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Geomorphic Disturbance and Anthropogenic Modifications in Big Barren Creek, Mark Twain National Forest, Southeast Missouri

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GEOMORPHIC DISTURBANCE AND ANTHROPOGENIC MODIFICATIONS IN BIG BARREN CREEK, MARK TWAIN NATIONAL FOREST, SOUTHEAST MISSOURI

A Masters Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geospatial Sciences in Geography, Geology, and Planning

By

Rachael A. Bradley

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ABSTRACT

This study investigates the influence of human disturbance on channel conditions in Big Barren Creek. The Big Barren watershed drains 191 km^2 of the Ozark Highlands in southeast Missouri. Several segments of the creek have been channelized by levee construction and gravel mining. Approximately 27.2 km of the main stem of Barren Creek were assessed for 13 photo-years ranging from 1939 to 2014.
Geomorphic classifications using channel conditions in aerial photographs and field observations were used to evaluate patterns of disturbance. While 52% of the creek is managed by private landowners, 81% of disturbed length occurs on private lands. Further, 43% of disturbed channel length on public land is associated with channelization along private segments where channel incision and head-cuts migrate upstream and excess sediment loads are released downstream. While channelization started before 1939 in the upper segments, first time channelization occurred as late as 2007 in downstream segments. Channelization by private land managers is the main cause of channel instability in Big Barren Creek, however road crossings may also create unstable conditions in some reaches.

KEYWORDS: Ozarks, disturbance, aerial photograph, channelization, land management

This abstract is approved as to form and content

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INTRODUCTION

Human activities can directly or indirectly cause changes to watersheds resulting in geomorphologic adjustments by streams (Graf, 1975; Jacobson and Primm, 1997; Collins et al., 2003; Buffington, 2012). Overall, watershed factors which influence channel form and stability include geology, topography, vegetation, discharge, and sediment supply (Buffington, 2012). Human activities that change or degrade these factors can result in geomorphic responses by bed forms, cross-sectional area, bank erosion and gradient (Owen et al., 2011). Typical geomorphic response to human factors include, channel incision, widening, and planform changes (Jacobson and Pugh, 1992; Simon and Rinaldi, 2006). In many streams there is a tendency for channel form to be controlled by equilibrium between stream flow and sediment transport (Mackin, 1948; Lane, 1955; Renwick, 1992). However, channel modifications can cause disequilibrium in streams resulting in channel instability including bed and bank erosion and excessive sediment loads (Renwick, 1992; Simon and Rinaldi, 2006; Hupp et al., 2009).

Channel Modification

Direct channel modifications such as channelization and levee formation not only physically modify channel form but also change the sediment transport capacity and energy transfers within the stream (Landwehr and Rhoads, 2003). River channelization is the modification of a river to improve flood control, regulation of erosion, and drainage by straightening and deepening of the channel and also raising bank height with levees (Brookes et al., 1983; Heine and Pinter, 2012). Channelization can include clearing of

riparian vegetation, widening, and deepening of the channel (Wohl, 2004). Sedimentation or incision within the channelized segment as well as upstream, progressive widening, and various ecological affects have been documented as a result of channelization (Kuenzler et al., 1977; Brookes, 1985; Landwehr and Rhoads, 2003). Channelized stream segments increase flow velocity and turbulence resulting in erosion and deposition. Upstream reaches of channelized segments can become incised and reduce floodplain connectivity while downstream reaches may experience increases in flood stages and aggradation from eroded upstream sediment (Hupp et al., 2009).

Artificial levees build up bank heights to contain flood waters and reduce the frequency of inundation on floodplain areas (Wohl, 2014). Limiting the connection of the stream to the floodplain can increase flood stages along stream segments affected by levee construction due to stream constriction (Heine and Pinter, 2012). The natural hydrologic connectivity of a stream to a floodplain is altered by levee construction and causes upstream erosion and downstream deposition (Hupp et al., 2009). Human alterations to channels including channelization and levee construction and consequential channel adjustments such as erosion and aggradation, result in the need for continued maintenance of structures and stream stability.

Maintenance of previously channelized reaches by tree clearing, gravel mining, and bridge/ road repairs are common. Channelization exposes fine grained sediment to flood scour which winnows the channel bed transporting finer sediment downstream and leaves a coarser bed lag surface of cobbles and boulders. Alterations made to the riparian zone by land clearing, agriculture, and over grazing of livestock can also contribute to bank erosion and instability (Jacobson and Primm, 1997). Channel segments that lack

riparian vegetation cover contribute to bank erodibility because vegetation provides an anchor for bank sediment and serves as a stabilization force during flooding (Groffman et al., 2003; Richardson et al., 2007). Floods and the movement of sediment in a stream is affected by road and bridge crossings (Jones et al., 2000). Debris and sediment may be backed up and even form jams upstream of road crossings that obstruct flow and act as dams to trap sediment and other materials (Nakamura et al., 2000). Bridge instability is linked to channel modifications that cause accelerated bank erosion and migration of headcuts that undermine support (Johnson, 2005). Upstream channel enlargement can release excess sediment downstream and clog the channel. The excess sediment often needs to be physically removed by heavy equipment for use in construction activities (Kondolf, 1994).

Gravel mining is the physical removal of gravel directly from an active stream bed (Kondolf, 1994). Gravel mining may offer temporary improved flood control in aggrading streams, but it also causes changes in the physical structure of the channel up and downstream of mining sites (Kondolf, 1994; Brown et al., 1998). Sediment transport rates vary over time and the geomorphology of a stream is reflected in the balance between sediment supply and transport. Therefore instream gravel mining can produce incision by locally lowering the base level of a stream. The resulting steeper gradient creates a head cut that can migrate upstream and may increase bankfull width (Kondolf, 1994; Brown et al., 1998). Bankfull widths are also increased in gravel mining areas due to the nature of excavation. In regions where bedrock and residuum underlie the gravel stream beds, lateral erosion of stream banks is common and results in channel widening from bank instability (Brown et al., 1998).

Human modifications on streams have been occurring throughout history (Gregory, 2006). This study will assess the temporal and spatial distribution of channelization in an Ozark headwater stream. Channel instability resulting from channelization and artificial levee construction have led to problems of incision and aggradation in streams. Using historical aerial photography indicators of disturbance and channelization can be identified in streams.

Historical Aerial Photography

Historical aerial photography can be a useful tool for evaluating stream planform change because information can be digitally extracted such as channel banks, gravel deposits, roads, and other infrastructure (Vanacker et al., 2005; Urban and Rhoads, 2008). Channel adjustments such as increases in channel width, migration of headcuts, and aggradation of excess sediment can be documented through the use of historical aerial photographs. Aerial photographs have been utilized by previous studies for analysis of planform changes over time (Jacobson and Primm, 1997; Vanaker et al., 2005; Urban and Rhoads, 2008; Owen et al., 2011; Martin and Pavlowsky, 2011).

In a study by Vanaker et al. (2005), a small headwater stream was examined to assess the channel responses to upland forest clearing for the expansion of agricultural lands and grazing pastures. Historical land use data and channel morphology of the Deleg River in the Ecuadorian Andes were collected through a series of aerial photographs (1963-1995) and channel morphology was measured through digitization of channel planform along the edges of the active channel. The authors identified a general trend of channel narrowing and the dissipation of large gravel bars along a 28.5 km river segment.

Jacobson and Primm (1997) used historical aerial photographs from 1939 to 1993 to document aggradation and instability in the Jacks Fork in the Missouri Ozarks region due to land use and management changes. Owen et al. (2011) examined sedimentation patterns along the upper James River in southwestern Missouri using historical aerial photographs to understand channel change over time in relation to historical floodplain sedimentation patterns. The authors found that Ozark rivers have been slow to recover in segments of disturbance due to changes in land use. Martin and Pavlowsky (2011) preformed an analysis of channel planform using aerial photography to classify the distribution of channel features including bar complexes such as longitudinal, point, and center bars along the Finley River in southwestern Missouri.

