located in the Current River Hills (Missouri Pine-Oak Woodlands Restoration Project 2011). By mechanical thinning, prescribed fires, and the reintroduction of the natural fire regime, the outcome will be a more natural forested landscape (Missouri Pine-Oak Woodlands Restoration Project 2011). This project ended in 2020. In 2012, the Eleven Point and Poplar Bluff ranger districts in Mark Twain National Forest were selected for the Collaborative Forest Landscape Restoration Program created by Congress (U.S. Department of Agriculture, Forest Service). The program's goal is to restore the shortleaf pine-oak woodlands and is set to end in 2022 (U.S. Department of Agriculture, Forest Service).

Native Americans were the first people to intentionally burn in the Ozarks to sustain an open landscape (Batek et al. 1999). Once Europeans settled the Ozarks, a fire suppression regime began to protect the land from wildfires (Jacobson and Primm 1997). In the 1920's logging was declining, and clear-cut land was left in place of the natural forested landscape. This meant open land-controlled burn were reintroduced to manage fields (Jacobson and Primm 1997). Unregulated burning of forests in the Ozarks averaged once every 3-5 years, often resulting in wildfires extending into the canopy (Callison 1953). With the introduction of Mark Twain National Forest, the fire regime shifted to more managed burns. The 21st century brought a need for restoration projects and the U.S. Forest Service has been executing prescribed burns in the Mark Twain National Forest where the pine is being reintroduced to the landscape. The prescribed burns in Mark Twain National Forest follow a 3-to-5-year interval to mimic the natural fire frequency (Guyette and Larsen 2000).

Stream Channel Characteristics in Big Barren Creek

The historical logging of Missouri's forests has had long-term effects on watersheds in the Ozarks. Increases in water and sediment yields, storm flows, and base flows were found in watersheds disturbed by logging (Jacobson 2004). The increase in sediment yields often came from roads and tramways that were built during the logging period (Jacobson 2004). Ozark uplands and slopes supplied an abundance of chert gravel from the weathering of carbonate rock that was deposited to valley bottoms (Jacobson and Pugh 1992; Jacobson 2004). Widespread disturbances such as logging and field clearing for row-crops caused Ozark watersheds to become “clogged” with gravel due to headwater valley incision, erosion of chert gravels, and rapid transport downstream (Hall 1983; Saucier 1983).

Historical disturbances in BBC have affected channel form and stability by increasing runoff due to soil disturbance and removal of pines causing the narrowing of multi-threaded channel systems and through the creation of relatively large single channels in some segments of the main channel and larger tributaries (Jacobson 2004; Reminga 2019). Reminga (2019) estimated that today about 8% of the main channel is multi-threaded as opposed to an estimated 58% based on evaluations of historical maps and geomorphic indicators. Runoff rates prior to logging were low due to the dense, well-established forest and have increased due to soil disturbance, roads, and forest changes due to the historical logging period (Jacobson 2004). Higher runoff rates could be responsible for increased flood peaks that cause higher stream power resulting in an enlargement of the channel (Jacobson 1995; Jacobson 2004; Lecce 2013).

Channelization and levee construction have been prevalent since at least the 1960’s in BBC (Jacobson and Primm 1997; Bradley R. 2017). The channelized segments are straight, single-threaded channels once material is removed by mechanical excavation (Jacobson and Primm 1997). Sediment removal can cause an increase in channel size and slope, as well as increase discharge and sediment loads (Simon and Rinaldi 2006). Gravel has been used for road construction and been pushed onto channel banks to inhibit flooding in neighboring fields in valley bottoms (Jacobson and Primm 1997). In summary, it is hypothesized that BBC channels have enlarged due to more runoff, larger floods and channel widening by roads, tramways, and channelization causing a shift from a multi-threaded drainage network to a single channel form.

Table 2. Alluvial soil series in BBC (U.S. Department of Agriculture, Natural Resources Conservation Service 2019).

Alluvial Soil Series	Area km^2	% of Alluvial Soils	Soil Order	Landform	Depth to Water Table (cm)	Flooding Frequency	Hydrologic Soil Group
Relfe-Sandbur complex	0.4	4.1	Entisols	Floodplain	> 203	Frequent	A
Sandbur-Wideman-Relfe complex	0.1	0.7	Entisols	Floodplain	124 to 200	Frequent	A
Tilk-Secesh complex	3.5	35.8	Alfisols	Floodplain	> 203	Occasional	B
Midco	2.8	28.9	Entisols	Floodplain	> 203	Occasional	A
Higdon	0.0	0.2	Alfisols	Floodplain	30 to 76	Occasional	C/D
Secesh	1.7	17.6	Alfisols	Terrace	> 203	Rare	B
Bearthicket	1.2	12.7	Alfisols	Terrace	> 203	Rare	B

Table 3. Major event timeline for the BBC watershed.

Event	Year
GLO surveys completed for BBC	1821
Schoolcraft travels through the Missouri Ozarks	1818
Van Buren, MO was established as a small village	1833
Open pit mining begins in Bonne Terre, MO about 70 miles away	1864
Missouri Lumber and Mining Company (MLMC) opens in Grandin, MO	1887
Railroad arrives in Grandin, MO	1888
Height of logging in Carter County	1899
Peak row cropping in Carter County	1900-1910
MLMC Grandin Mill closes and moves to Shannon County	1909
Large drop in row cropping in Carter County	1935
U.S. Forest Service purchases 3.3 million acres of land and forms Mark Twain National Forest	1935
U.S. Forest Service introduces cyclical timber harvesting	1950
Landowners begin channelizing on private property	1960's
U.S. Forest Service introduces prescribed burning management	2000
Start of hydrologic monitoring network	2016
Field work for this study	2020

Table 4. Carter County agricultural data (U.S. Department of Agriculture, National Agriculture Statistics Service 2021).

Year	Number of Farms	Cattle	Hogs	Corn Harvested (Bushels)	Wheat Harvested (Bushels)
1860	N/A	1,037	2,726	68,176 *	2,694
1870	N/A	1,183	3,589	73,250 *	4,992
1880	257	1,798	8,480	100,830 *	6,546
1890	207	3,148	4,645	158,979 *	602
1900	554	4,703	11,487	244,580	8,900
1910	602	6,663	7,538	239,930	3,967
1920	608	N/A	N/A	N/A	N/A
1925	650	5,051	8,358	163,332	3,742
1930	586	6,491	8,848	147,703	1,649
1935	777	6,481	9,007	26,416	5,426
1940	660	4,807**	7,465***	59,264	1,697
1945	590	5,367	4,143	50,606	5,459
1950	547	4,778	8,057	75,512	6,054
1954	431	6,259	6,266	21,107	0
1959	393	4,986	11,576	110,771	6,778
1964	260	6,586	5,622	39,840	2,604
1969	215	4,789	5,056	N/A	N/A
1974	196	7,880	4,444	14,240	2,725
1978	232	6,302	5,558	10,040	3,250
1982	202	6,459	3,918	Data Withheld	2,875
1987	190	6,707	4,322	Data Withheld	11,818
1992	196	6,868	4,060	Data Withheld	Data Withheld
1997	202	9,489	5,864	Data Withheld	Data Withheld
2002	228	11,147	16	Data Withheld	Data Withheld
2007	203	8,058	2,192	Data Withheld	0
2012	196	7,071	0	0	0
2017	160	7,095	21	N/A	N/A

N/A = Not Available

* Specified as "Indian Corn"

** Cattle and Calves Over 3 Mo. Old

*** Hogs and Pigs Over 4 Mo. Old

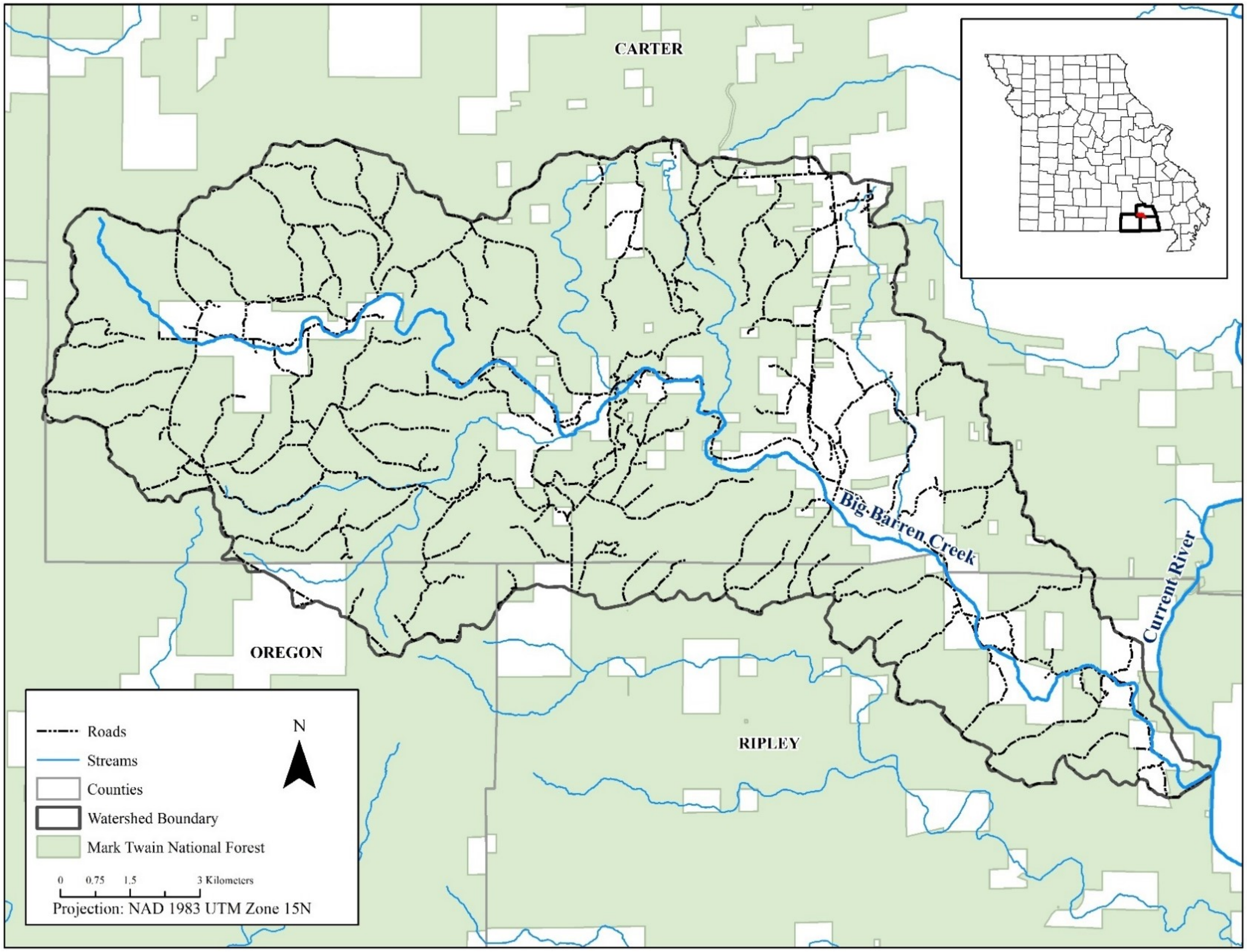


Figure 3. Location of GLO survey crossings in the BBC watershed (Data provided by the National Forest Service, Doniphan Ranger Station).

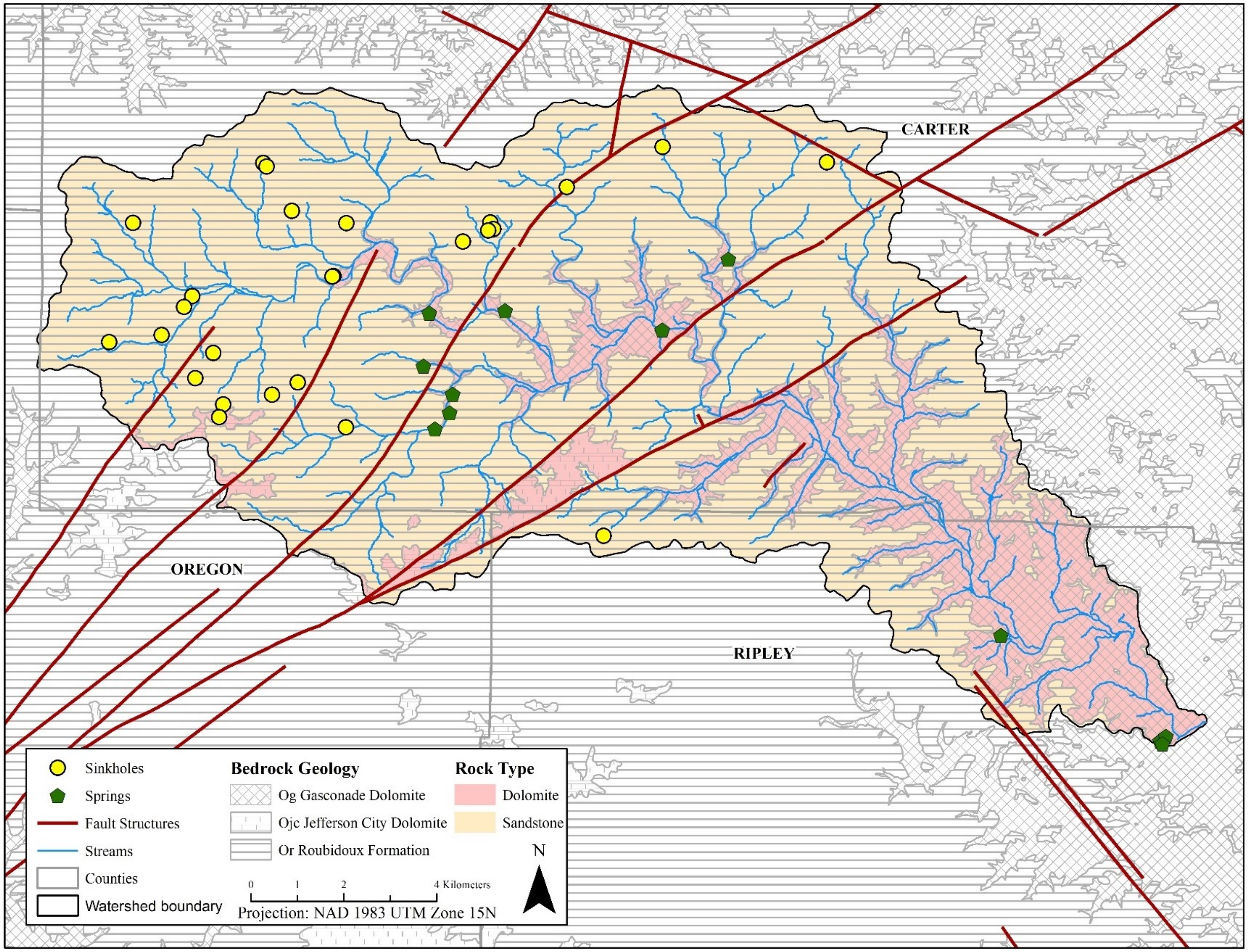


Figure 4. Geology map of the BBC watershed (Data obtained from the Missouri Spatial Data Information Service).

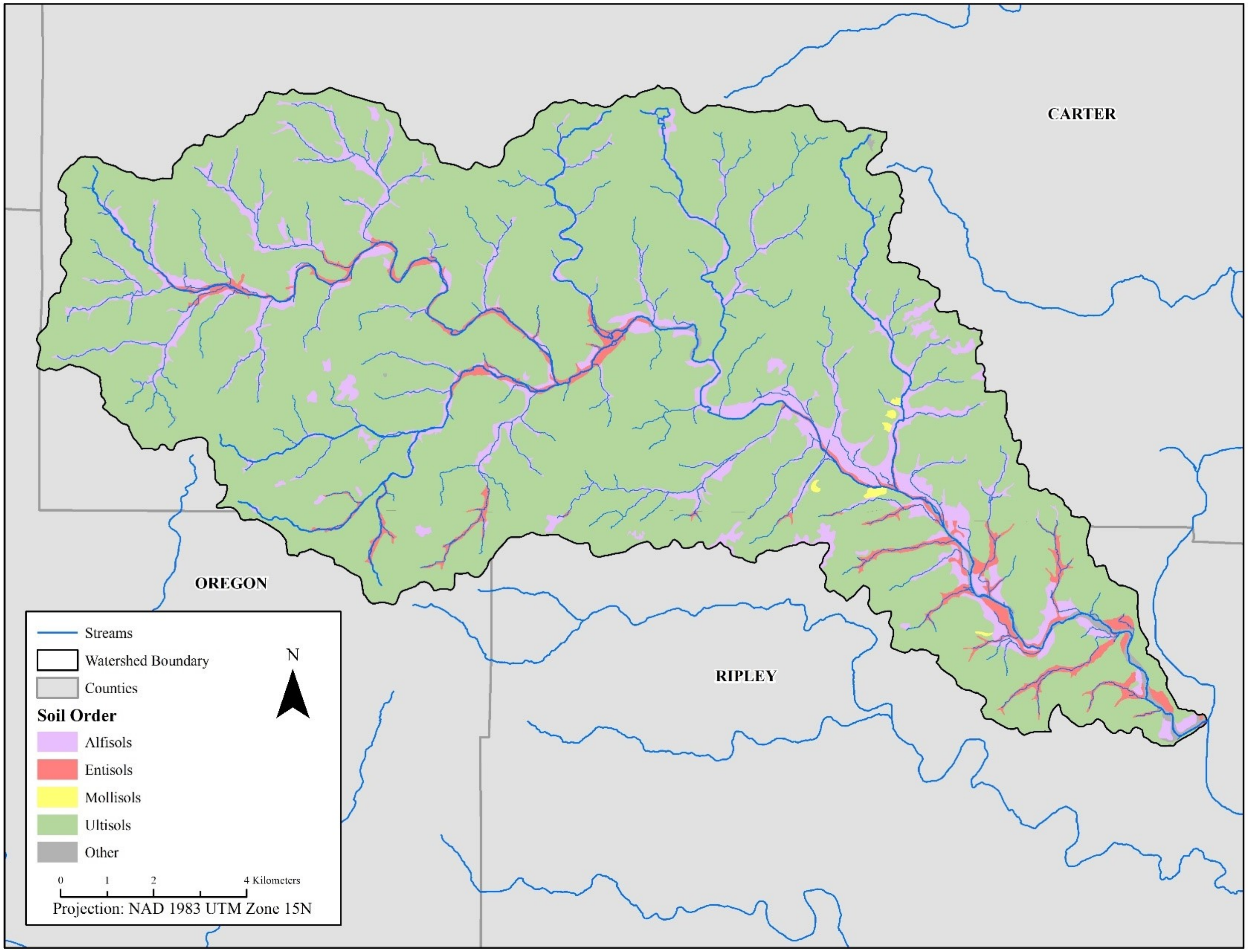


Figure 5. Soil order map of the BBC watershed (Data obtained from the Web Soil Survey).