Ozark Highlands Channel Disturbance

Land use disturbances throughout the Ozarks have caused changes to pre-settlement channel form and sediment. The Ozark Highlands are located in portions of Arkansas, Missouri, Oklahoma, and Kansas and are dissected by gravel and sand dominated rivers with low sinuosity (Jacobson and Pugh, 1992; Jacobson and Primm, 1997). Previous studies have linked anthropogenic activities such as channelization, levee construction, and gravel mining to changes in Ozark stream morphology (Jacobson and Primm, 1997; Owen et al., 2011). Historical accounts, aerial photographs, and sediment analysis were used to show that the Ozarks have experienced anthropogenic induced changes in channel form and sediment transport over the past 150 years (Jacobson and Pugh, 1992; Jacobson, 1995). Bank erosion, channel aggradation, migrating head cuts, and legacy sediment deposition on floodplains have been show to result from human

activities (Saucier, 1983; Jacobson, 1995; Owen et al., 2011). Accounts as early as 1877 describe Ozark streams as “rapid-flowing” and “clear” without mention of gravel and a mixed sediment load free of excess gravel bar deposition (Williams, 1877; Jacobson and Pugh, 1992; Jacobson and Primm, 1997). Considerable amounts of chert gravel was eroded from the slopes and banks of Ozark headwater streams leading to excessive gravel aggradation in downstream rivers (Jacobson and Pugh, 1992; Jacobson and Primm, 1997).

Gravel mining can significantly alter the geomorphology in the Ozark streams. In a study conducted on three Ozark streams, Brown et al. (1998), examined the impacts of direct channel manipulation from gravel mining on channel form for the area of gravel mining as well as reaches upstream and downstream. At all of the study sites, the bankfull width increased downstream of and at the mining operations. The authors also concluded that migrating headcuts that started as a result of gravel mining increased the channel width upstream as well. Gravel-bed channel morphology was also altered in pool areas as distance between riffles decreased. Underlying bedrock is common for Ozark streams and therefore causes banks to erode laterally and undercut riparian vegetation, increasing sediment to the stream, and reducing the stream’s ability to move bedload sediment (Brown et al., 1998; Zaimes et al., 2004). Direct channel modifications in the Ozarks are a management concern and call for a better understanding of local channel modification of stream form and function. The Missouri Department of Conservation and United States Forest Service have several strategies for watershed assessment and management, but lack advisement on how to address local modifications of a headwater channel (Shifley and Brookshire, 2000).

Big Barren Creek

This study focuses on the understanding of recent changes in an Ozark headwater stream, Big Barren Creek, due to human modifications on the channel. Big Barren Creek is located in southeastern Missouri in the Current River basin (Figure 1). Big Barren Creek belongs to the Current River Hills subsection that is characterized by moderate to steep hillslopes and narrow valley bottoms (Kabrick et al., 2000). Currently, sections of Big Barren Creek are disturbed due to the presence of excess gravel and lack of riparian vegetation (Figure 2).

The causes of recent disturbance conditions in Big Barren Creek have been a question for current land managers and may be linked to land use factors. From 1880 to 1920 the timber industry boomed in the Ozark region and large forested areas were cleared (Jacobson and Primm, 1997; Karstensen, 2010). After the timber "boom" the land use in Ozark watersheds such as Big Barren became predominately small farming communities dispersed along valley bottoms in recovering forest areas (Jacobson, 1995). According to the U.S. Department of Agriculture, erosion of soils and abandoned lands by logging operations became a serious problem and began the acquisition of units that are now part of Mark Twain National Forest (www.fs.usda.gov/main/mtnf/learning /history-culture). In 1939, the forest areas went under government control and became Mark Twain National Forest in 1976. The main stem of Big Barren Creek is approximately 40.5 km long with the confluence at the Current River as 0 km. Portions of the Big Barren watershed are still privately owned and managed with this study area from river- kilometer 13.3 to 40.5 (Figure 3). Of the 27.2 km of channel length included in the study area approximately 52% is managed by private landowners. Private management of

segments of Big Barren Creek affect the riparian corridor and channel form. Private landowners often use constructed levees and gravel mining to create desired channel form and protect their farmlands from flooding events. Direct modifications by private landowners has created disturbance zones in Big Barren Creek (Figure 4).

Indirect causes or non-point sources of disturbance also exist in the Big Barren watershed. Disturbances can be caused by natural and human induced fire that controls the distribution and composition of vegetation in a watershed (Flannigan et al., 2000). However, the effect of managed fires on watersheds and their drainage channels is unclear (Wondzell and King, 2003). Prescribed burning can reduce hazardous fuels, remove undesired plant species, and improve habitat by promoting tree growth and recycling nutrients into the soil (www.fs.fed.us/fire/management/rx.html). Since 2011, prescribed burning has been used in the Big Barren watershed to encourage oak and pine regeneration and reduce competition according to the Missouri Pine-Oak Woodlands Restoration Project (2011). Forest management would like to know if prescribed burning is contributing to the increased number of flooding events and upland sediment erosion due to the lack of vegetation (Marshall et al., 2008; Cerda and Robichaud, 2009).

In addition to indirect human causes, climate change may also be altering Big Barren Creek. Across the Midwestern region of the U.S. there have been reported increases in heavy precipitation events and flooding according to the National Climate Assessment (2014). High magnitude rainfall events in the Midwest have also increased in frequency (Villarini et al., 2013). A study conducted by Angel and Huff (1997) used a digitized record of precipitation events starting in 1901 that contains 304 sites across the Midwest. Angel and Huff's (1997) precipitation record shows that it is more likely for

extreme rainfall events to occur in recent years. This means that climate in the Ozark region may be changing to an increased rainfall frequency that produces more floods.

There is some evidence to indicate that rainfall rates are increasing in the Big Barren watershed. Pavlowsky et al. (2016) conducted annual and seasonal rainfall analysis of Big Barren Creek by using surrounding weather stations with rainfall data obtained over the past 60 years in the Ozarks. The authors concluded that rainfall amounts in Big Barren Creek have increased an average of 0.22 mm per year over the past 60 years, and since 2005, annual rainfall has increased 7% over the period from 1985-2004 (Pavlowsky et al., 2016). Further, over the past 60 years the threshold for daily rainfall events over 7.5 cm has been surpassed 16 times, and of those 16 occurrences, 6 have occurred between 1955-2005, while 10 have occurred from 2005-2015 (Pavlowsky et al., 2016). Since there is a substantial relationship between rainfall increase and overbank flooding, an increase in frequency of intense rainfall events can have ramifications of flooding that cause channel disturbances (Knox, 2000). In addition, previous studies have shown that changes in different land cover types, such as forest to farmland, combined with an increase in precipitation can increase discharge and change channel form (Knox, 2000; Hu et al., 2005).

Purpose and Objectives

The purpose of this study is to evaluate the historical disturbance history of Big Barren Creek to document the influence of human modifications on the geomorphology of the stream and how natural factors, land use, and management practices have influenced the condition of the present day stream system. Previous studies have

examined land use changes and human-induced changes on Ozark stream channels (Jacobson, 1995; Jacobson and Primm, 1997). Destabilizing effects of land management practices in the Ozarks have led to the development of disturbance zones characterized by aggradation of substantial gravel within streams (Jacobson and Primm, 1997). The objectives of this study are to assess historical channel morphological changes in relation to human modifications and evaluate the relative influences of private and public management on disturbance patterns in Big Barren Creek. This is the first study to document the occurrence, history, and geomorphic effects of channelization practices on headwater Ozark stream channels. Increased understanding of historical stream and land use changes related to human activities can provide a better starting point for restoration efforts and future land use and management decisions.