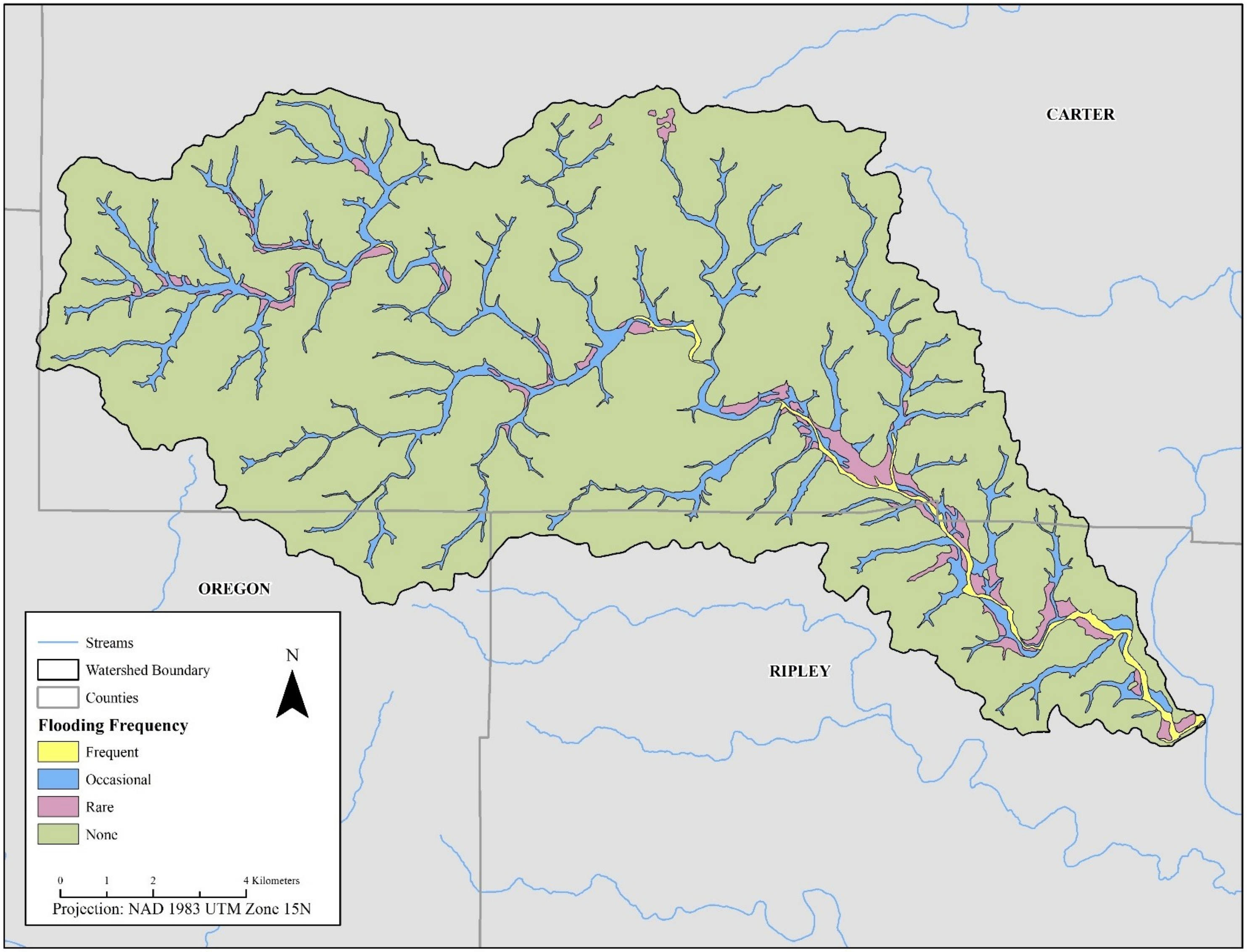


Figure 6. Flooding frequency of the BBC watershed (Data obtained from the Web Soil Survey).

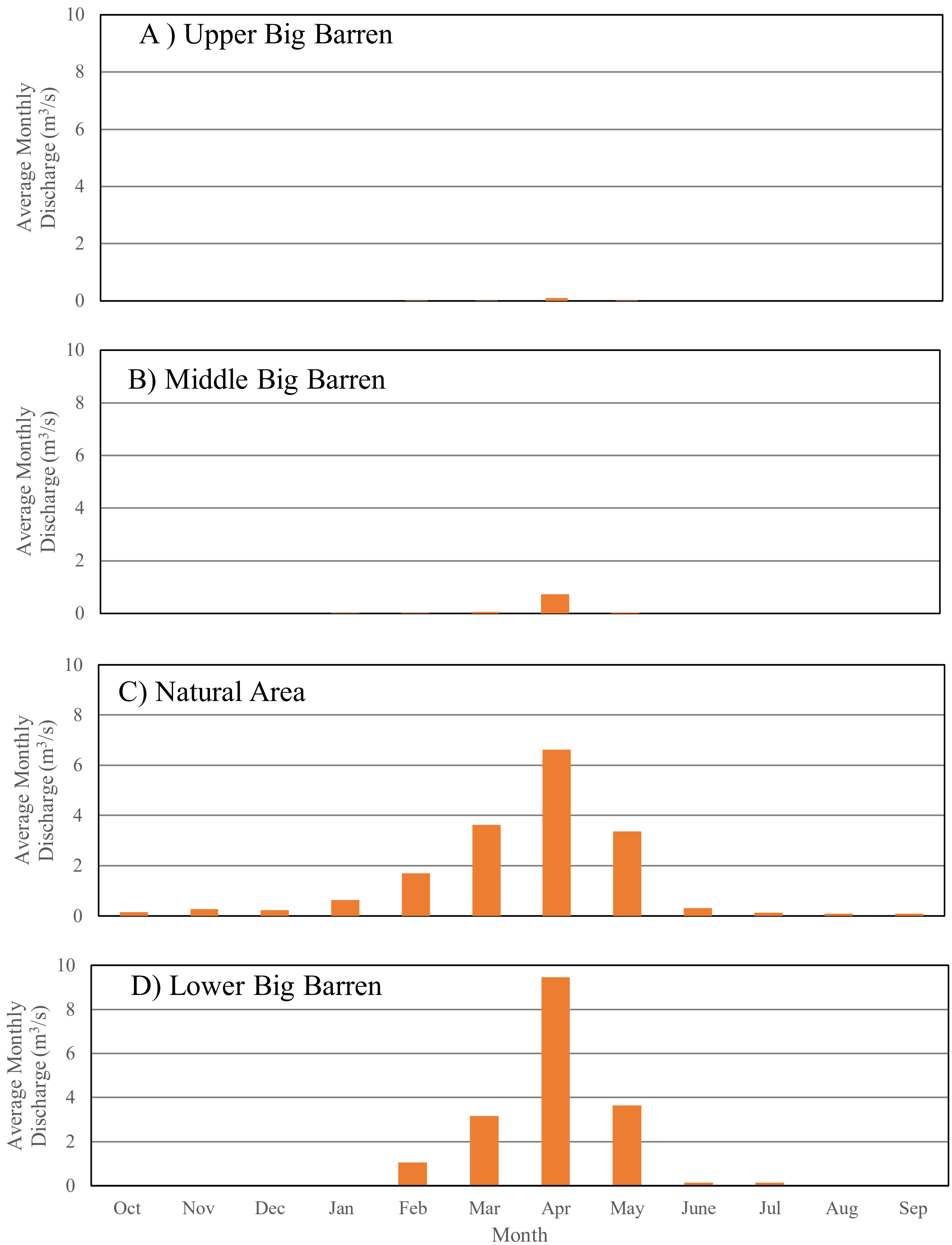


Figure 7. Mean of water years 2017 and 2018 for average monthly discharge for four gaging stations in BBC.

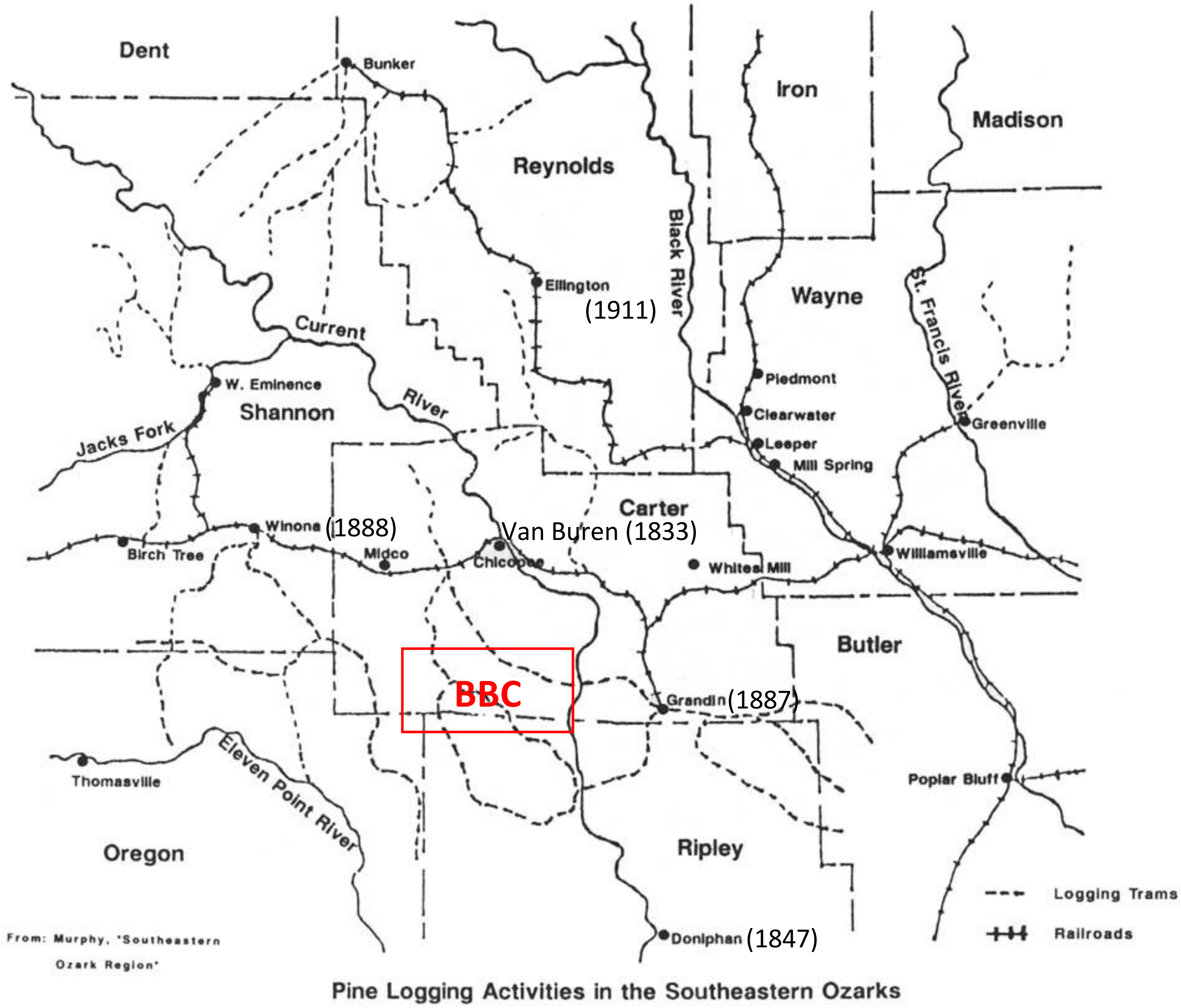


Figure 8. Logging tram map with the approximate location of Big Barren Creek (BBC) (Stevens 1991).

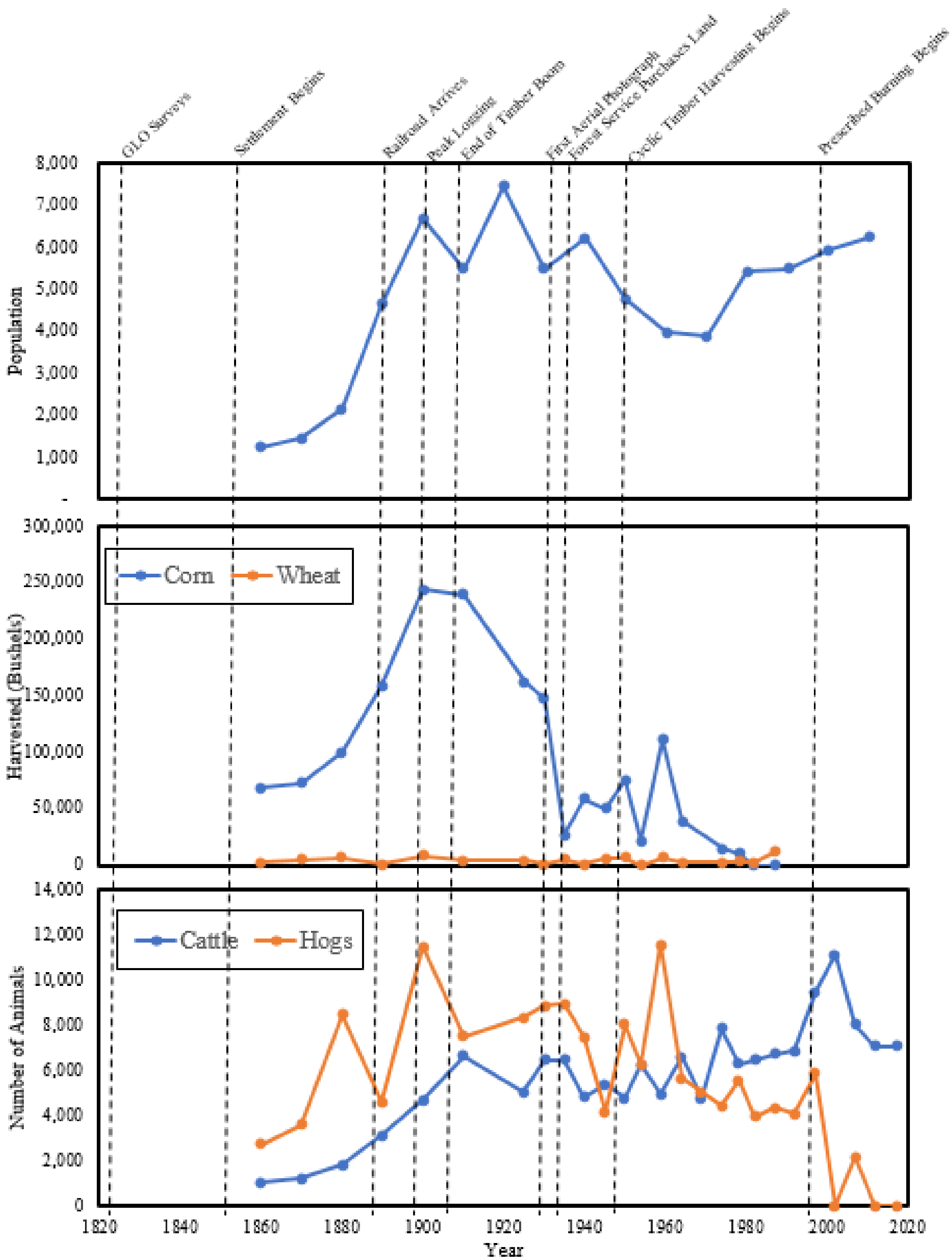


Figure 9. Carter County comparison of population, major events, corn and wheat harvested, and hots and cattle from 1820-2020 (U.S. Department of Agriculture, National Agriculture Statistics Service 2021).

METHODS

The main goal of this study was to assess the historical channel width changes in a headwater stream system. A combination of geospatial and field methods were used to complete the following tasks: 1) determine the channel width changes from the 1821 General Land Office surveys to the channel widths extracted from the LiDAR derived DEM, 2) ensure the accuracy of the extracted width measurements by conducting ground truthing at historical sites, 3) determine the spatial and temporal trends of channel width changes in the Big Barren Creek watershed, and 4) use gage survey data provided by the Ozarks Environmental and Water Resources Institute to evaluate current channel morphology. These tasks were used to evaluate the channel response to historical disturbances in the Big Barren Creek watershed.

Geospatial Methods

GLO Survey Georectification. GLO survey notes, from spring 1821, and maps, from 1853 and 1861, were obtained from the U.S. National Forest Service for townships, T25NR1E, T25NR1W, T25NR2W, T25NR3W, T26NR1W, and T26NR2W which covered the entire study area (Figure 10 & 11). The survey maps were geo-rectified, and a section line grid was created for the entire watershed. Points were created on all the crossings of section lines and channels that were described by the GLO surveyors and the information from the survey notes was added to the point's attribute table. Surveyors took measurements using Gunter Chains which were converted to meters for this study (National Museum of American History). Each unit chain length is 20.1 meters and includes 100 links that are 0.2 meters long (National Museum of American History). We cannot be certain how the historical width measurements were collected in the field by GLO surveyors. It is assumed that surveyors measured the main “active” channel as channels in BBC are ephemeral channels, in most cases. Furthermore, the specific procedure for how the GLO surveys were completed were not clear. Instructions for GLO surveyors were published in 1855, however, this was 34 years after the surveys of BBC were completed and survey procedures were not standardized before 1855 (Bourdo 1956). The instructions are clear on how to measure navigable streams, however, streams in BBC are smaller and do not fall under this category. Streams in BBC would be measured quickly, and the 1855 instructions state the following: “Intersections by line of water objects. All rivers, creeks, and smaller streams of water which the line crosses; the distance on line at the points of intersection and their widths on line.” This instruction suggests that channels were normal to flow on along the section line. Therefore, for this study, we assume that channel widths were measured perpendicular to flow direction. This assumption is supported by recent channel width measurements collected during this study.

Network Delineation. The U.S. Forest Service provided a one-meter spatial resolution, LiDAR derived digital elevation model (DEM) for Ripley county collected in 2016 and a 0.5-meter spatial resolution, LiDAR derived DEM collected in 2017 and were combined into a one-meter LiDAR derived DEM for the entire watershed to be used for this study. Using ArcMap 10.8.1, the DEM and ArcGIS hydrology toolset was utilized to produce fill, flow direction, and flow accumulation rasters. The raster calculator created a flow accumulation threshold where pixels that drain 2,000 m^2 were classified as a stream head and used to form the stream network to calculate drainage density. The stream network was delineated at this scale because it included small valleys and topographic lows on the hillshade, created from the LiDAR derived DEM. The stream network was ordered by the Strahler stream order method using the “stream order” tool in

ArcMap (Strahler 1957). A second stream network was delineated for GLO survey analysis. The threshold used for this stream network classified a stream when pixels drained 500,000 m^2 which was the smallest threshold that included all GLO survey points and could be used to find crossings unnoticed by GLO surveyors. Crossing sites were assigned numbers as they were marked on the stream network (i.e., 1-38).

Current Channel Site Analysis. Using ArcMap 10.8.1, channel widths were measured by creating lines that stretched from bank top to bank top on the hillshade at each point to determine active channel width. Widths for five sites were measured upstream or downstream from the survey site due to disturbance to better represent the width and drainage area relationship (Table 5). Valley elevations were extracted from the DEM and used to plot cross-sectional graphs in excel for each of the 38 GLO sites. These graphs were used to measure the channel width and determine the measurement error between hillshade and cross-section measurements. The slope for each point reach was also calculated by creating a 500-meter line on the DEM and extracting the elevations at the downstream and upstream end of the line and calculating the difference, then dividing the difference by 500.

To find trends on the main channel, minimum and maximum reach widths were recorded for each river kilometer (R-km) (Figure 12). At every kilometer along the main stem, 500-meter reaches, 250-meters upstream and downstream were evaluated, and the minimum and maximum widths were extracted using the same method as the extraction of survey site widths. This was used to compare width trends along the main channel with drainage area.

Sub Watershed Delineation. Sub watersheds were delineated using the stream channel crossings that included historical data as pour points for sub watersheds. The created stream network that used a threshold of 2,000 m^2 was used to create a drainage density for each watershed by clipping the stream network to the watershed polygon. Drainage density was calculated by dividing the total channel length by the area of the watershed polygon. A road network density was also calculated using a road network shapefile obtained from the U.S. Department of Agriculture FSGeodata Clearinghouse. The road network includes all roads, forest roads, and trails. The road network was clipped to each sub watershed to calculate road network density for each watershed.

Aerial Photograph Width Measurements. Aerial photographs for BBC were obtained for 1939-2015 from multiple sources (Table 6). Resolution of the aerial photographs ranges from 0.15-1.1 meters. These photographs were used to estimate the channel changes overtime for specific GLO survey sites (De Rose and Basher 2011). Channel widths were measured by estimating the width of the channel at GLO sites where the channel was clearly visible. To be used for analysis, sites needed to include a width measurement prior to 1986 to show more accurate width change trends.

Field Methods

Field surveys were used to evaluate measurement errors and accuracy of the LiDAR width measurements. They were conducted by two teams at 20 of the 38 GLO sites that were close to the road or on National Forest Service land in October 2020. Channel form of each site was classified to indicate if the measurement was a main channel or secondary channel for multi-threaded channels or if the site was a single threaded channel (Figure 13). Measuring tapes were pulled across the channel to determine the bankfull width at the site, as well as ten meters upstream and downstream. Maximum depth, or bank height, was measured using a stadia rod at the thalweg of the channel, also collected ten meters upstream and downstream from the site. Water depth was measured, where applicable, in the thalweg at the site location.

Gage Network and Discharge

Gaging stations in the BBC watershed were installed by the Ozarks Environmental and Water Resources Institute from Missouri State University in 2015 and 2016. There are 14 Water Level Logger gaging stations recording data every five minutes which is downloaded approximately every 10 weeks in second and third order streams in BBC (Owen, Ahmed, and Pavlowksy 2018). For this study, flow records from nine of the gaging stations were used to understand current channel morphology (Table 7, Figure 14). During installation, channel surveys were completed and included cross-sectional surveys to calculate bankfull width and mean bankfull depth. The data from the surveys was used to determine discharge using the cross-section hydraulic analyzer spreadsheet created by the National Resource Conservation Service (Moore 2011). Gage data was then used to determine the annual exceedance-probability for the 50% discharge using the regression equation for streams in region 2 of rural Missouri (Southard and Veilleux 2014).

$$Q_{50\%} = (10^{2.493})(DRNAREA^{0.686})(BSHAPE^{-0.222})$$

Where:

$$DRNAREA = \text{Drainage Area } (mi^2)$$

$$BSHAPE = \text{Stream Length}^2 / \text{Drainage Area } (mi^2)$$

The U.S. Geological Survey regression equation produces a discharge rate of cubic feet per second that was then converted to cubic meters per second for comparison with the gage data.

Table 5. Re-measured GLO survey sites.

Site ID	Stream Order	Width at GLO Survey Site (m)	Re-measured Width (m)	Location of Re-measured Width
5	4	11	23	20m Downstream
21	2	14	8	30m Upstream
27	3	18	9	50m Upstream
37	4	23	14	307m Upstream
38	3	27	8	413m Upstream

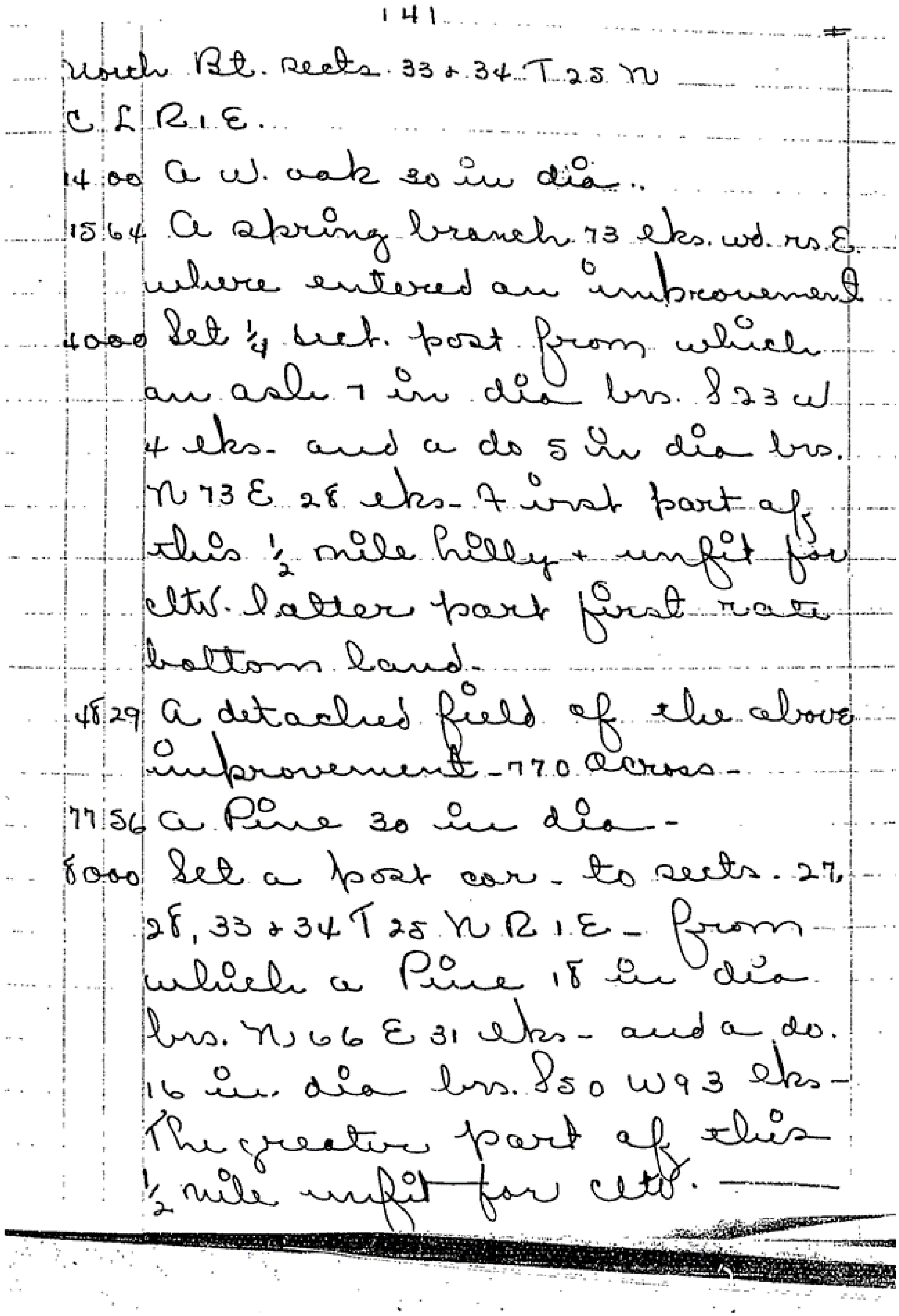
Table 6. Aerial photographs for BBC.

Year	Date	Source	Resolution (m)
1939	April 24th, 1939 and July 6th, 1939	USFS	1.0-1.1
1956	1956	USFS	0.77-0.79
1966	March 28th, 1966	USGS EROS	0.86-1.0
1986	September 6th, 1986	USDA-FS	0.67-0.73
1995	April 6th, 1995	MSDIS	1
1995	April 6th, 1995 and February 18th, 1995	USGS EROS	1.0
2007	March 7th, 2007 to April 16th, 2007	USGS EROS	0.6
2013	May 13th 2013	Google Earth	0.41-1.1
2015	March 15th 2015	MSDIS	0.15

Table 7. OEWRI stream gage network data.

Gage Name *	Drainage Area (km^2)	Bankfull Width (m)	Mean Bankfull Depth (m)	Bankfull Discharge (m^3/s)	2-Year Discharge Recurrence Interval (m^3/s)
Upper BBC	2.51	18.7	0.61	6.94	7.22
Polecat	6.19	24.7	0.51	8.02	12.7
Fools Catch	7.82	48.8	0.51	19	14.3
Middle BBC	47.8	87.8	0.56	38	46.5
Lower NA	124.2	117	0.91	63	89.4
Lower BBC	186.1	122	0.99	75.2	107.2
Upper NA	103.6	54.3	1.04	53.7	78.8
Tram	1.59	29.8	0.28	3.01	4.6
Wolf Pond	5.13	54.6	0.36	11.7	10.6

* See locations in figure 14



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North Bt. Sects. 33 & 34 T 25 N
C. L. R. 1. E.
14 00 A W. oak 30 in dia.
15 64 A spring branch 73 lks. wd. rs. E. where entered an improvement
40 00 Set ¼ sect. post from which an ash 7 in dia brs. S 23 W 4 lks. and a do 5 in dia brs. N 73 E 28 lks. First part of this ½ mile hilly & unfit for cltv. latter part first rate bottom land.
48 29 A detached field of the above improvement 7.70 across.
77 56 A Pine 30 in dia.
80 00 Set a post cor. to sects. 27, 28, 33 & 34 T 25 N R 1 E. From which a Pine 18 in dia brs. N 66 E 31 lks. and a do. 16 in dia brs. S 50 W 9 3 lks. The greater part of this ½ mile unfit for cltv.

Figure 10. Example of a GLO survey note for a section line.

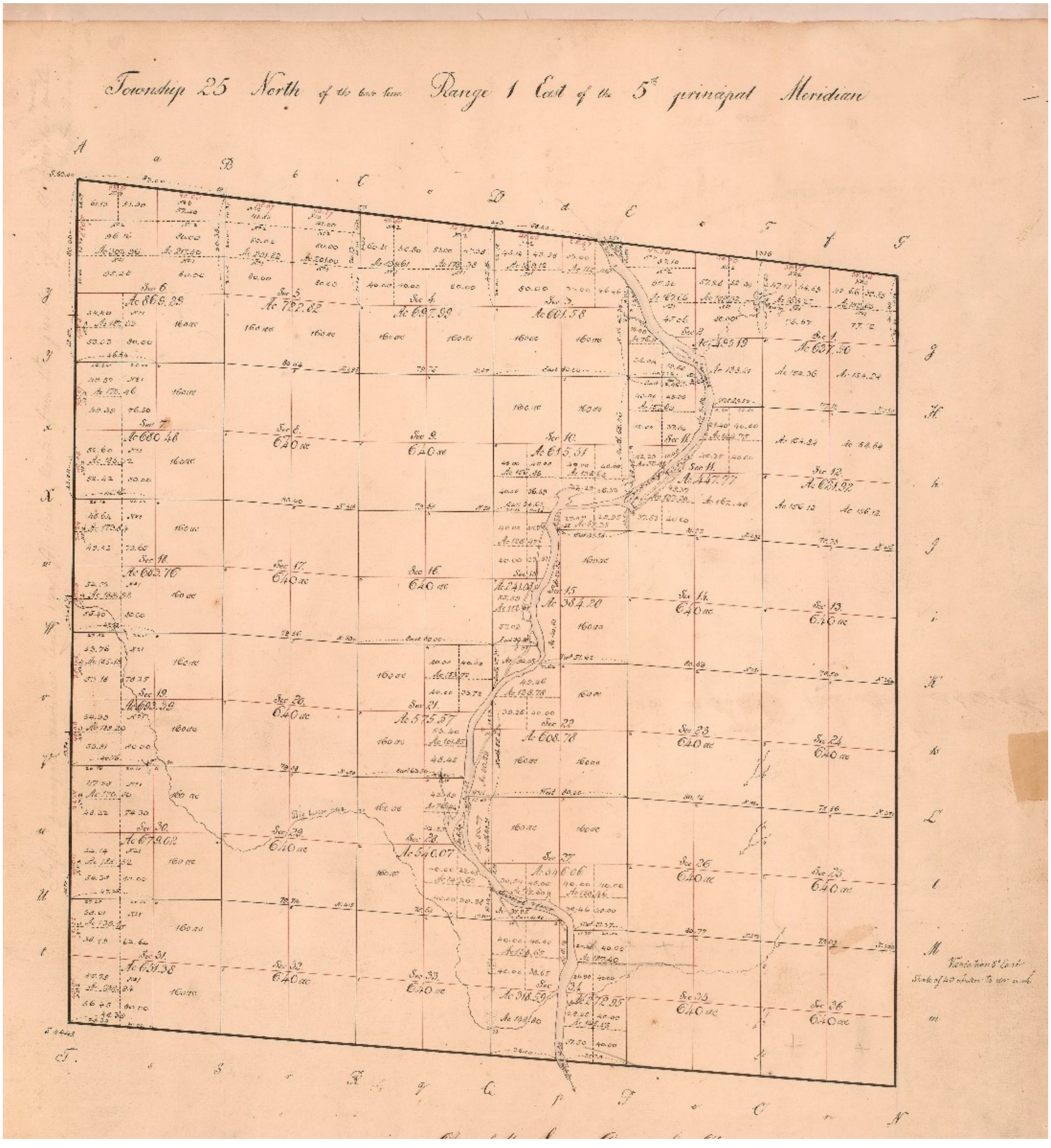

Figure 11. A township map created from GLO notes.

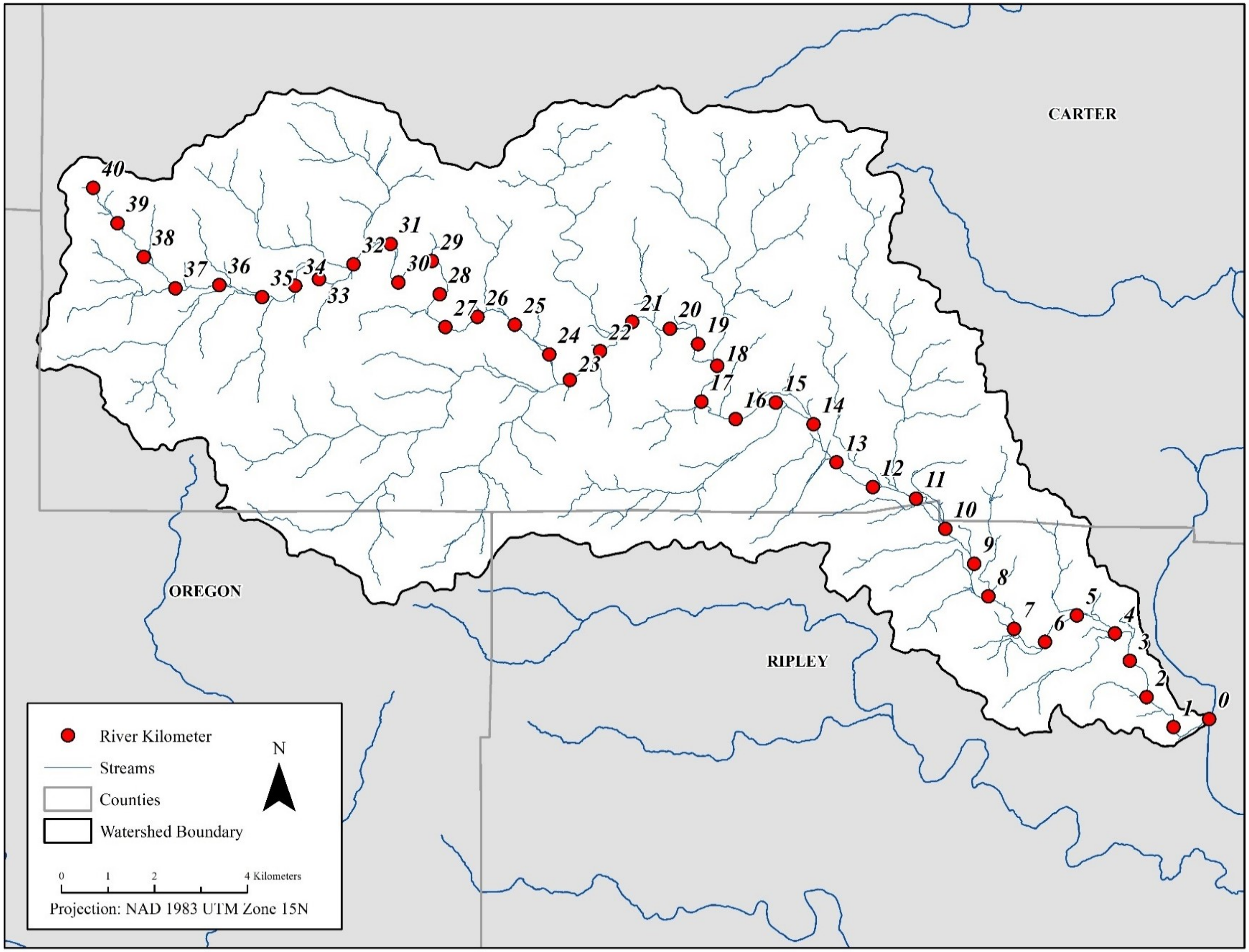

Figure 12. River kilometer map of BBC.

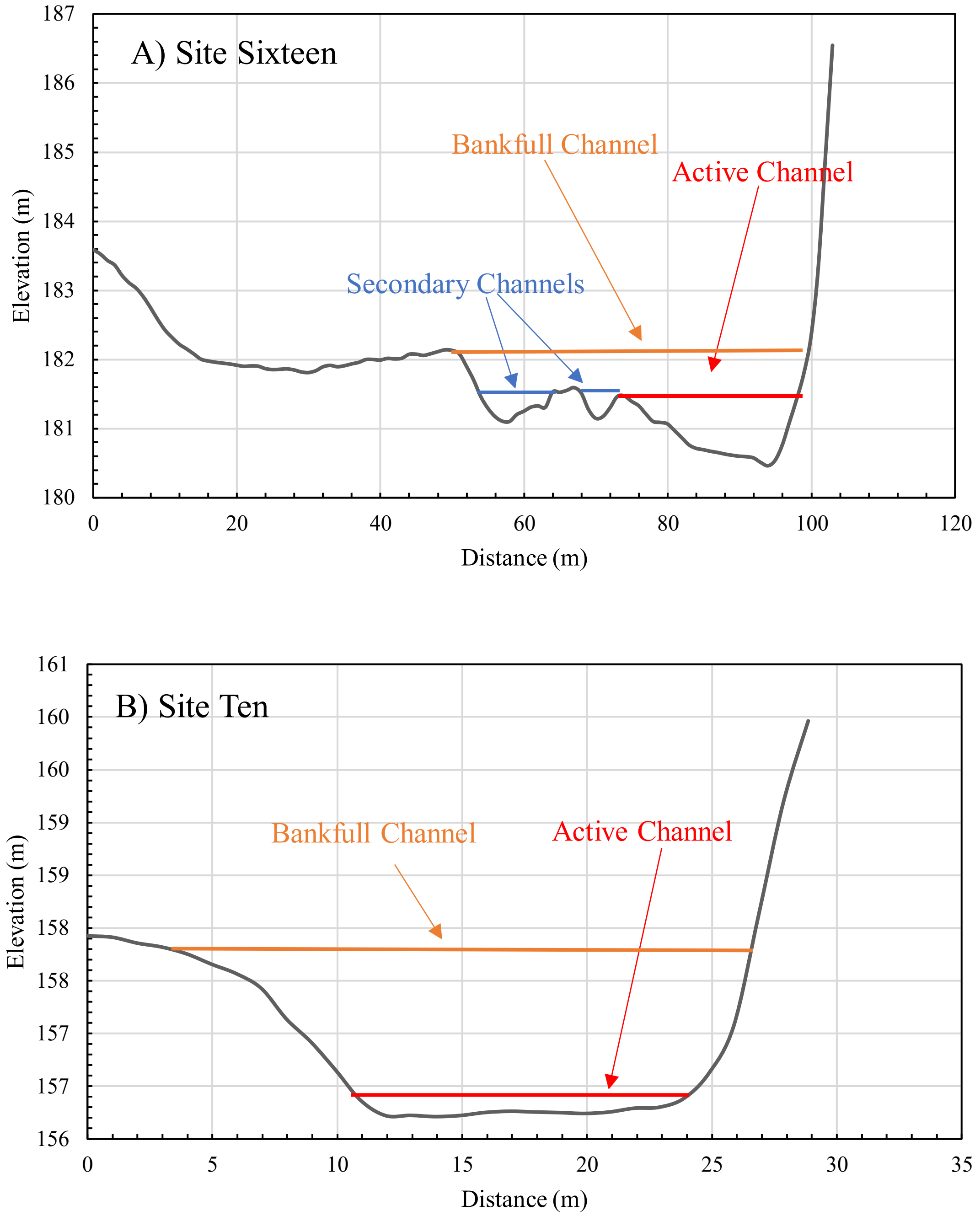

Figure 13. Extracted cross-section from LiDAR of A) a multi-threaded channel in BBC and B) a single channel is BBC.