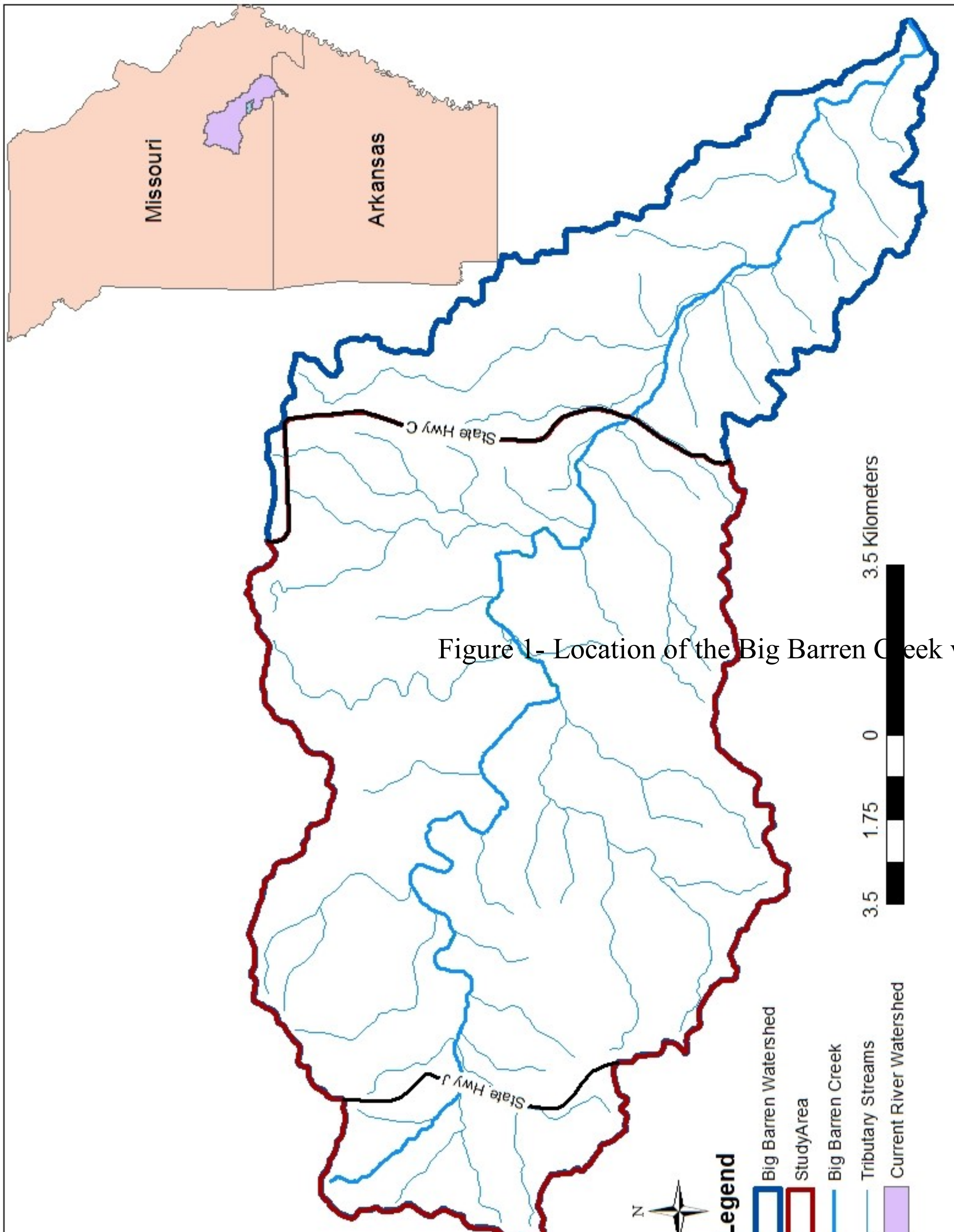

Figure 1- Location of the Big Barren Creek watershed in southeast

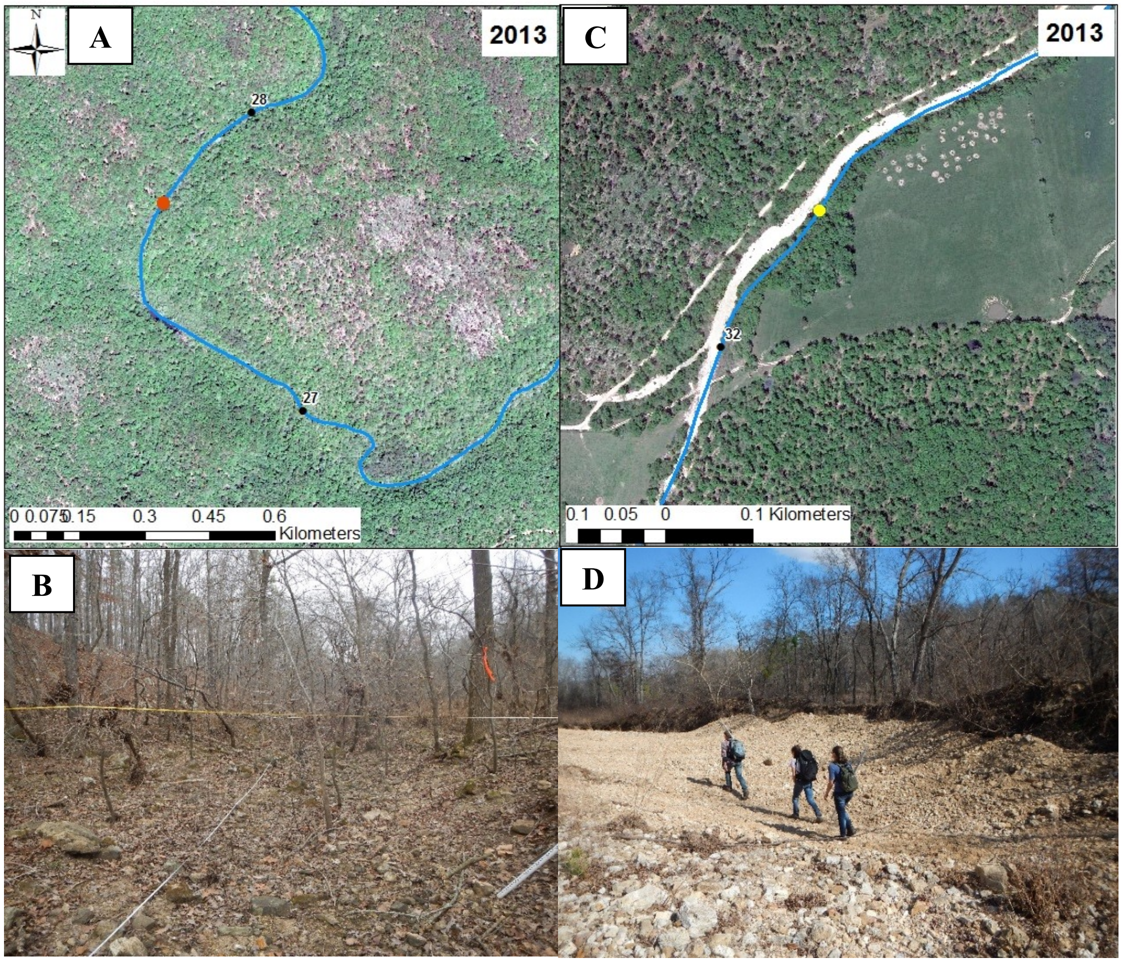

Figure 2 - Stable and disturbed sections of Big Barren Creek. A: Recent aerial photograph (2013) of stable segment. B: Ground-truthing photograph at river kilometer 27.7 that corresponds to the orange circle on the image above. C: Recent aerial photograph (2013) of disturbed segment. D: Ground-truthing photograph at river kilometer 31.8 that corresponds to the yellow circle on the image above.