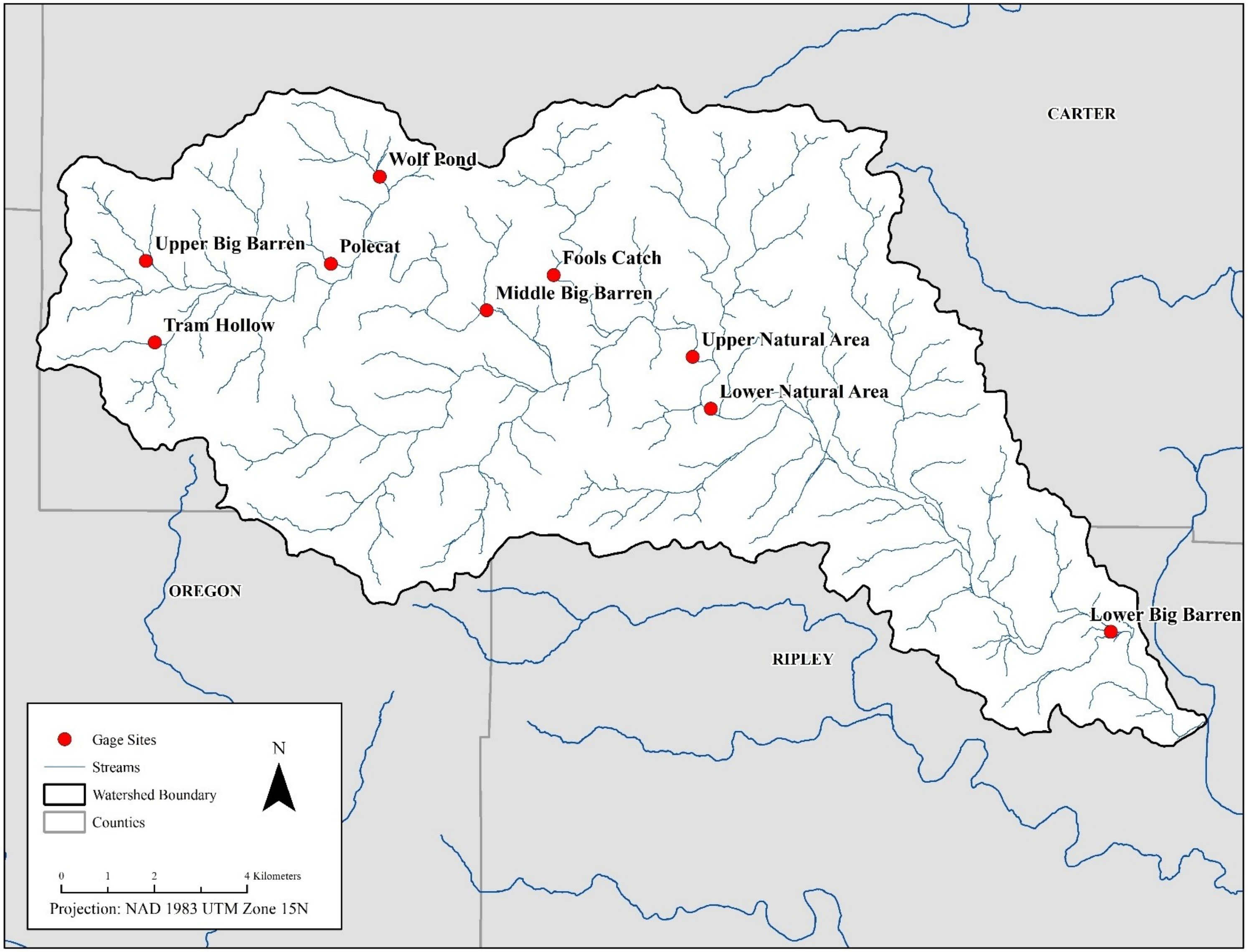

Figure 14. Stream gage sites.

RESULTS AND DISCUSSION

Number and Network Distribution of Pre-Settlement Survey Sites

Surveyed Channel Sites. A total of 167 crossings were identified in the watershed at locations where section lines intersected stream lines using the LiDAR derived DEM (Figure 15). GLO teams surveyed 38 (23%) of the total identified. As expected, the number of crossing sites decreased with increasing order: first, 74 (44%); second, 49 (29%); third, 18 (11%), and fourth 26 (16%) (Table 8) (Strahler 1957). Additionally, recent field surveys at 20 of the original GLO sites were completed in 2020 (Figure 16). All four stream orders were represented in the field surveys including: first, 4; second, 5; third, 3 and fourth, 8 (Table 8). One of the original GLO sites surveyed in the 1820s (site #1) was located at a spring located approximately 1 km upstream of the Current River confluence (Figure 17). This site was not included in the delineated stream network as its drainage area was less than the threshold given for delineation. Therefore, being the only spring site, this location will not be used for further analysis of channel changes in the watershed for this study. Nevertheless, estimation of LiDAR and aerial imagery indicate that human alterations have probably increased the wetted branch width of site one by about 11 meters or 60% since 1821.

GLO Site Selection. According to documentation, GLO sites were located at places where section lines crossed stream channels (General Land Office 1855; Knox 1977), but as shown above, surveys were not recorded for all crossings. GLO surveys recorded 11 crossings on first order streams totaling about 27% of the total crossings, 8 crossings on second order streams and 6 and 13 crossings on third and fourth order streams (Table 9). Two surveyors, “A. Gamble” and “W. Clarkson”, were responsible for surveying the five township section lines that covered this area and each surveyor recorded width measurements for 19 sites. The area was probably first surveyed before 1821 since township lines were surveyed prior to the section line surveys used in this study (General Land Office 1855). There were 33 crossings out of the total 167 that were located on township lines; therefore, they were not included in the 1821 GLO survey notes available for this study and were not used for further analysis. A breakdown of the percent of crossings surveyed showed Clarkson surveyed 29.2% of the total crossings while similarly, Gamble surveyed 27.5% of the total crossings (Table 9). Clarkson surveyed the upstream portion of the watershed as well as the downstream portion where BBC flows into the Current River while Gamble surveyed the middle of the watershed (Figure 18). These similarities in site distribution suggested that GLO surveyors used the same methods for site selection.

The minimum size of the stream widths measured by the two surveyors was also similar. The smallest width recorded by Gamble was three links or 0.6 meters and water was present in the channel at the time of the survey (Appendix A). The smallest width recorded by Clarkson was four links or 0.8 meters which was recorded one time by this surveyor and twice by Gamble. The crossing measured by Clarkson was noted as a dry stream suggesting the smallest ephemeral channel measured would be no less than 0.8 m wide. These records indicate that the lower limit of channel detection was about 0.5 m to 1 m and, as expected, there may have been a lower detection limit for wetted channels, than dry channels, since they would be more noticeable and easier to see in lush riparian vegetation.

Given the section lines provided a grid sampling framework for the channel network, it is not surprising that the distribution of GLO sites follows stream order trends with surveyors sampling more smaller rather than larger channels. However, how they selected only 38 sites out of the total 167 available sites is unknown. Many first order stream crossings that GLO surveyors did not sample have clearly defined channels shown on the LiDAR derived DEM indicating that network extension or an increase in drainage density caused by logging and increased road networks may have taken place in the watershed meaning first order streams that are clearly defined today may not have been present in the 1821 surveys (Wemple, Jones, and Grant 1996). Nevertheless, the similar number and distribution for each survey crew suggests a systematic procedure for selection stream sites. Further, channel networks and drainage density tend to be consistent in similar geologic and climate regions such as the Salem Plateau of the Ozark Highlands (Adamski et al. 1995). Therefore, the combined effects of similar, yet undocumented, site selection protocol, uniform grid spacing, and channel network patterns may have contributed to similar site selection and order distribution by the two survey teams.

Assuming the un-surveyed GLO crossing sites were not recognized as channel by the crews in 1821, then those missing width measurements may indicate locations where the channel maybe be poorly formed with low relief features and vegetation cover such as with "wet meadows" or low energy multi-threaded channel. When the missing sites were checked, all were visually judged to contain some expression of a channel at least 1 m wide on the LiDAR DEM. Further, a channel thread was detected at most missing GLO sites in 2015 using high-resolution aerial photography with visual evidence of a channel lacking for 11 first order and 2 second order stream sites. Therefore, it is estimated that diffuse multi-threaded riparian conditions have decreased since 1821 in Big Barren Creek by 85% for first, 84% for second, 67% for third, and 50% fourth order stream reaches. The presence of flow in small channels may have helped surveyors identify channels to assess, but the effect of spring flow on local channel conditions in 1820 was not evaluated.

Comparison of Historical and Recent Channel Widths

Recent channel widths were measured from a LiDAR derived DEM and compared to GLO channel widths for all surveyed sites in BBC. Recent widths were typically found to be significantly larger than historical widths. Additionally, LiDAR and GLO widths (n=37) plotted over drainage area produced r^2 values of 0.8 and 0.7, respectively with similar slope coefficients indicating a systematic increase in channel widths for the entire watershed (Figure 19). There seemed to be more variability for recent widths for drainage area < $1 km^2$. However, LiDAR and GLO widths plotted with drainage areas >1 km^2 (n=32) produced r^2 values of 0.8 for LiDAR and 0.7 for GLO widths. Trendline comparison between "all points" and "points with drainage areas >1 km^2" indicate little difference in the width and drainage area relationship (Figure 19). As expected, average LiDAR width and average GLO width showed an increasing trend with increasing stream order (Table 10). Overall, the relative percent difference (RPD) between 1821 and recent widths for first order streams was 81% while second, third and fourth order streams show an RPD of 92%, 54%, and 41%, respectively.

The change ratio was calculated for each site to evaluate the changes in width between the 1821 GLO surveys and the LiDAR derived DEM. The average change ratio for all sites shows an average increase of channel width by 2.6 times with increases ranging from 0.5 to 7.5 times (Table 10). Second order streams show the largest change ratio indicating second order streams have increased an average of 3.4 times with increases ranging from 1.0 to 7.5 times. The smallest increase was found in fourth order streams showing an average width increase of 1.9 times ranging from 0.9 to 3.4.

Field surveys of recent (2020) channel widths were used to verify a ground-truth LiDAR measurement at 19 sites (excluding site one) where access allowed (Figure 16). Field widths (n=19) were similar to LiDAR derived DEM widths when plotted over drainage area with almost identical regression coefficient (Figure 20A). The r^2 value for LiDAR widths was 0.8 while the field width r^2 value was 0.8. The field width and LiDAR width relationship produced an r^2 value of 0.9 with the trend line overlapping the 1:1 line (Figure 20B). Average widths were not consistently larger for LiDAR or field measurements (Table 11). First and third order streams averaged larger measurements in the field while second and fourth order streams averaged larger measurements using LiDAR. The largest RPD was 31% in first order streams followed by 28% in second order streams while third and fourth order streams had RPD of 12.5% and 12.7%, respectively. The relationship between field and LiDAR width measurements suggest that LiDAR widths could be used to accurately measure current widths in the BBC watershed, however, the most accurate measurements were found in third and fourth order streams.

To better understand the causes of channel widening; each GLO survey site was evaluated to determine if direct human disturbance had occurred indicating a known cause of channel widening that was not caused by increase in runoff by logging, land use change, or climate change. Four types of direct channel disturbance were found affecting six GLO survey sites, including: channelization, pond dams, road ditches, and bridge crossings (Figures 21, 22, 23, 24, 25, and 26). Channelization is known to modify stream power due to the deepening and widening of channels to decrease flooding effects on agricultural land (Franklin et al. 2009), therefore, channel widths at these sites were measured upstream of the survey site at a stable and undisturbed location. Change ratios for the remaining sites ranged from 1.3-3.4 which is well within the range of change ratios calculated for all sites, therefore, these sites were not re-measured upstream.

Spatial and Temporal Trends

Longitudinal Width Changes. To better understand how recent channel widths, vary in BBC, channel widths at 1 km intervals were evaluated along the total length of the main channel (Figure 27A). Maximum and minimum widths in a km reach generally increased downstream. At R-km 10 there is a peak in the maximum width for the reach because of disturbance caused by a road crossing within the 500 m reach where maximum and minimum widths were extracted causing the maximum width value to be high. This corresponds with the peak width at site # 6 for the LiDAR derived DEM measurement as previously discussed (Figure 27B). Further analysis of this site reveals a secondary "chute" channel closer to the GLO survey site location rather than the main channel. A cross-section of the chute was extracted and produced a width of 15 meters which flattens the peak and is comparable to the widths recorded upstream and downstream at R-km 7.9 and 16.4 (15m and 17m). A relatively large width measurement was also recorded at R-km 32.4 (site # 38) from the LiDAR measurements. This section is channelized and the current bankfull width was originally measured, however, a measurement of the active channel width produced a width of 15 meters which better represents the width trends of the segment both upstream and downstream (Figure 28).

Interestingly, width comparisons in the main channel segment between R-km 15 and 20 indicate minimal width change from 1821. There are four GLO sites located between in the segment including two sites that have LiDAR derived DEM widths decreasing by two meters from recorded 1821 GLO widths (Table 12). The average change ratio for the four sites is 1.1. These sites are in the natural area of BBC, a confined valley with strong geologic controls and is spring fed that covers almost two kilometers of the main channel and provides a habitat for an endangered freshwater mussel species with minimal disturbance (Finley et al. 2015). This finding supports the idea that the natural area is the best example of "natural" stream conditions in BBC and provides habitat for endangered flora and fauna (U.S. Forest Service 2008).

Second order streams experience the largest change ratios averaging an increase in channel width by 3.4 times. There are eight sites located in second order streams and a spatial analysis of sites located in second order streams and the change ratios show the most change occurred in the downstream portion of the watershed at sites 8, 9, and 21. The average change ratio for these three sites is 5.4 while the average change ratio for the remaining five sites is 2.1. Reach slopes for second order stream sites do not have much variance among all sites. However, elevations from the LiDAR derived DEM indicate a high local relief at these sites which could generate more stream power and may be responsible for the larger change ratios (Knight 1999).

Influence of Sub-Watershed Characteristics. Variations in channel widths may be related to land use factors, such as forest or pasture. To show this, sub-watersheds were delineated above the 37 GLO survey points. Drainage density (km/km^2) and road density (km/km^2) indicated minimal differences for each site by stream order (Table 13). Median drainage density for each stream order ranged from 7.3 to 8.3 km/km^2. The smallest drainage density was in a first order stream (5.9 km^2) and the largest was in a second order stream (8.7 km/km^2). Median road density for each stream order ranged from 1.3 to 2.0 km/km^2. The smallest road density was in a third order stream (0.4 km/km^2) while the largest was recorded in a first order stream (3.1 km/km^2). First order streams also have a change ratio averaging an increase in channel width by 3.0 times indicating higher road densities in first order streams could be contributing to higher change ratios.

Land uses within the BBC watershed at the time of this study were mostly forest with some pasture and urban land. The median forest cover was highest in first order streams at 100%

ranging from 67% to 100% followed by second, third, and fourth order streams with median values of 96% (88%-99%), 94% (89%-100%), and 92% (78%-94%), respectively. Median urban area was very low ranging from none to 3.0% with the highest urban percentage in a first order stream at 9.3%. Median pasture percentage ranged from none to 4.6% with the highest pasture percent being in a first order stream at 20.6%. No relationships were found between sub-watershed characteristics and change ratio (Table 14). Scatter plots also determined no visual correlations between sub-watershed characteristics and change ratio. Additionally, forest dominates these watersheds with little urban or agriculture land and drainage densities do not vary between the watersheds.

Temporal Trends in Width Changes. Aerial photographs were used to estimate trends in channel change between GLO surveys in 1821 and the LiDAR derived DEM. Out of the 38 sites, 31 were able to be measured in at least one year of the aerial photographs (Appendix B). To analyze trends, sites that did not have visible width measurements prior to 1986 were removed leaving 15 sites. The 15 sites were classified as either an early response to settlement disturbance, a gradual response to settlement disturbance, or low response to settlement disturbance. There were three sites that showed an early response, five sites that showed a gradual response, and seven sites that showed no response (Figure 29). This suggests that response trends for widening are varied overtime.

Some sites showed increase in channel width more recently. Recent width changes were analyzed as change ratio for 2007 aerial photographs to the LiDAR derived DEM and change ratio for 2015 aerial photographs to the LiDAR derived DEM by stream order. There were 22 sites that had aerial photograph measurements in 2007 and 29 sites that had aerial photograph measurements in 2015 (Table 15). The mean change ratio for channels with 2007 aerial photograph widths for all stream orders was 1.6 ranging from 0.8 to 3.5 with the highest mean change ratio in first order streams increasing a mean of 2.3 ranging from 1.4 to 3.5. The smallest mean increase was in fourth order streams with an increase ratio of 1.2 ranging from 0.8 to 1.7. The median change ratio for channels with 2015 aerial photograph widths for all stream orders was 1.4 ranging from 0.8-3.5. The highest mean change ratio was found in second and third order streams at 1.5 with second order streams ranging from 1.0 to 2.3 and third order streams ranging from 1.3 to 2.0. The smallest mean increase was in fourth order streams with and increase ratio of 1.1 ranging from 0.8 to 1.6. Comparing aerial photograph measurements in Table 15, average channel widths increased from 2007 to 2015 (8 years) by the following percentages according to stream order: 35%, first order; 33%, second order; 20%, third order; and 14%, fourth order.

The use of historical aerial photographs for channel change analysis can be a beneficial tool for finding width change trends. Kessler, Gupta, and Brown (2013) found that historical aerial photographs were useful when finding trends in data over long periods of time. Riparian vegetation in aerial photographs adds difficulty to measuring the channel width consistently, therefore, width measurements in aerial photographs are estimations of the width between the active channel and the bankfull channel (De Rose and Basher 2011). These width estimations were then compared to GLO and LiDAR derived DEM widths that are active main channel widths and used to find general width change trends. Furthermore, the trends found using aerial photography in BBC indicate areas of low response to early disturbances are in the natural area supporting the conclusion that the natural area of BBC has had a limited response to disturbances overtime which is also supported by the change ratio of natural area survey points. Additionally, recent increases in width since the 2007 aerial photography is indicative of climate change effects of channel width due to an increase of high magnitude floods in the Ozarks (Pavlowsky, Owen, and Bradley 2016).

Hydrogeomorphic Analysis

Hydrological monitoring is conducted by the Ozarks Environmental and Water Resources Institute in BBC (Owen, Ahmed, and Pavlowksy 2018). For this study, nine of these gage sites are used to complete a hydrogeomorphic analysis to the watershed. Using the USGS regression equation, the two-year discharge recurrence interval (Q2 RI) was calculated and compared to the gage survey bankfull discharge and plotted against drainage area (Figure 30). The Q2 RI produced an r^2 value of 0.9 while the gage survey produced an r^2 value of 0.9 with a slope difference of 0.2 determining that the bankfull discharge calculated for the gage surveys correlates to the two-year discharge recurrence interval. The trendline for bankfull discharge calculated from gage surveys plots just below the 2-year recurrence interval which is typically the channel forming discharge that occurs every 1-2 years (Rosgen 1995).

GLO and LiDAR widths reflect bank-top widths of the main channel and not the entire bankfull stage flow. Therefore, LiDAR main channel widths can be extracted for each gage site and compared to the gage survey main channel widths to show the relationship between LiDAR and survey measurements for the main channel and be compared to the bankfull channel widths for those sites. Gage site widths for the main channel and bankfull channel and the LiDAR main channel widths have an increasing trend with increasing drainage area. Main channel widths from the survey data produced an r^2 value of 0.2 while LiDAR widths produced and r^2 value of 0.6 (Figure 31). Gage survey bankfull widths had the strongest relationship with an r^2 value of 0.7. These trends have similar slopes, but widths are smaller. This suggests that LiDAR width measurements generally need to be increased by an average of five times to correspond with the bankfull width.