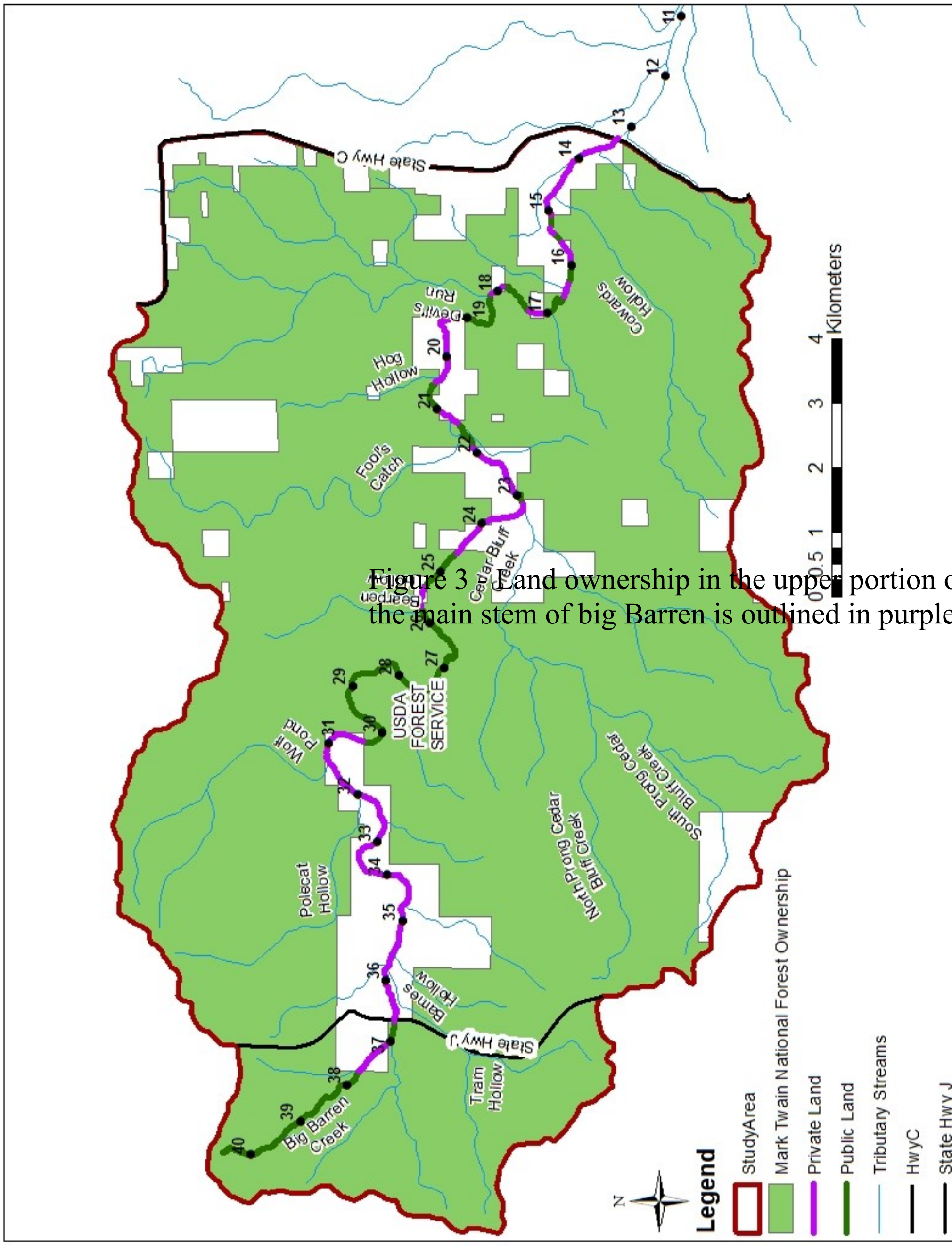

Figure 3 : Land ownership in the upper portion of the Big Barren watersh
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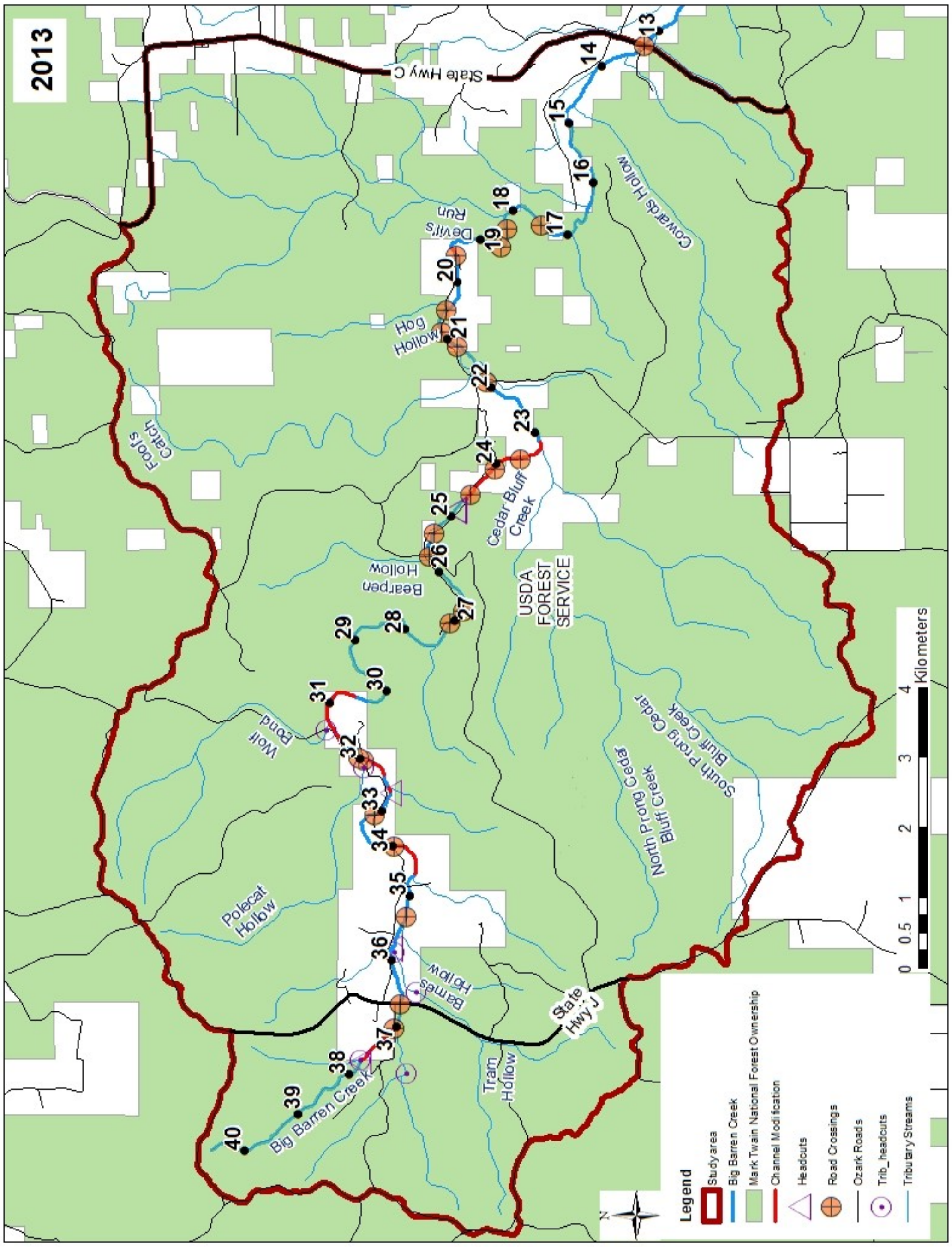

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STUDY AREA

This study evaluates the effects of anthropogenic channelization on stream channel conditions in Big Barren Creek, a tributary of the Current River Basin located in Mark Twain National Forest. According to the U.S. Forest Service website, on February 17, 1976 Mark Twain National Forest was established and covers approximately 6,070 km^2 of the Ozark Highlands in southern Missouri and northern Arkansas (www.fs.usda.gov). Overall, the Ozark region spans approximately 108,332 km^2 of southern MO, northern AR, northeastern OK, and the southeastern corner of KS (Jacobson and Primm, 1997; Karstensen, 2010; Martin and Pavlowsky, 2011). Big Barren Creek is located in portions of Ripley, Oregon, and Carter counties of southeast, MO (Figure 5). Big Barren Creek watershed drains 191 km^2 of which 26% of the area is private and cleared land area and the rest is national forest (Panfil and Jacobson, 2001). The main channel of the creek is approximately 40.5 km long with longitudinal locations described in river-kilometers with zero at the confluence with the Current River. The study area for the present study drains 140 km^2 and stretches from State Hwy C at the upper most channel point at 13.3 km to 40.5 km (Figure 6).