The width/depth ratio was used to evaluate the channel form in BBC. Ratios ranged from 30 to 157 with an average ratio of 100. The width/depth ratio was plotted over drainage area and produced a r^2 value of 0.1 with a slightly increasing trend with increasing drainage area (Figure 32). Slopes for gage sites ranged from 0.002 meters to 0.009 meters. Based on Rosgen's classification, BBC tends to naturally be a stream type D or braided/multi-threaded channel with its high width/depth ratios and slopes <0.04 (Rosgen 1995). Rosgen's classification for a braided channel has a width/ depth ratio of >40 with high erosion rates and a large sediment supply (Rosgen 1995). Although the watershed tends towards multi-threaded channels, single channel forms increase in the downstream portion of the watershed and there has been a tendency for multi-threaded forms to transition to single channel forms (Reminga 2019).

Implications of GLO Surveys for Understanding Channel Change

GLO survey notes and LiDAR were useful to evaluate long term trends in channel widths. In addition, aerial photographs can go back to the 1930s and be used to compare change trends overtime. LiDAR widths were determined to be active widths of the main channel and narrower than the bankfull width in multi-threaded channels. However, field surveys and LiDAR were shown to have equivalent width measurements. In BBC, an overall channel width increase was found with an average increase of 2.6 times ranging from 0.5 to 7.5 since the 1821 surveys. Increased runoff following a period of exploitative logging would have caused an increase in channel width with some sites responding more quickly. A study in a more recently clear-cut watershed in California found that storm runoff volumes could increase by up to 400% within the first three years after logging (Lewis et al. 2001). Still, some sites showed a gradual response to disturbance. Similarly, Jacobson (2004) who found that logging alone does not provide consistent disturbances, but brief episodes of disturbance unlike a transition to agricultural land that produces constant increases in runoff due to soil disturbance therefore causing increases in erosion the provide an early response to channel widths.

Disturbances altering channel form typically increase channel width (Knox 1977; Hession et al. 2003). Accelerated channel width and depth increases can be caused by multiple disturbances. The introduction of logging roads to a watershed can cause increased runoff which causes increased erosion and channel widening (Jacobson and Pugh 1992; Jacobson 2004). After the construction of roads and selective logging storm peaks during small storms were shown to increase by up to 132% in a watershed in northern California (Wright et al. 1990). The change in forest composition from a pine dominated forest to an oak dominated forest can have an impact on the amount of interception of rainfall by the vegetation (Luce 1995). Pine trees were found to intercept 45% of the annual rainfall resulting in a decrease in runoff meaning the transition from pine to hardwood would increase runoff in winter by 2 times because of hardwoods losing their leave in winter (Zabret and Sraj 2019). Similarly, transitions from forest to agriculture land in a watershed has been shown to increase channel widths by up to 2.7 times (Roy and Sahu 2016). Additionally, climate change has been shown to cause an increase in high flood magnitude events which can cause channel instability and be responsible for sharp increases in channel widths beginning in the early 2000s (Pavlowksy, Owen, and Bradley 2016). This is supported by aerial photograph analysis for the BBC watershed which indicated 18 GLO sites increasing in width since 2007 and then 13 of those sites increasing since 2015.

The results from this study show that present-day forested streams can be >2 times wider compared to pre-settlement widths with more single channel forms compared to the more dominant multi-threaded forms in the past. However, streams in BBC are relatively resistant to some changes as indicated by the limited upstream and downstream effects of channelized reaches. Restoring channelized reaches to a more natural channel can reduce sedimentation and possibly reestablish a natural hydrologic system (Nakamura et al. 2002). Additionally, there has been a tendency for multi-threaded channels in the BBC system to transition to a single channel form, but there is a natural resistance to change and in most cases width increases were gradual with most beds still having stable and treed beds. Currently, the watershed is being affected by climate change indicated by almost 50% of GLO survey sites showing width increases since 2007. Ford et al. (2010) found that forest management including an increase in pine stands has the potential to lessen the intense yearly rainfall events linked to climate change and therefore lessen the increased runoff from the increase in high magnitude events.

Table 8. Survey sites by stream order.

Stream Order	GLO Crossing Sites (1821)		2020 Field Surveys (This Study)		All Section Line Crossings	
	Count	Percent	Count	Percent	Count	Percent
1	11	28.9	4	20.0	74	44.3
2	8	21.1	5	25.0	49	29.3
3	6	15.8	3	15.0	18	10.8
4	13	34.2	8	40.0	26	15.6
Total	38	100	20	100	167	100

Table 9. Comparison of sites completed by each surveyor.

Stream Order	Surveyor					
	Clarkson			Gamble		
	Surveyed Crossings	All Section Line Crossings	% Surveyed	Surveyed Crossings	All Section Line Crossings	% Surveyed
1	4	32	12.5	7	30	23.3
2	4	17	23.5	4	22	18.2
3	5	7	71.4	1	3	33.3
4	6	9	66.7	7	14	50
Total	19	65	29.2	19	69	27.5

Table 10. Comparison of mean LiDAR and GLO widths by stream order.

Stream Order	Mean 1821 GLO Width (m)	Mean LiDAR DEM Width (m)	Mean Difference (m)	Mean Change Ratio	Mean Change Ratio Range	RPD %
1	1.3	3.1	1.8	3.0	0.5-7.0	81.8
2	2.3	6.5	4.2	3.4	1.0-7.5	94.6
3	4.3	10.8	6.5	2.5	1.3-4.0	85.7
4	14.2	20.8	6.6	1.9	0.9-3.4	37.7
Total	6.6	11.3	4.8	2.6	0.5-7.5	53.3

Table 11. Comparison of mean LiDAR and field widths by stream order.

Stream Order	n	Mean LiDAR Width (m)	Mean Field Width (m)	RPD%
1	3	2.7	3.7	31.2
2	5	6.2	4.7	27.5
3	3	7.3	8.5	12.5
4	8	20.9	18.4	12.7

Table 12. Survey sites in the natural area of a fourth order segment.

Point ID	R-km	GLO Width (m)	LiDAR Width (m)	Change Ratio
10	16.4	11.0	17.0	1.5
11	17.7	30.0	27.0	0.9
12	18.0	20.0	18.0	0.9
13	18.6	26.0	26.0	1.0

Table 13. Average sub-watershed characteristics by stream order.

Stream Order	Drainage Density (km/km^2)		Road Density (km/km^2)		Urban %		Forest %		Pasture %	
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
1	7.3	5.9-8.1	2.0	1.3-3.1	none	none-9.3	100.0	67.3-100	none	none-20.6
2	8.0	7.1-8.7	1.4	1.0-2.2	3.2	0.4-6.1	96.2	87.8-98.5	none	none-6.1
3	8.3	7.3-8.6	1.3	0.4-1.7	3.0	none-4.3	93.9	89.4-100	3.9	none-6.4
4	7.8	7.8-8.4	1.6	1.6-1.6	2.8	2.5-9.0	92.3	78.2-94.2	4.6	3.2-12.7

Table 14. Correlation matrix of sub-watershed characteristics.

	Drainage Density (km/km^2)	Road Density (km/km^2)	Urban %	Forest %	Pasture %	Change Ratio
Drainage Density (km/km^2)	1.00					
Road Density (km/km^2)	-0.20	1.00				
Urban %	0.26	0.23	1.00			
Forest %	-0.07	-0.34	-0.91	1.00		
Pasture %	-0.01	0.34	0.81	-0.98	1.00	
Change Ratio	-0.29	0.04	-0.03	0.02	-0.02	1.00

Table 15. Mean change ratios at GLO sites from 2007 to 2016/2017 and 2015 to 2016/2017.

Stream Order	Since 2007			Since 2015		
	n	Mean Change Ratio	Mean Change Ratio Range	n	Mean Change Ratio	Mean Change Ratio Range
1	3	2.3	1.4-3.5	6	1.7	1.0-3.5
2	4	2.0	1.3-3.0	5	1.5	1.0-2.3
3	4	1.8	1.2-3.0	5	1.5	1.3-2.0
4	11	1.2	0.8-1.7	13	1.1	0.8-1.6
Total	22	1.6	0.8-3.5	29	1.4	0.8-3.5

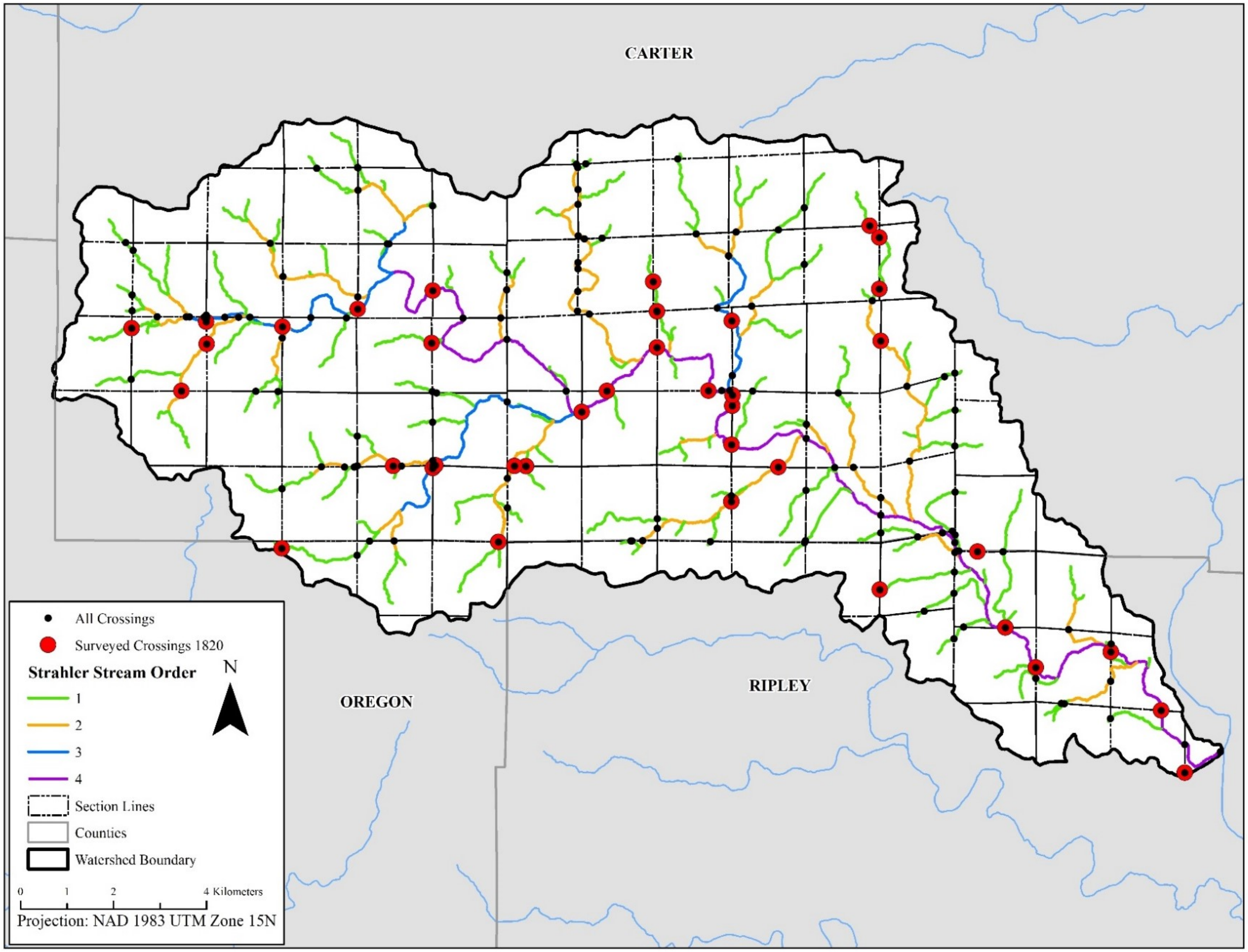

Figure 15. Location of all section line crossings and survey sites by stream order.

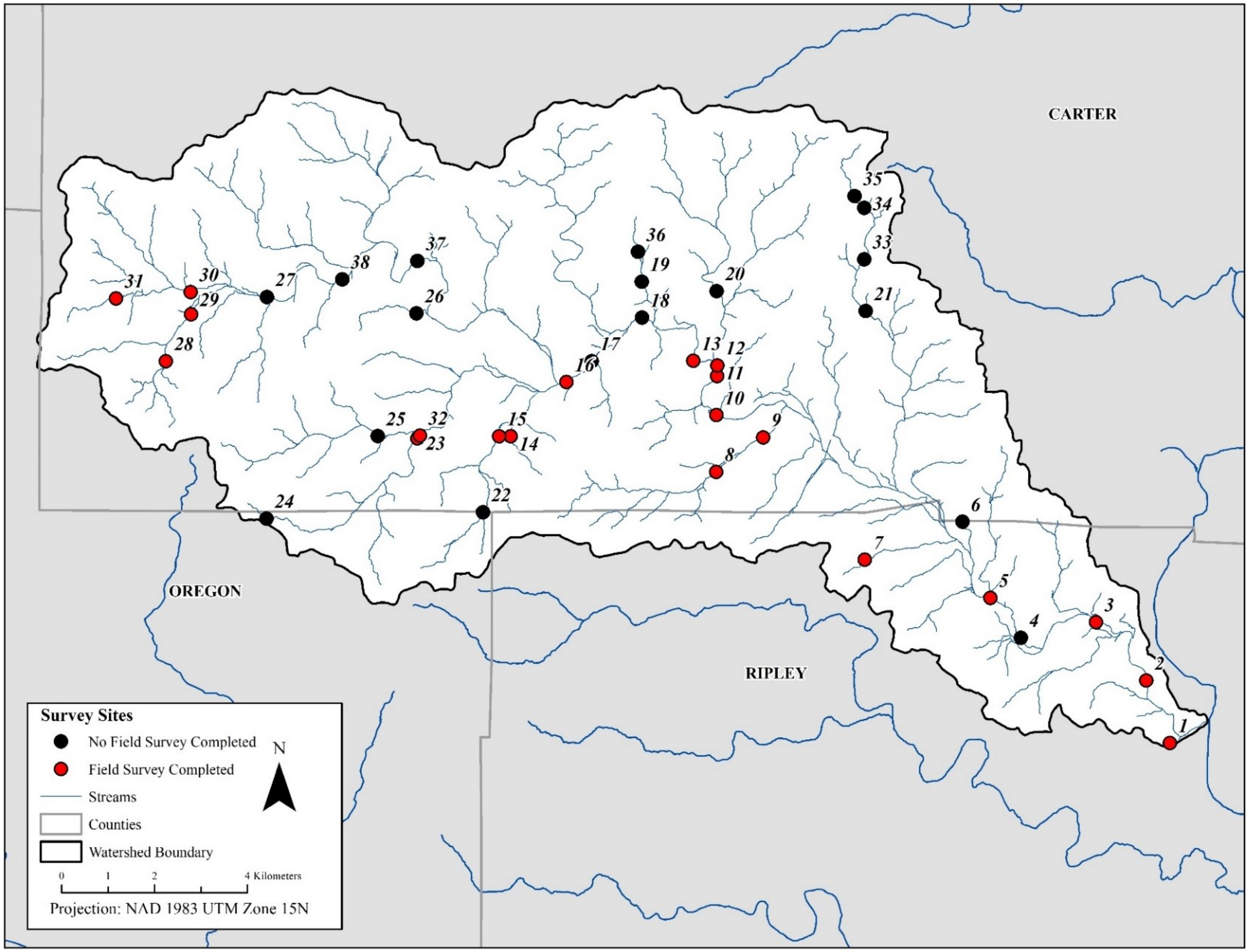

Figure 16. Locations of 2020 field surveys.

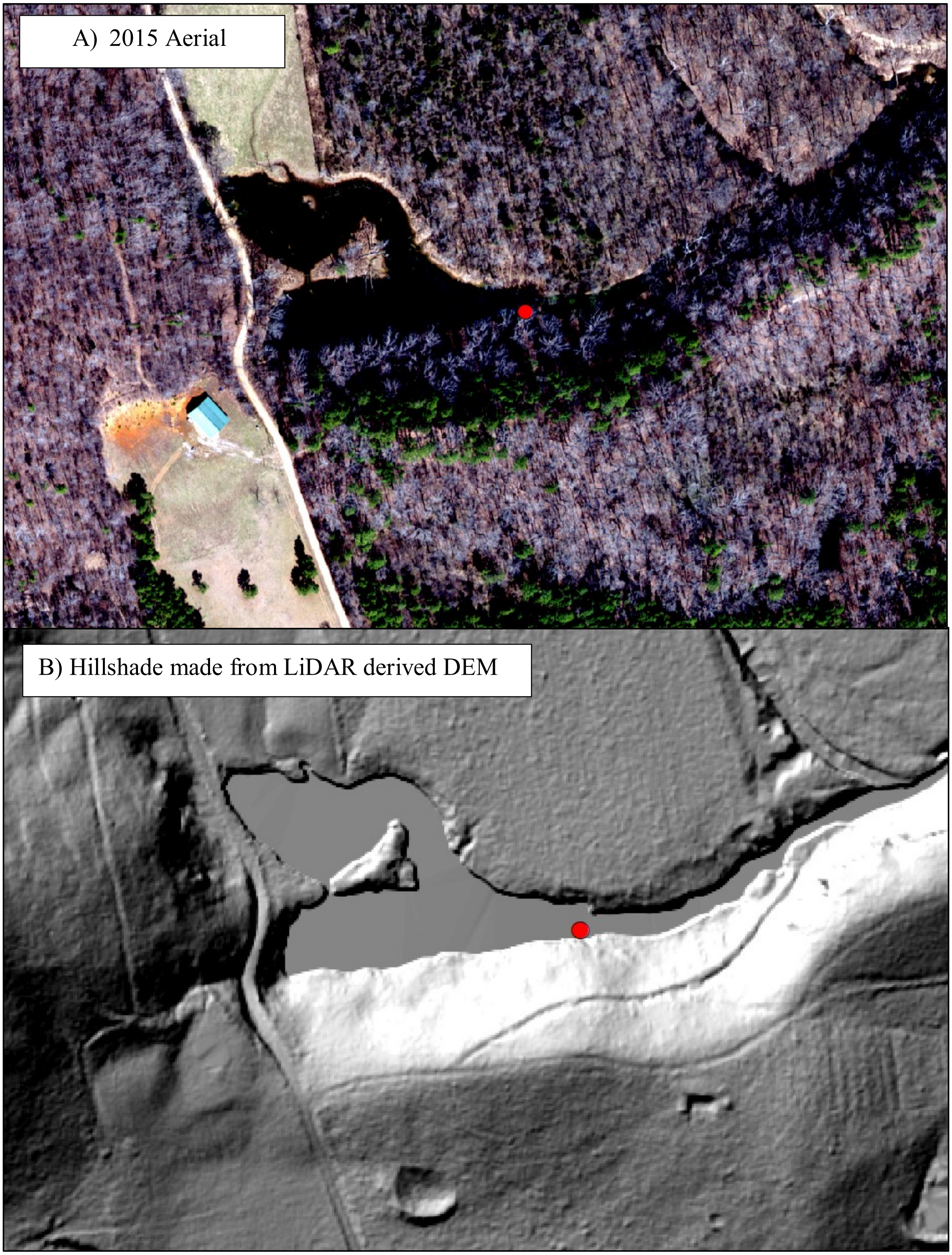

Figure 17. Site one.

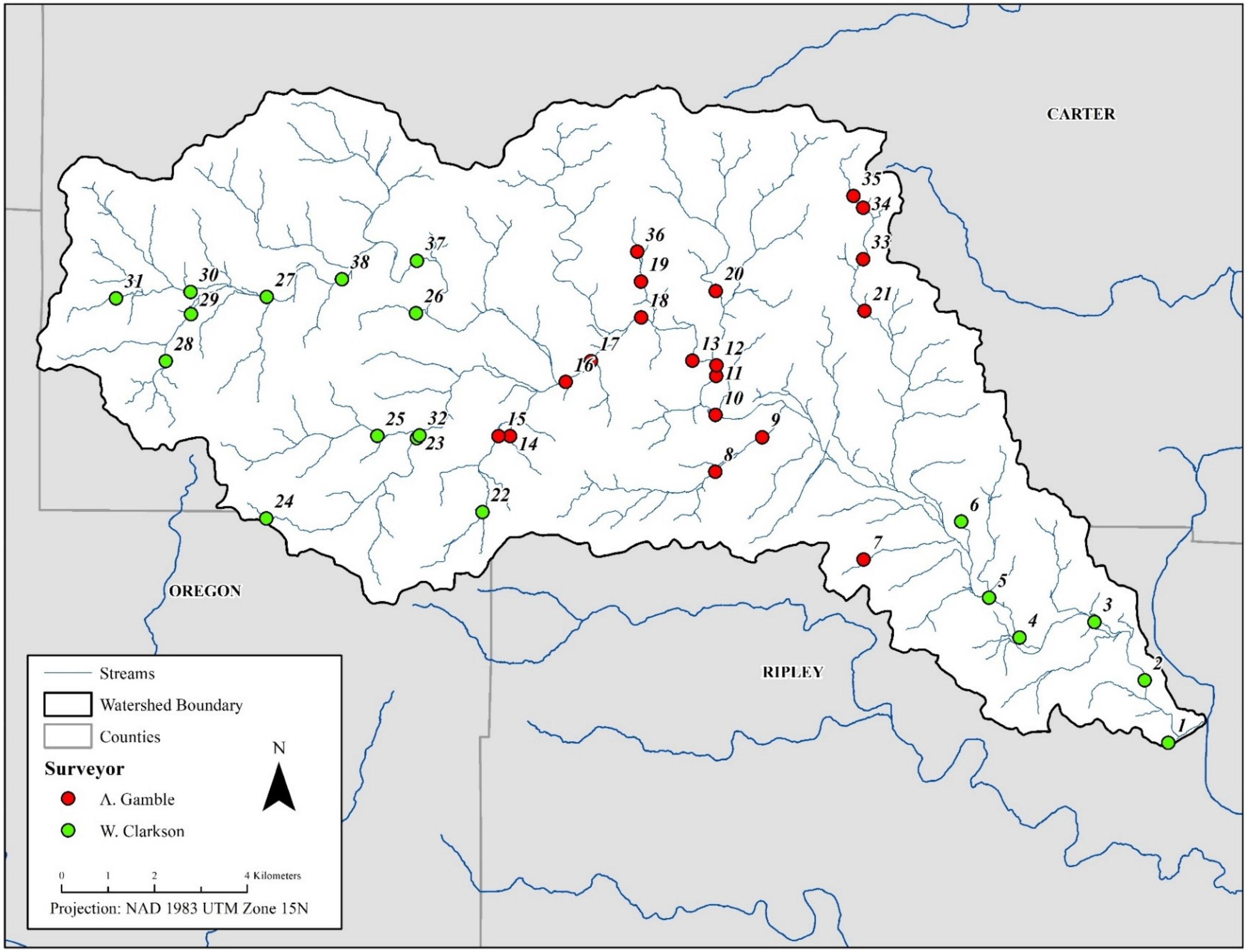

Figure 18. Locations of survey sites for each surveyor.

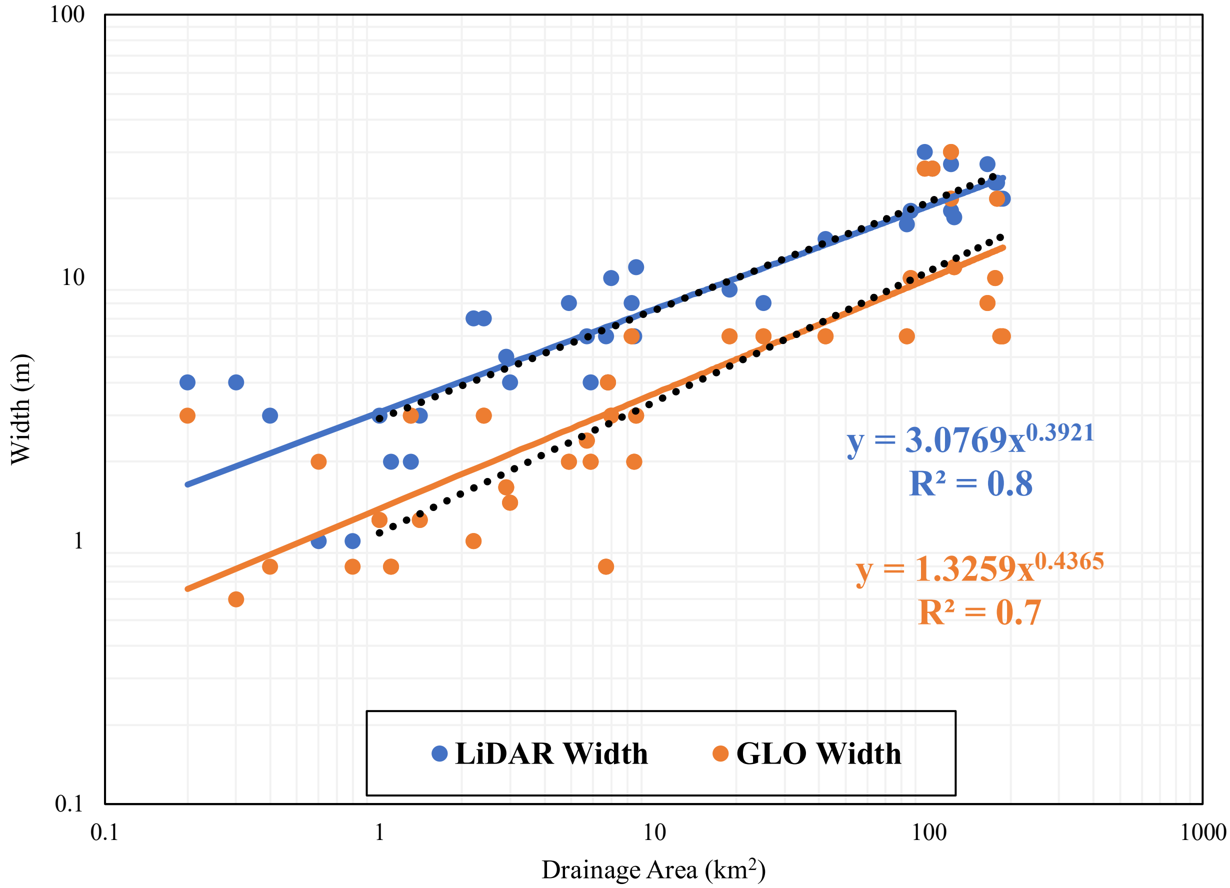

Figure 19. LiDAR and GLO width comparison. Dashed trendlines show trends for drainage areas >1.

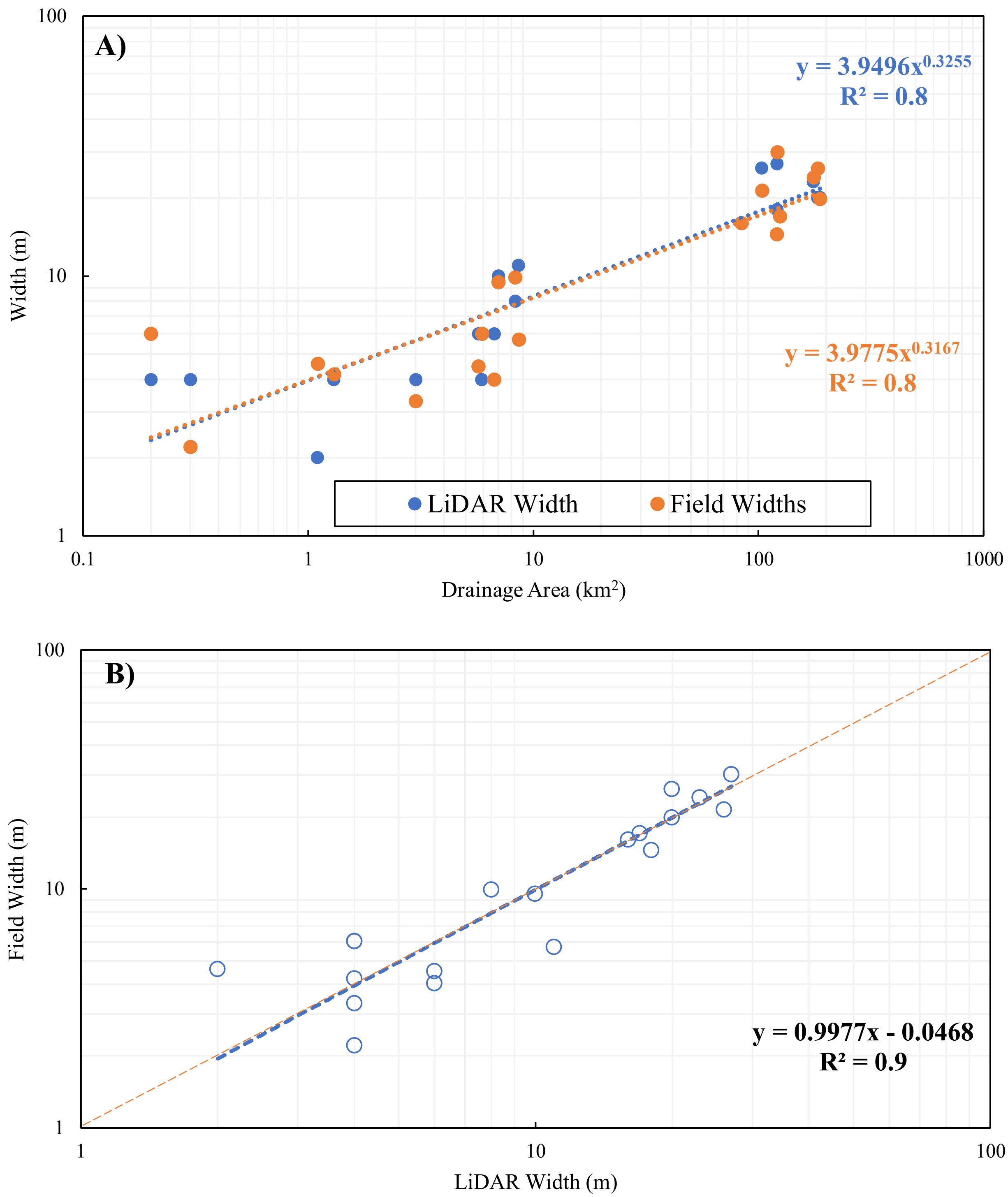

Figure 20. Field and LiDAR width comparisons. A) LiDAR and field widths plotted with drainage area km^2 and B) ratio of LiDAR and field widths shown with a 1:1 line.

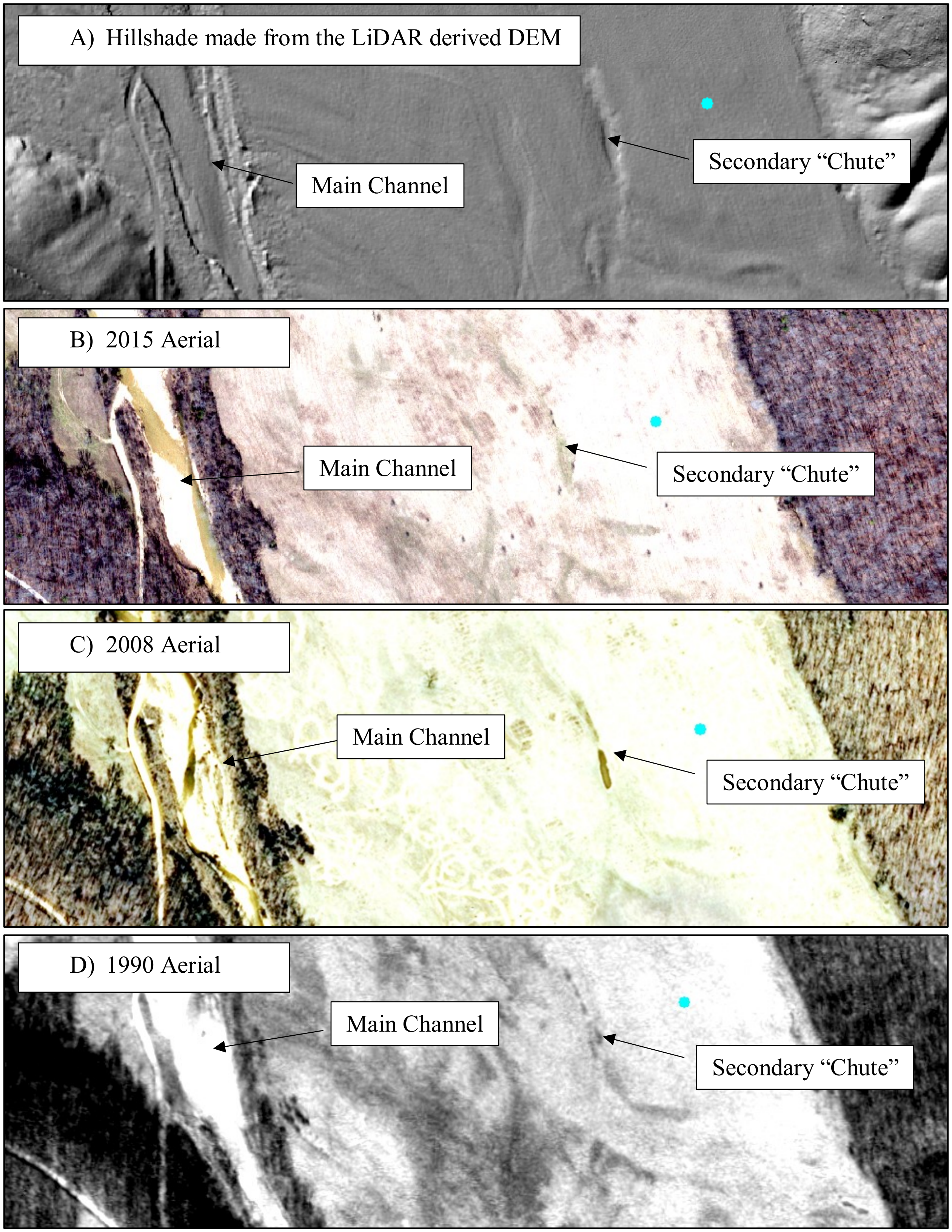

Figure 21. Site 6 shown with the LiDAR derived DEM and multiple years of aerial photographs.

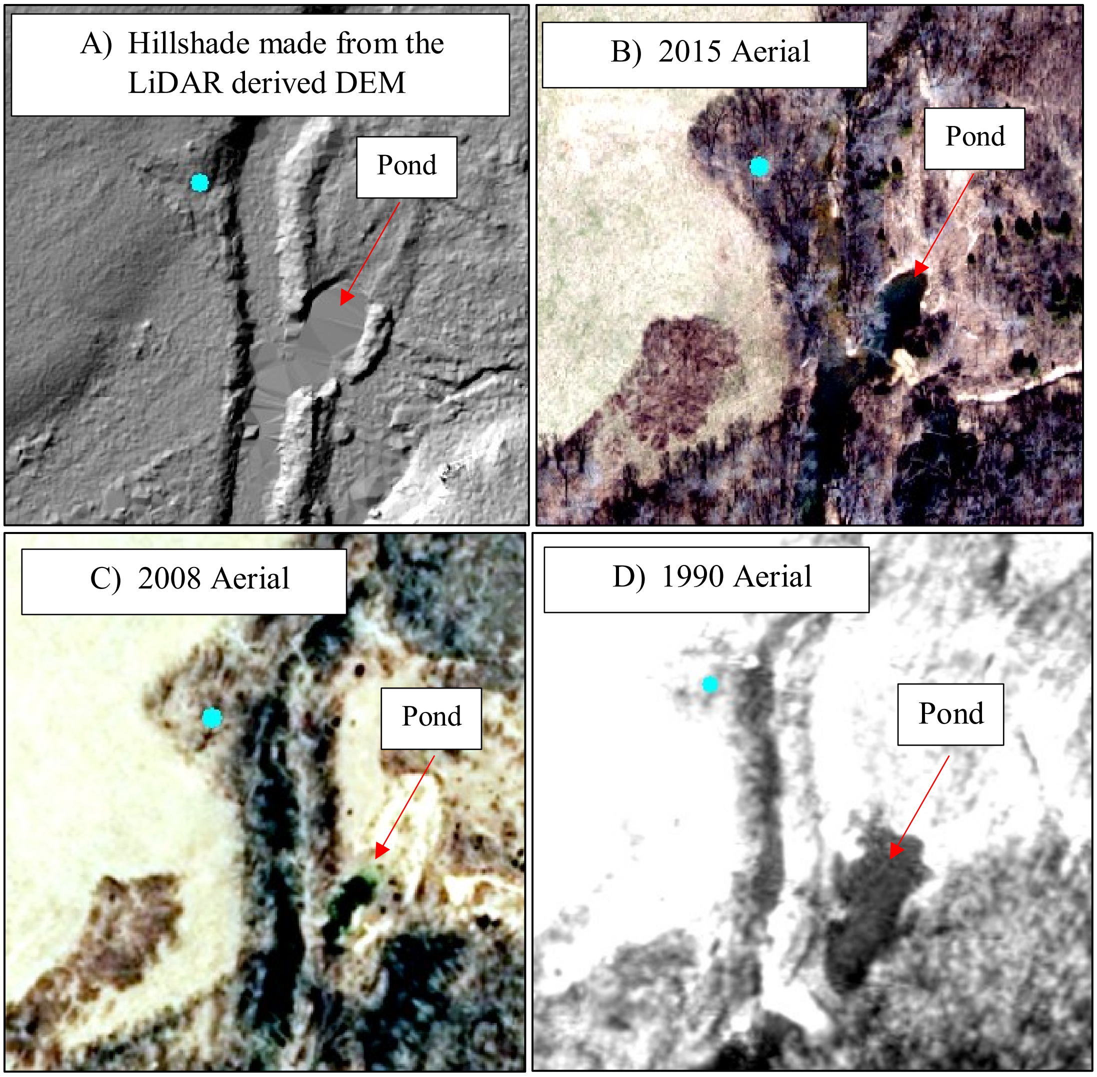

Figure 22. Disturbed site 17 classified as a pond dam shown with the LiDAR derived DEM and historical aerial photographs.