Geology and Soils

The Ozark region is a large geologic uplift of Paleozoic sedimentary rocks composed mainly of limestone and dolomite (Panfil and Jacobson, 2001; Jacobson, 2004). The physiography of the Ozarks can be divided into three sections: St. Francois Mountains, Springfield Plateau, and the Salem Plateau (Karstensen, 2010). The Big

Barren watershed is located in the Current River basin within the Salem Plateau (Panfil and Jacobson, 2001) (Figure 5). Karst development in this region contains features such as sinkholes, caves, losing streams, and spring-fed streams is due to the dissolution of limestone and dolomite bedrock (Hu et al., 2005; Martin and Pavlowsky, 2011).

The Roubidoux and Gasconade Formations from the Lower Ordovician are the two main contributors for the light, whitish or grayish, colored limestone and chert gravel substrate observed in Big Barren Creek (Soil Survey of Carter County, 1990; Weary et al., 2014) (Figure 7). The Gasconade Dolomite is the primary formation in Big Barren Creek and is comprised of chert, dolomite, and limestone. The thickness of this unit ranges from 45 m to 235 m (Weary et al., 2014). In the headwater sections of Big Barren Creek, the Roubidoux Formation overlies the Gasconade Dolomite. The Roubidoux Formation is characterized by sandstone, dolomite, sandy dolomite, and chert. This formation is typically weathered and not very well exposed in the watershed and its thickness ranges up to 76 m (Weary et al., 2014).

Geology can influence many soil characteristics (Panfil and Jacobson, 2001). The Ozarks region is characterized as having alfisols and utisols that formed a thin loess over cherty limestone or dolomite residuum (Adamski et al., 1995; Wilkerson, 2003). Low slope and chert-dominated substrate can accumulate up to 7 m of residuum and colluvium, while higher sloped areas may have a thiner layer of soil or none at all (Jacobson and Primm, 1997). According to the U.S. Department of Agriculture, Natural Resources Conservation Service Soil Surveys (2013), the Ozark Highlands alluvial soils can be divided into uplands, stream terraces, and floodplain soils. The soil series for the Big Barren Creek watershed include 14 upland soil units and 7 floodplain soil units

(Table 1, Figure 8). Permeability of the upland soils ranges from slow to moderate meaning the potential for runoff and subsequent erosion is high to moderate in the Big Barren Creek watershed (Soil Survey Staff, 2013). Floodplain soils provide both channel structure and sediment supply as channel banks form and erode (Montgomergy and Buffington, 1998). Dominant floodplain sediment material in Big Barren Creek is from the Midco soil unit that contains 20-80% gravel (Soil Survey Staff, 2013). The Midco soil unit covers 16.6 km of the Big Barren Creek study area and the second largest unit, Tilk-Secesh, covers 5.6 km. The Tilk-Secesh unit contains 5-50% gravel (Soil Survey Staff, 2013). Channelized segments of Big Barren Creek are located in the Midco and Tilk-Secesh units. The moderate to high gravel content in the two predominant soil units is linked to the appearance of the active channel bed and bar material. The gravel size material eroding from the floodplain soils is from the Gasconade and Roubidoux Formations that contain white to gray chert nodules, and gray to light brown dolomite (Soil Survey of Carter County, 1990).

Climate and Hydrology

The climate of the Ozarks is continental with mean annual precipitation of 100-120 cm and mean annual temperatures between 15-18 degrees Celsius (Jacobson and Pugh, 1992; Panfil and Jacobson, 2001). According to the Missouri Department of Conservation website, the Current River Basin receives the most precipitation from April to June and receives the least from December to February. The climate of the Ozarks is affected by east-moving storm systems and southern moisture sources with varied seasonal and annual rainfall (Jacobson and Primm, 1997).

Precipitation, soil, land cover type, and topography determine the hydrology of the Big Barren Creek watershed. The karst and cavernous topography of the Ozarks creates a subsurface drainage system in which upland precipitation infiltrates into the ground and can be transported and resurface in valley bottom springs (Jacobson and Primm, 1997). Upland streams to be dry due to the karst drainage system except under intense rainfall conditions (Jacobson and Primm, 1997; Jacobson, 2004). Some Ozark streams have springs that provide constant flow, such as the spring-fed Designated Natural Area that was created in 1989 by the Missouri Department of Conservation due to its habitat diversity. Upstream of the spring-fed natural area, Big Barren Creek is a losing, ephemeral creek. Increased precipitation and storm events cause increased runoff and flooding especially in areas with low soil permeability and steep slopes (Jacobson and Pugh, 1992; Knox, 2000; Jacobson, 2004; Pavlowsky et al., 2016). Cleared land cover types can also contribute to the increases in stream discharge from a basin (Jacobson, 2004).

Vegetation and Land Use

Pre-settlement Vegetation and Land Use. During the pre-settlement period tribal groups of hunter and gatherers existed in the Ozarks (Jacobson and Primm, 1997). Pre-settlement vegetation distribution in the Ozark region was different from today. Vegetation before the early 1800s was characterized by dense pine and oak forest with thick undergrowth on slopes and wooded valley bottoms with some areas of grassland (Jacobson and Primm, 1997). According to the U.S. Forest Service, shortleaf pine once dominated the Missouri Ozarks, but due to historical logging and land use changes oak

forest types now cover much of the landscape. In the early 1800s the first Euro-Americans settled in the area and began agricultural practices, logging, and the use of livestock (Guyette and Larsen, 2000). Currently, vegetation in the Ozark region consist of oak and pine forest types and tallgrass prairies (Ethridge, 2009; Piva and Treiman, 2015). According to the U.S. Forest Service Forest Inventory, oak-hickory dominates as the forest-type group throughout Missouri, but especially in the Eastern Ozark region where oak-hickory covers over 3,500 acres of forest land (Piva and Treiman, 2015) (Figure 9). In Big Barren Creek 94% of the study area is forested, 1.3% is grassland, 2.7% is pasture covered, and 2% is developed land.

Densely wooded areas are more commonly found on steep slopes and higher elevations, while near valley bottoms or low slope areas farmland and logging operations are more common (McKenney et al., 1995). Soils in floodplains tend to be better for agriculture and were often cleared first during settlement, significantly reducing or eliminating riparian vegetation. Riparian vegetation is important in that it helps bank stability and keeps sediment from eroding into the stream (Raeker et al., 2011). According to the 2006 National Land Cover Database, the Ozarks region has experienced land cover change from the years 2001 to 2006 (Fry et al., 2011). Today, land use in Big Barren Creek is national forest, privately owned and managed for pasture and grazing, and used for timber production.

Timber Harvesting Period. In the late 1800s the timber industry found the Missouri Ozark region ideal and roads, railroads, and temporary homes were constructed in watersheds like Big Barren to in order to support the timber industry (Jacobson and Primm, 1997; Guyette and Larsen, 2000; Karstensen, 2010). The value of timber, and

number of people increased until the 1920s when the timber industry began to decline (Guyette and Larsen, 2000). The post-timber period (1920-1960) witnessed an increase in agriculture in the form of row crops, and open range livestock grazing (Jacobson and Primm, 1997).

Fire History. Population density and cultural economics are two of the most important factors that influence the frequency of fire (Guyette and Larsen, 2000). In the pre-settlement period, Native Americans used fire to maintain prairie conditions (Jacobson and Primm, 1997). The period from the late 1700s to the mid-1800s witnessed an increase in population (up to 4.6 humans per km^2), a shift in economic approaches, and an increase in the use of fire (Guyette and Larsen, 2000). Burning practices decreased and fire suppression increased as timber production increased (Guyette and Larsen, 2000). The percentage of burned regions decreased to less than 5% per year in the 1940s and continued to decrease into the 1990s to only 1% per year. In 2011, restoration of target vegetation, shortleaf-pine, by prescribed burning was started by the U.S. Forest Service as part of the Missouri Pine-Oak Woodlands Restoration Project in the Big Barren watershed. The Missouri Pine-Oak Woodlands Restoration Project requires federal, state, and private landowners to work together in order to achieve ecological restoration in the Current River Hills.

Land Ownership. Across the state of Missouri the forest land privately owned is approximately 83%, while public forest land is approximately 17% (Moser et al., 2012). Most of the private forest land is owned by families and individuals, however, approximately 40% of private forest landowners are part- or full-time farmers (Raeker et al., 2011). Public ownership is further divided by the Forest Service, state and local

government, and other federal bodies. The eastern portion of the Ozarks region has the largest portion of public ownership in the state with approximately 33% of forest land under public ownership (Piva and Treiman, 2015). According to the U.S. Forest Service website, of the eastern public forest lands, Mark Twain National Forest is the largest government-owned forest in Missouri (www.fs.usda.gov).

Land Management along Big Barren Creek

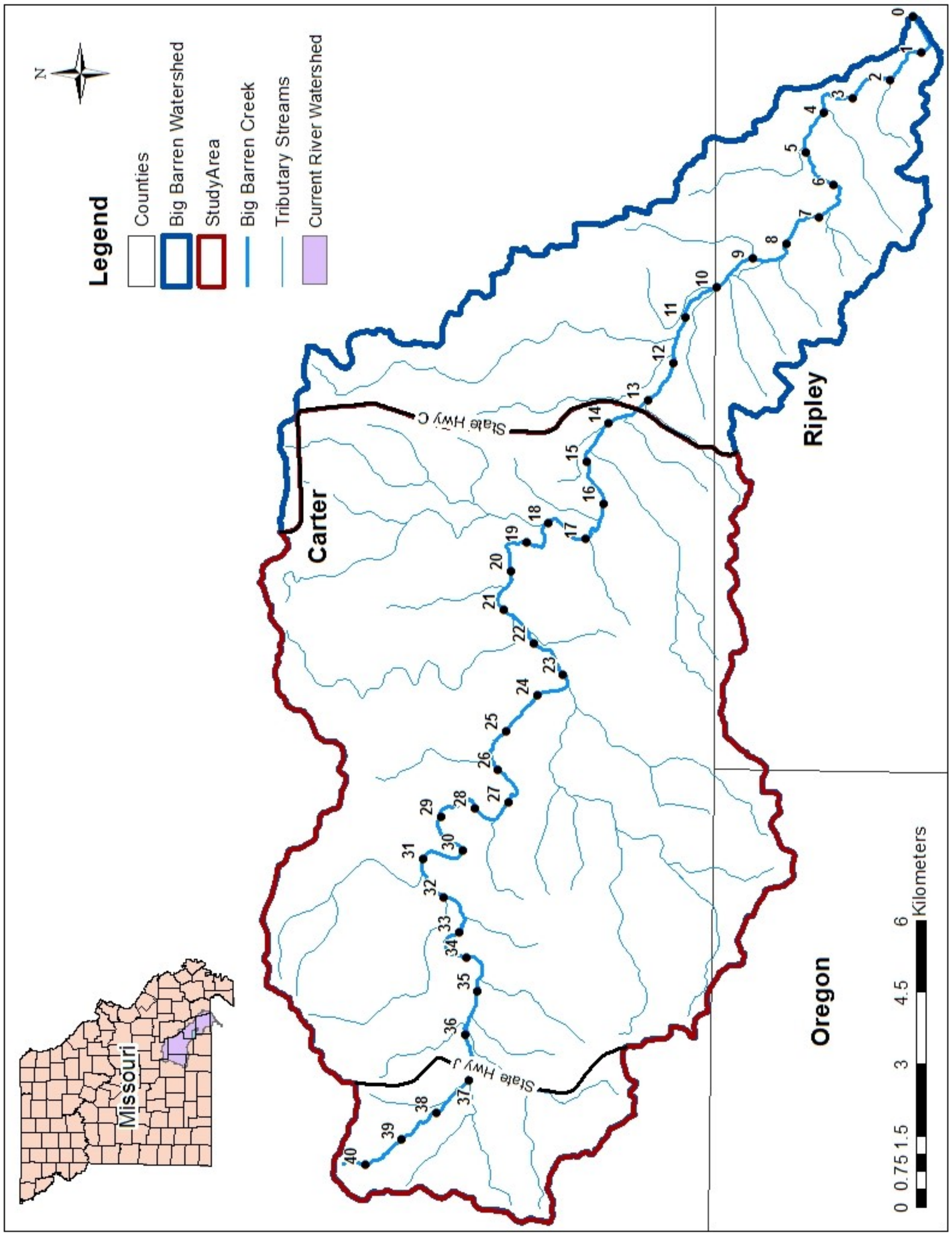
The main stem of Big Barren Creek is divided among sections of public and private land ownership (Figure 3). Approximately 48% of the riparian area along the creek is under U.S. Forest Service management, while 52% is managed for hay pasture and livestock grazing by private landowners according to the U. S. Department of Agriculture, Forest Service Automated Lands Program (http://fsweb.r6.fs.fed.us/alp/). Areas managed by the U.S. Forest Service are part of the Missouri Pine-Oak Woodlands Restoration Project to promote a sustainable forest ecosystem. Of longitudinal river kilometer length a total of 12.6 km of the main stem of Big Barren Creek was directly part of the most recent prescribed burns. Approximately 9.8 km of the main stem of Big Barren Creek is included in a 2015 burn unit and 2.8 km is included in a 2016 burn unit, totaling 46% of the longitudinal study area length (Figure 10). An area of approximately 36.9 km^2 and 9.8 km of river length was part of the 2015 burn units. In the 2016 burn units an area of approximately 30.5 km^2 and 2.8 km of river length was included. Of the total study area, approximately 48% of the land area was part of the 2015 and 2016 prescribed burns.

Channelization

Visible channel modification of Big Barren Creek extends to the beginning of this study's aerial photograph record in 1939. Channelization and stream modification are causes of disturbance in present day Big Barren Creek. Areas that are identified as affected by channelization and channel modification show one or more of the following: a high gravel reflectance, little to no riparian vegetation present, and visible bulldozer tracks (Figure 11). Currently, channelization and other channel modifications such as levee construction and gravel extraction occur on privately owned sections of land in the Big Barren Creek watershed. These types of disturbances cause channel deepening, widening, or excessive sedimentation (Brookes, 1985; Kuenzler et al., 1977; Landwehr and Rhoads, 2003; Hupp et al., 2009; Heine and Pinter, 2012; Wohl, 2014).

Table 1- Floodplain soil units of Big Barren Creek. Data obtained from NRC Soil Surveys (2013).