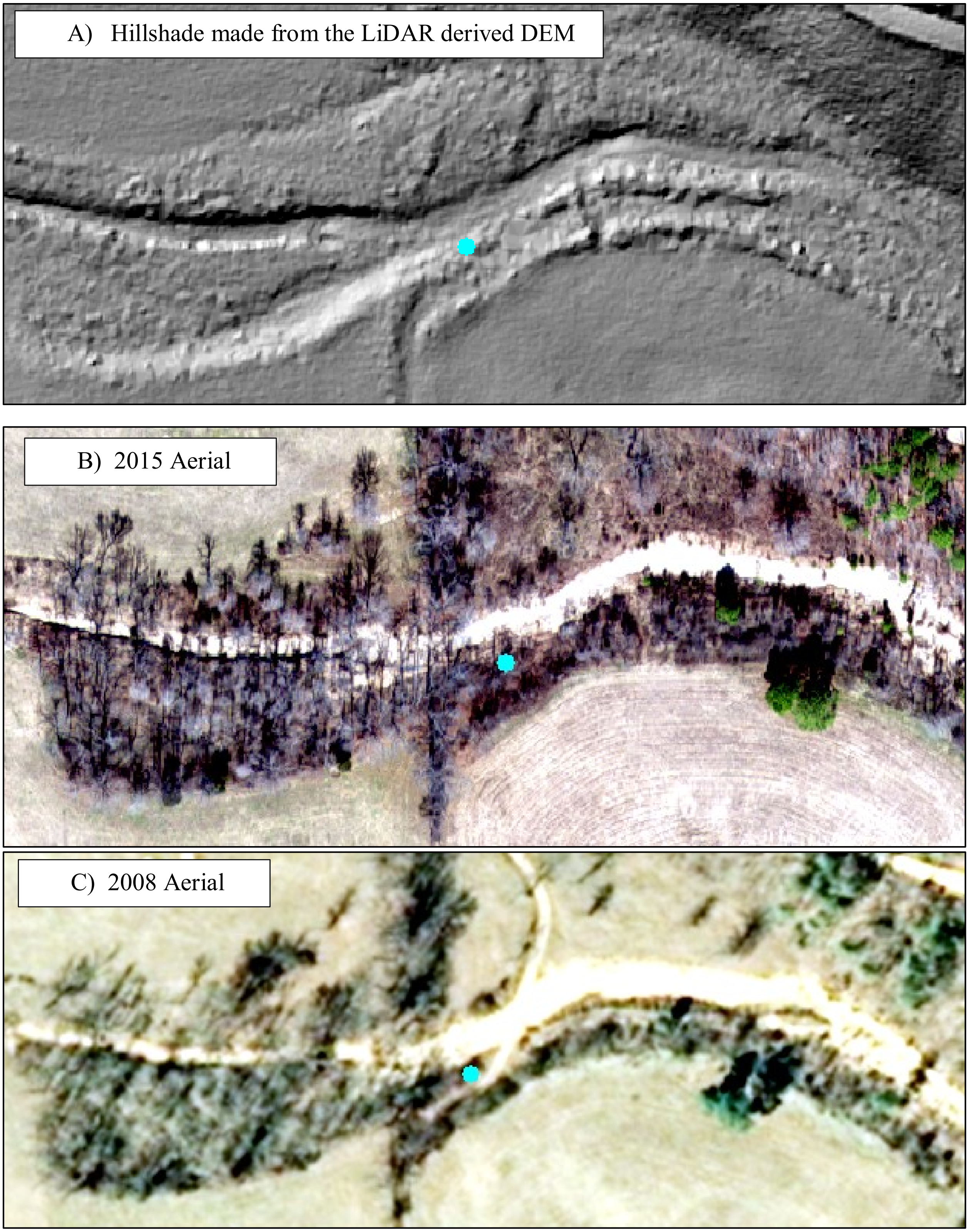

Figure 23. Disturbed site 27 classified as channelization shown with the LiDAR derived DEM and historical aerial photographs.

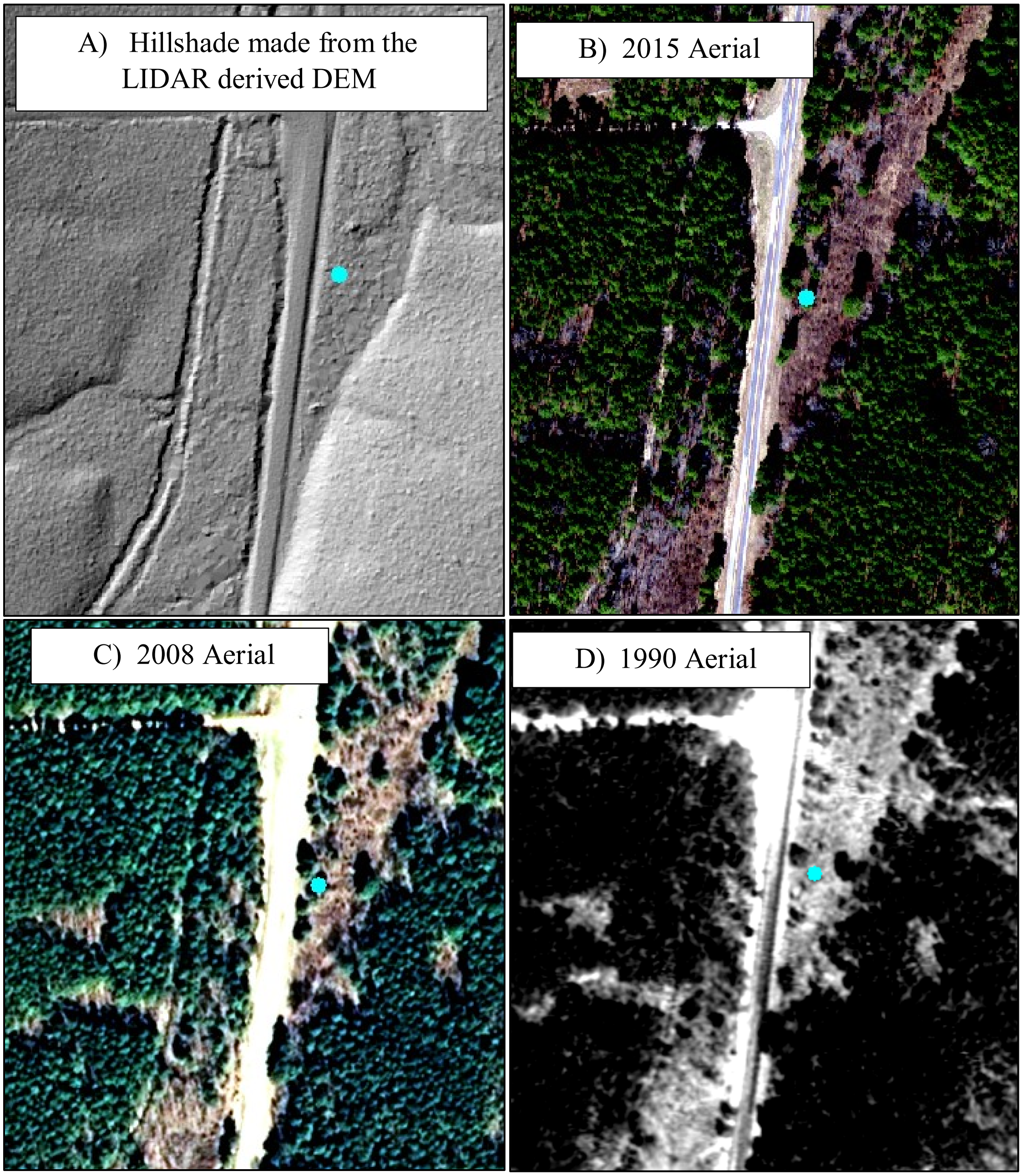

Figure 24. Disturbed site 28 classified as a road ditch shown with the LiDAR derived DEM and historical aerial photographs.

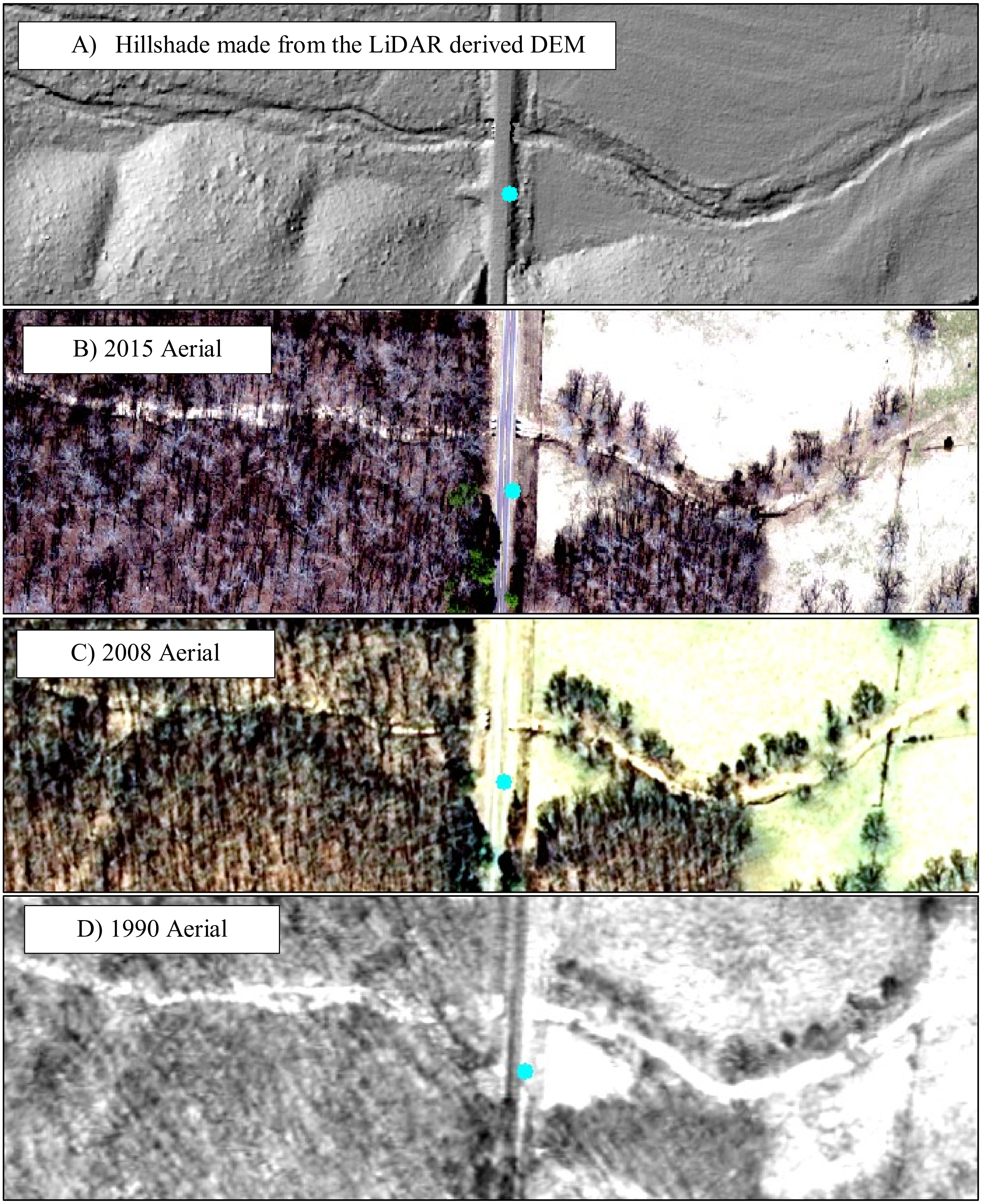

Figure 25. Disturbed site 30 classified as a bridge crossing shown with the LiDAR derived DEM and historical aerial photographs.

Figure 26. Disturbed site 38 classified as channelized shown with the LiDAR derived DEM and historical aerial photographs.

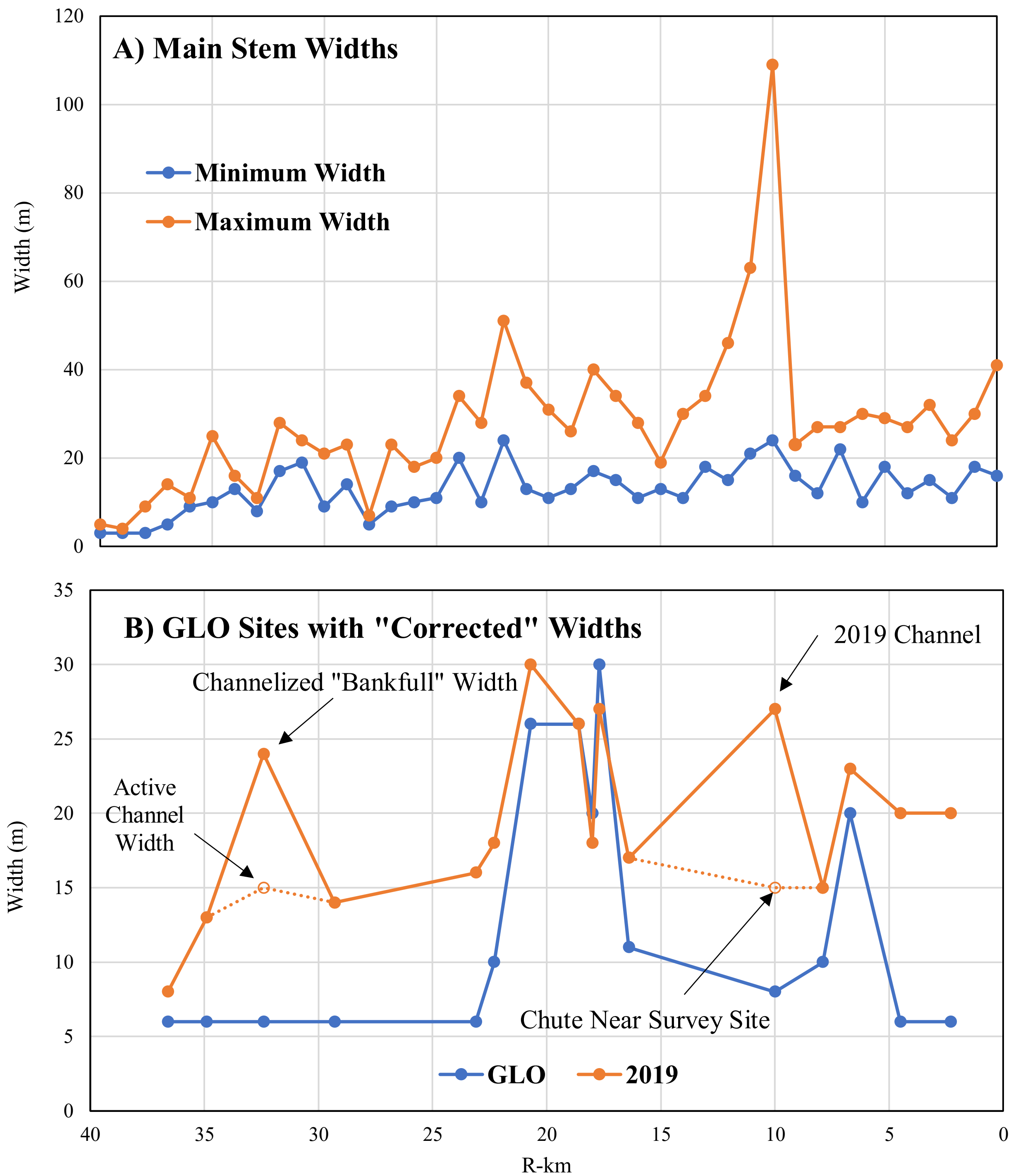

Figure 27. Main stem width comparison. A) Minimum and maximum reach widths and B) GLO and recent main stem widths with re-measured peak sites.

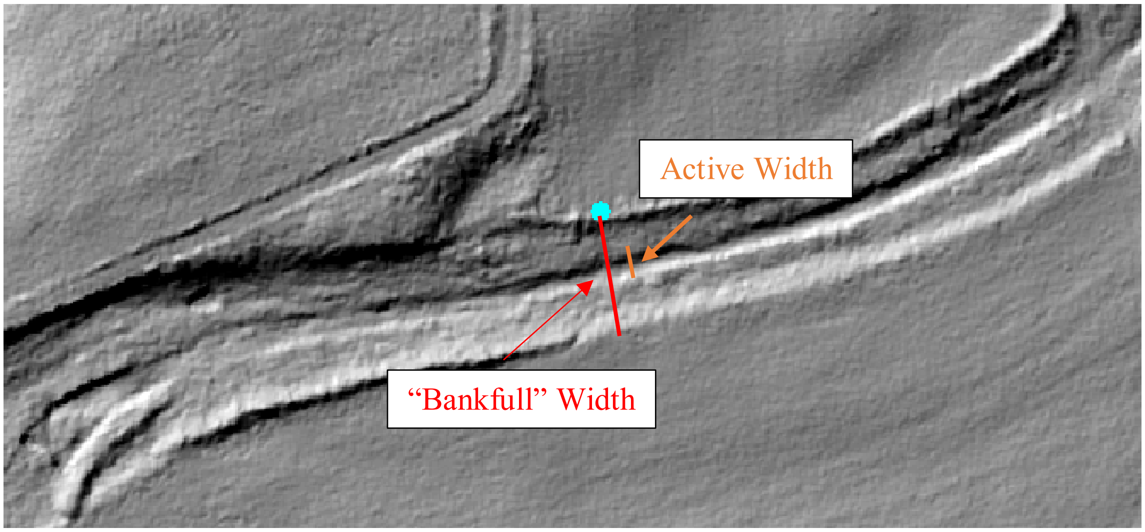

Figure 28. "Bankfull" and active width measurements at site 38 shown using the hillshade made from the LiDAR derived DEM.

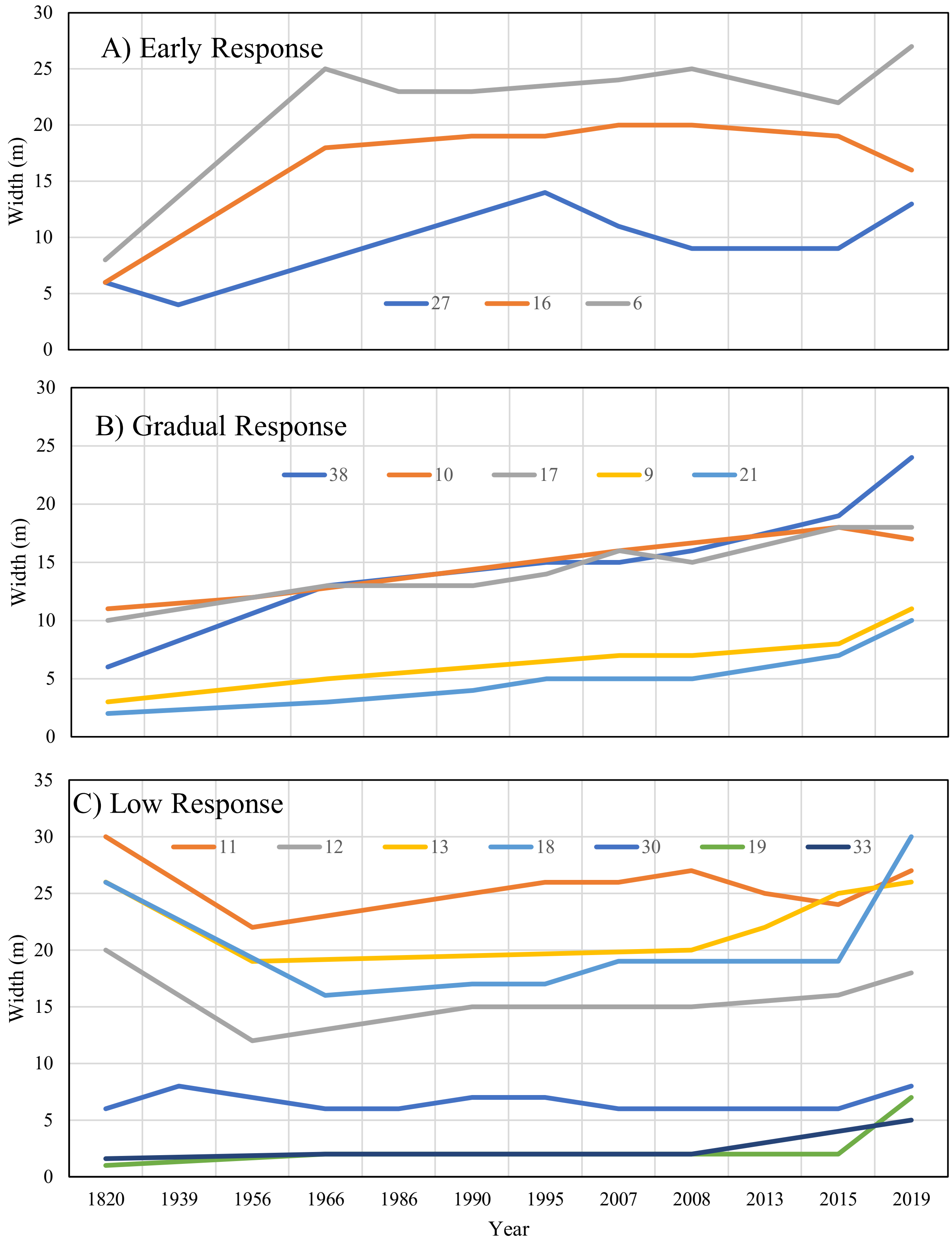

Figure 29. Aerial photograph analysis trend response types for GLO sites with recorded widths prior to 1986.