	A-horizon			B-horizon			C-horizon		
Unit Name	Depth (cm)	Texture	Gravel %	Depth (cm)	Texture	Gravel %	Depth (cm)	Texture	Gravel %
Bearthicket	0-30	silt loam	0-5	30-200	silty clay loam	0-30	>200	silty clay loam	0-80
Higdon	0-30	silt loam	0-2	30-230	silt loam or silty clay loam	0-40	N/A	N/A	N/A
Midco	0-20	very gravelly loam	20-80	N/A	N/A	N/A	20-150	extremely gravelly sandy loam	20-80
Relfe-sanbur	0-30	sandy and gravelly loam	50	N/A	N/A	N/A	30-150	extremely gravelly sandy loam	65-90
Sandbur-Wideman-Relfe	0-30	sandy and gravelly loam	0-50	N/A	N/A	N/A	30-150	extremely gravelly sandy loam	0-90
Secesh	0-20	silt loam	5	20-165	gravelly silty loam	5-75	N/A	N/A	N/A
Tilk-Secesh	0-20	gravelly silt loam	5-50	20-165	extremely gravely course sandy loam to very cobbly loam	5-50	165-180	extremely gravely course sandy loam	45



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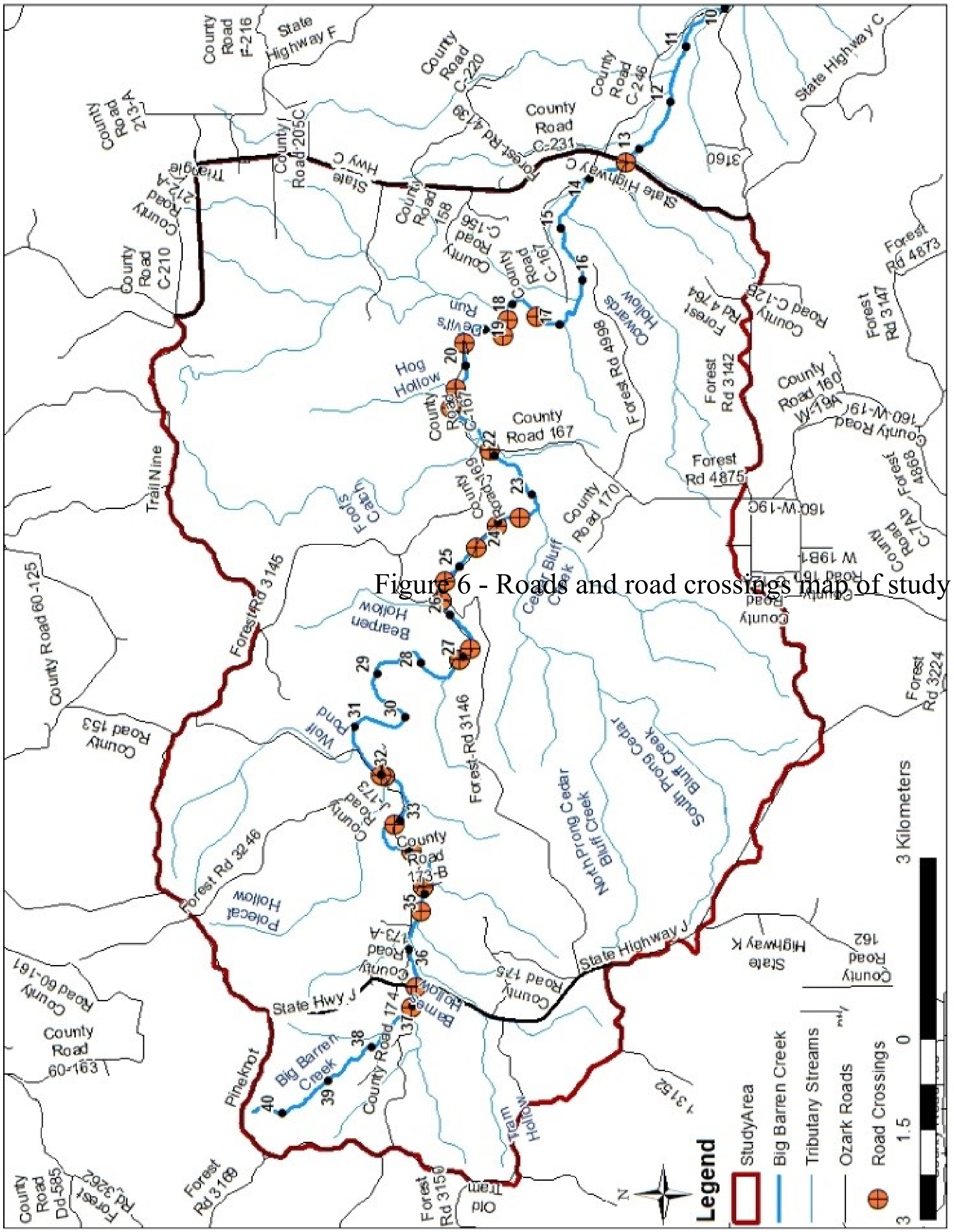
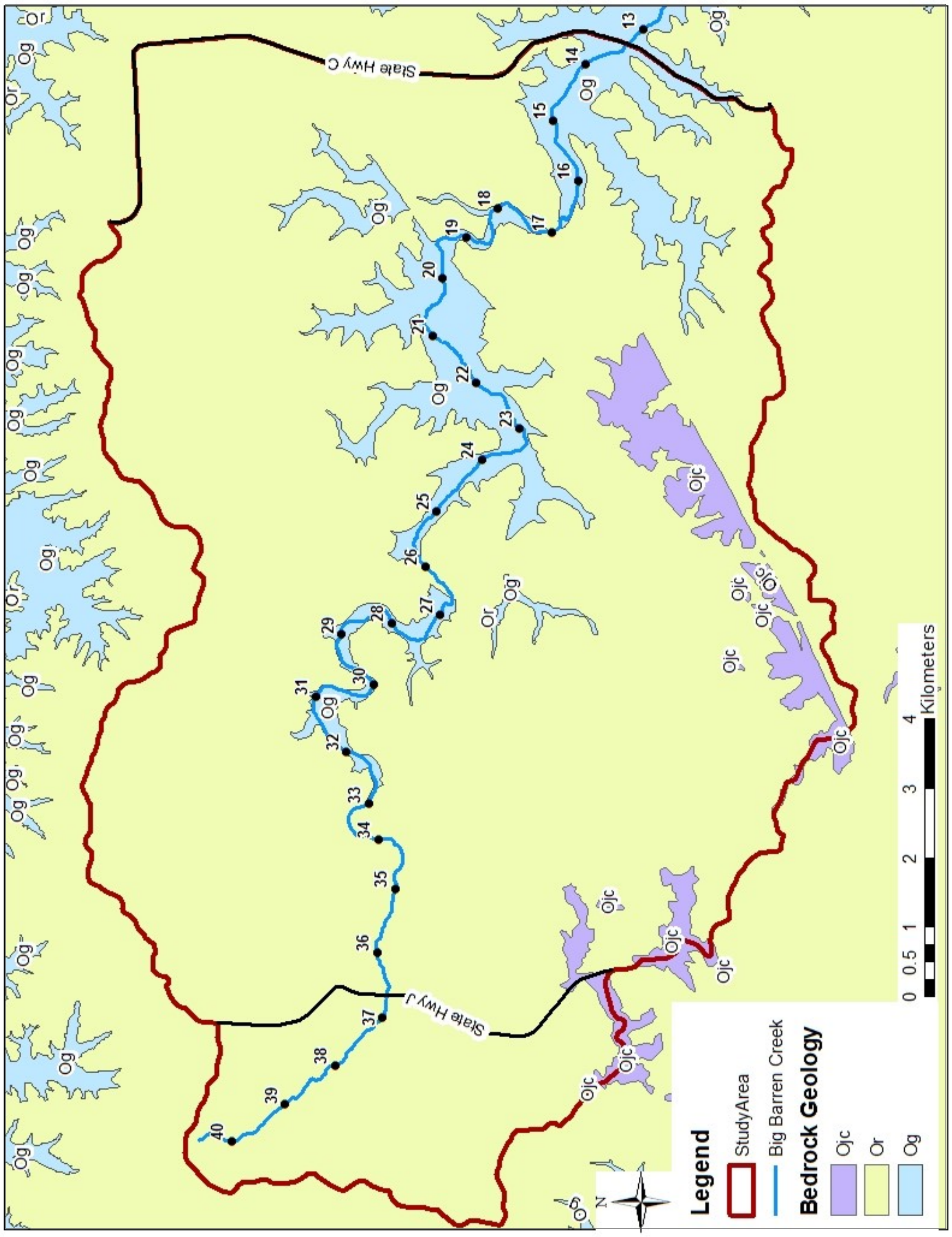