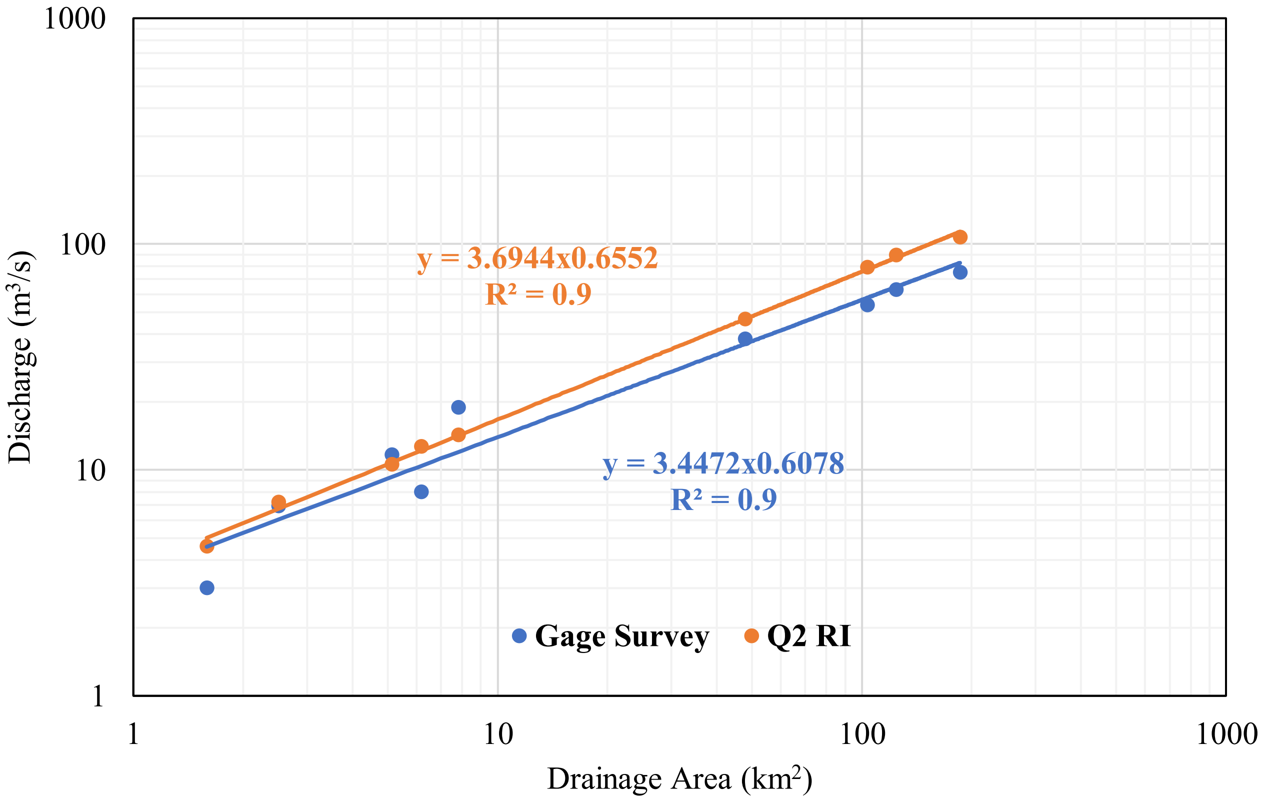

Figure 30. Bankfull discharge for gage sites compared to calculated two-year recurrence interval.

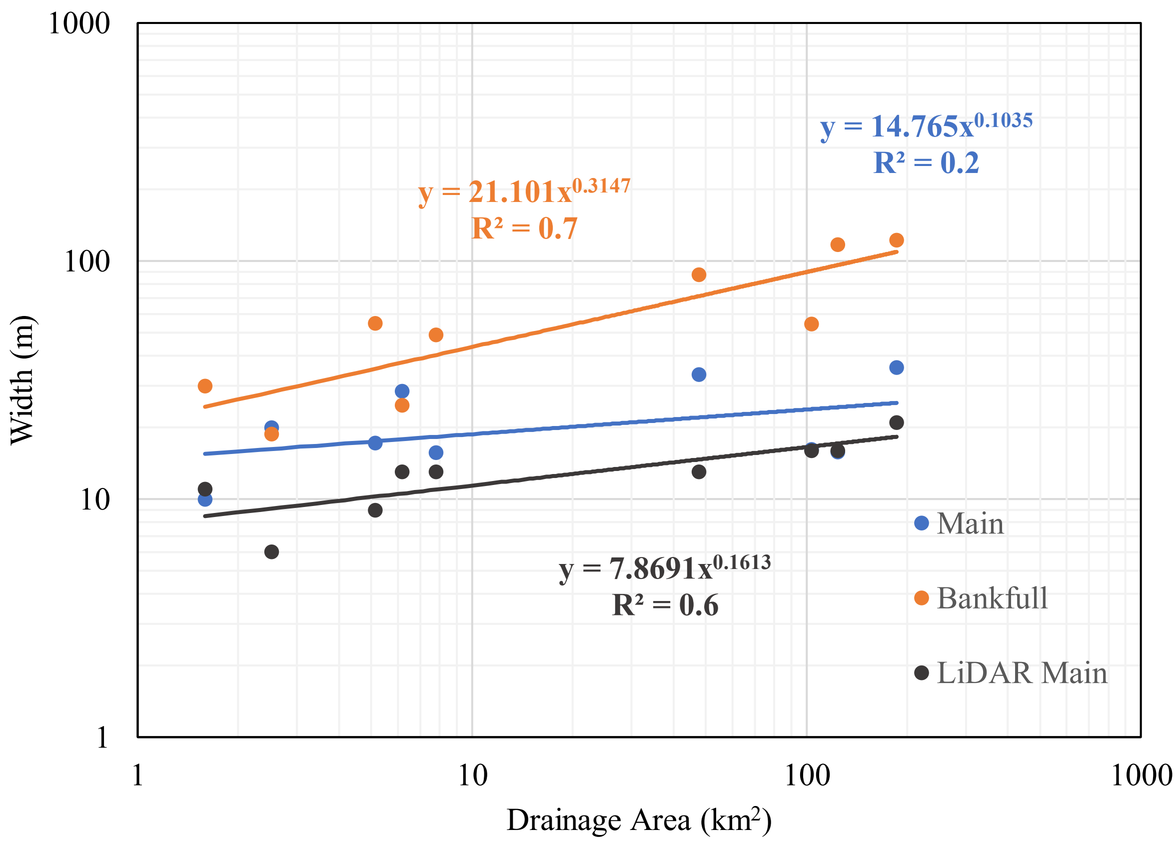

Figure 31. Width comparisons of gage survey widths and LiDAR widths.

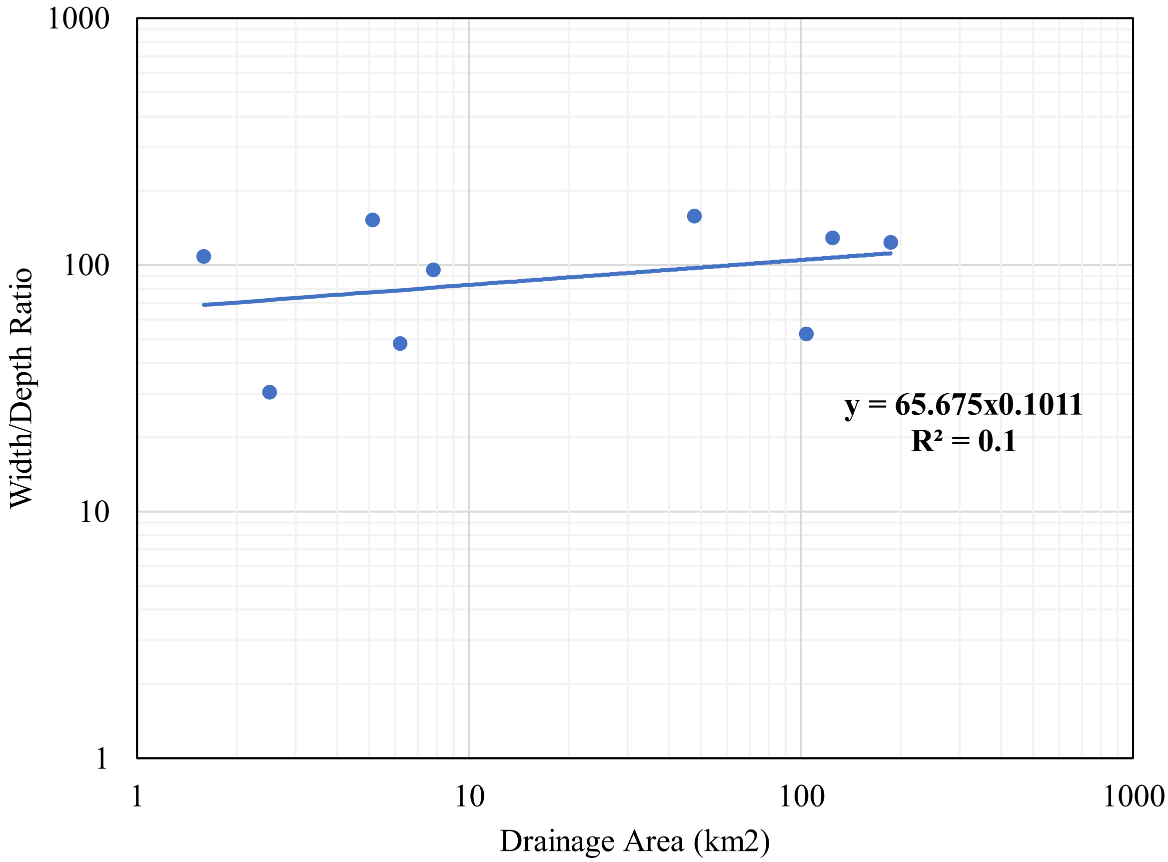

Figure 32. Width and depth ratio of gage sites.

CONCLUSION

The purpose of this study was to use General Land Office surveys from the 1820s to assess the channel and be used to evaluate channel widths changes since before Euro-American settlement to present day. Specifically, channel widths recorded in 1821 were compared to widths obtained from LiDAR derived DEMs to quantify channels changes due to human induced disturbances. Furthermore, field checks indicated that LiDAR derived DEM could measure widths accurately. Additionally, aerial photographs were used to examine temporal width trends in the watershed since the 1930s. Finally, gage data provided by the Ozarks Environmental and Water Resources institute were used to describe relationships between active main channel width and bankfull width for nine gage sites throughout the watershed. There are five main findings of this study:

1. GLO surveyors used consistent methods for stream detection. The two General Land Office surveyors responsible for the townships covering the Big Barren Creek watershed surveyed a consistent number of channel crossings for each stream order with similar distributions across streams of different sizes. Clarkson surveyed 19 crossings or 29% of the total crossings indicated by the delineated stream network for this study. Gamble surveyed 19 crossings or 28% of the total crossings indicated by the delineated stream network. Additionally, the minimum width for a wetted channel was 0.6 m while the minimum width for an ephemeral channel was 0.8 indicating wetted channels had a lower detection limit than ephemeral channels.

2. LiDAR derived DEMs can be used to accurately measure active channel widths. Crossings on public lands were measured in the field to check the accuracy of LiDAR derived DEM widths. Field checks of survey sites found relative percent differences averaging 21% showing limited variance between measurements. Third and fourth order streams had the lowest relative percent difference of 13%. Well defined bank tops in third and fourth order streams made them the most accurately measured channel widths.

3. Channel widths have increased an average of 2.6 times since 1821. The largest width increase was in second order streams with an average increase of 3.4 times. First order streams recorded the next highest increase averaging a 3 times width increase. Third and fourth order streams increased by 2.5 and 1.9 times on average. This is consistent with the Lecce (2013) finding in the Driftless Area of Wisconsin showing width and cross-

sectional area increases are the highest in small headwater streams and decreases downstream. Along with channel width increases, an increase in drainage density through network extension could have created more defined or new channels where GLO surveyors did not record measurements.

4. The natural area of Big Barren Creek has experienced minimal channel width changes including decreases and no change in channel width. Four sites were in the natural area with only one site showing a 54% increase, one site with no change, and two sites showing a 10% decrease. The natural area is a unique section that is spring fed and has constant flow and strong geologic controls (U.S. Forest Service 2008). The location and nature of this area makes it less susceptible to human disturbances.

5. There were 18 sites that show a width increase since 2007. The average increase in channel width since 2007 for those sites was 1.7 times. There were 14 showing increases from 2015 to 2016/2017. The average increase in channel width since 2015 was 1.4 times. The recent width increases at these sites in indicative of climate change effects on stream channels with an increase in high flooding magnitude events (Pavlowsky, Owen, and Bradley 2016).

Findings from this study provide a basis for evaluating watershed responses to human induced disturbances in a forested watershed. This study focused on the Big Barren Creek watershed, future work needs to be completed in other forested watersheds in the Ozarks evaluated similarities between other forested watersheds in Mark Twain National Forest that have undergone similar land use and land cover changes. By better understanding human disturbances on channel change, we can help reduce the negative effects of these actions on channel stability in forested streams. This study is the first to utilize historical surveys to explain how human disturbances such as logging, and land use changes have affected channel widths since the 1820s in forested headwater streams in Mark Twain National Forest. It is suggested here that the removal of pine by exploitative logging caused hydrologic response that increased runoff and progressively enlarged stream channels.

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APPENDICES

Appendix A. GLO Data.

Site ID	Width (links)	Width (m)	Sinking	Water Present	Surveyor	Description
1	73	14.6	No	Yes	W. Clarkson	A spring branch....where entered improvement
2	30	6	Yes	N/A	W. Clarkson	A sinking creek
3	30	6	No	N/A	W. Clarkson	A creek
4	100	20	Yes	N/A	W. Clarkson	A creek that sinks
5	50	10	Yes	No	W. Clarkson	A dry or sinking creek
6	40	8	Yes	No	W. Clarkson	A dry or sinking creek
7	3	0.6	No	Yes	A. Gamble	A spring branch
8	4	0.8	No	Yes	A. Gamble	A spring branch, two in distance of fifty L runs E
9	15	3	No	Yes	A. Gamble	A bold running stream
10	55	11	No	N/A	A. Gamble	A brook
11	150	30	No	Yes	A. Gamble	A creek runs little water
12	100	20	No	N/A	A. Gamble	A creek
13	130	26	No	Yes	A. Gamble	a creek, little water, soon sinks
14	4	0.8	No	N/A	A. Gamble	A brook
15	10	2	No	Yes	A. Gamble	A ditto, runs strong
16	30	6	No	N/A	A. Gamble	A creek

Appendix A-Continued. GLO Data.

Site ID	Width (links)	Width (m)	Sinking	Water Present	Surveyor	Description
17	50	10	No	N/A	A. Gamble	A creek
18	130	26	No	N/A	A. Gamble	A creek, general width thirty L
19	5	1	No	N/A	A. Gamble	A brook
20	10	2	No	N/A	A. Gamble	A branch
21	10	2	No	N/A	A. Gamble	A brook
22	15	3	No	N/A	W. Clarkson	A brook
23	15	3	No	N/A	W. Clarkson	A brook
24	10	2	Yes	No	W. Clarkson	A dry or sinking brook
25	20	4	Yes	No	W. Clarkson	A sinking brook, over hilly rocky pine land
26	4	0.8	No	N/A	W. Clarkson	A stream
27	30	6	Yes	No	W. Clarkson	A sinking creek
28	7	1.4	No	N/A	W. Clarkson	A stream
29	12	2.4	Yes	No	W. Clarkson	A sinking brook
30	30	6	Yes	No	W. Clarkson	A sinking creek
31	15	3	Yes	No	W. Clarkson	A sinking brook
32	15	3	No	N/A	W. Clarkson	A brook
33	8	1.6	No	N/A	A. Gamble	A branch
34	6	1.2	No	N/A	A. Gamble	A branch
35	6	1.2	No	N/A	A. Gamble	A branch
36	4	0.8	No	N/A	A. Gamble	A branch
37	30	6	Yes	No	W. Clarkson	A sinking creek
38	30	6	Yes	No	W. Clarkson	A sinking creek

Appendix B. Aerial Photograph Data.

Point ID	Stream Order	R-km	GLO Width (m)	Aerial Photograph Width (m)										LiDAR Width (m)
			1820	1939	1956	1966	1986	1990	1995	2007	2008	2013	2015	2019
1	1	-	14.6	N/A	N/A	N/A	N/A	17	N/A	18	17	N/A	20	25
2	4	2.3	6	N/A	N/A	N/A	N/A	15	N/A	16	19	N/A	21	20
3	4	4.5	6	N/A	N/A	N/A	N/A	10	10	12	12	N/A	19	20
4	4	6.7	20	N/A	N/A	N/A	18	20	21	19	17	N/A	21	23
5	4	7.9	10	N/A	N/A	N/A	N/A	10	10	11	10	N/A	10	15
6	4	10.0	8	N/A	N/A	25	23	23	N/A	24	25	N/A	22	27
7	1	-	0.6	N/A	N/A	N/A	N/A	N/A	N/A	2	2	N/A	2	4
8	2	-	0.8	N/A	N/A	N/A	N/A	N/A	N/A	2	2	N/A	5	6
9	2	-	3	N/A	N/A	5	N/A	N/A	N/A	7	7	N/A	8	11
10	4	16.4	11	N/A	12	N/A	N/A	N/A	N/A	16	N/A	N/A	18	17
11	4	17.7	30	N/A	22	N/A	N/A	25	26	26	27	25	24	27
12	4	18.0	20	N/A	12	N/A	N/A	15	15	15	15	N/A	16	18
13	4	18.6	26	N/A	19	N/A	N/A	N/A	N/A	N/A	20	22	25	26
14	1	-	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	2
15	2	-	2	N/A	N/A	N/A	N/A	3	N/A	3	3	N/A	4	4
16	4	23.1	6	N/A	N/A	18	N/A	19	19	20	20	N/A	19	16

Appendix B-Continued. Aerial Photograph Data.

Point ID	Stream Order	R-km	GLO Width (m)	Aerial Photograph Width (m)										LiDAR Width (m)
			1820	1939	1956	1966	1986	1990	1995	2007	2008	2013	2015	2019
17	4	22.3	10	N/A	N/A	13	N/A	13	14	16	15	N/A	18	18
18	4	20.7	26	N/A	N/A	16	N/A	17	17	19	19	19	19	30
19	1	-	1	N/A	N/A	2	N/A	N/A	N/A	2	2	N/A	2	7
20	3	-	2	N/A	N/A	N/A	N/A	N/A	N/A	2	2	N/A	3	6
21	2	-	2	N/A	N/A	3	N/A	4	5	5	5	N/A	7	10
22	2	-	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A	3	7
23	3	-	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4	N/A	6	10
26	1	-	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	3
27	3	34.9	6	4	N/A	N/A	N/A	N/A	14	11	9	N/A	9	13
29	2	-	2.4	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6
30	3	36.6	6	8	N/A	6	6	7	7	6	6	N/A	6	8
33	1	-	1.6	N/A	N/A	2	N/A	N/A	N/A	N/A	2	N/A	4	5
36	1	-	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A	N/A	1
37	4	29.3	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	14
38	3	32.4	6	N/A	N/A	13	N/A	N/A	15	15	16	N/A	19	24