Figure 6 - Roads and road crossings map of study area with tributaries t



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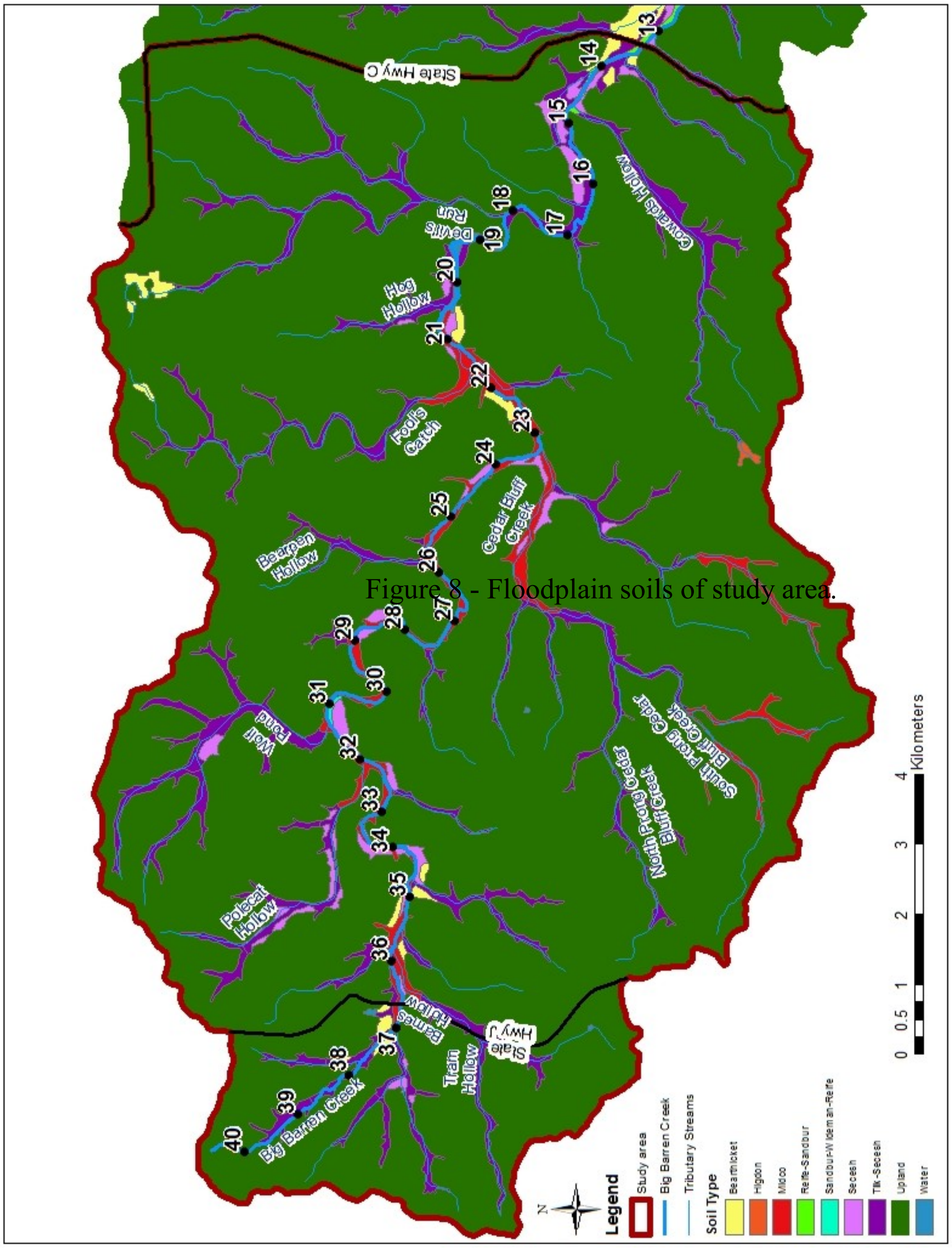

Figure 8 - Floodplain soils of study area.

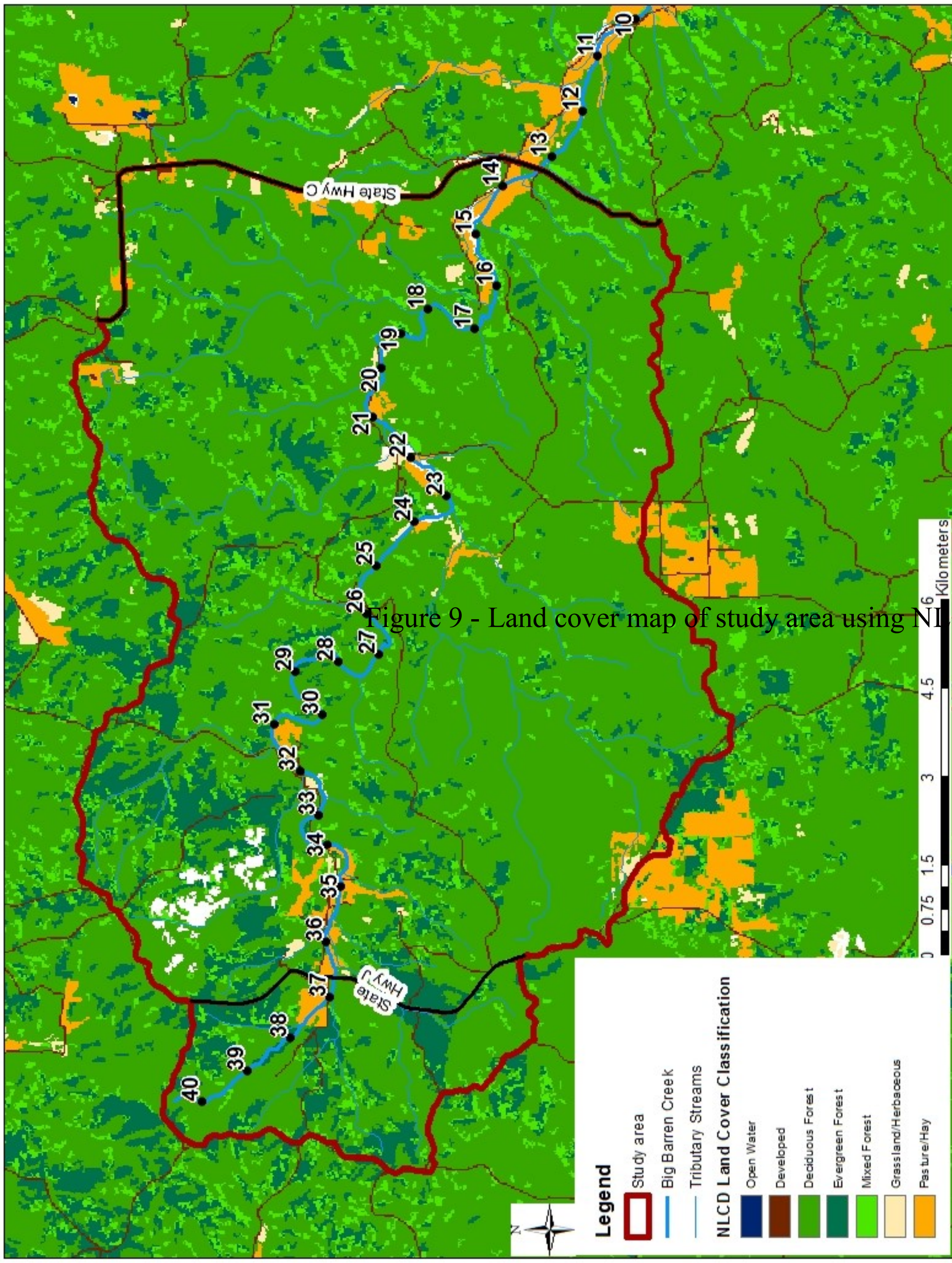

Figure 9 - Land cover map of study area using NLCD classification.

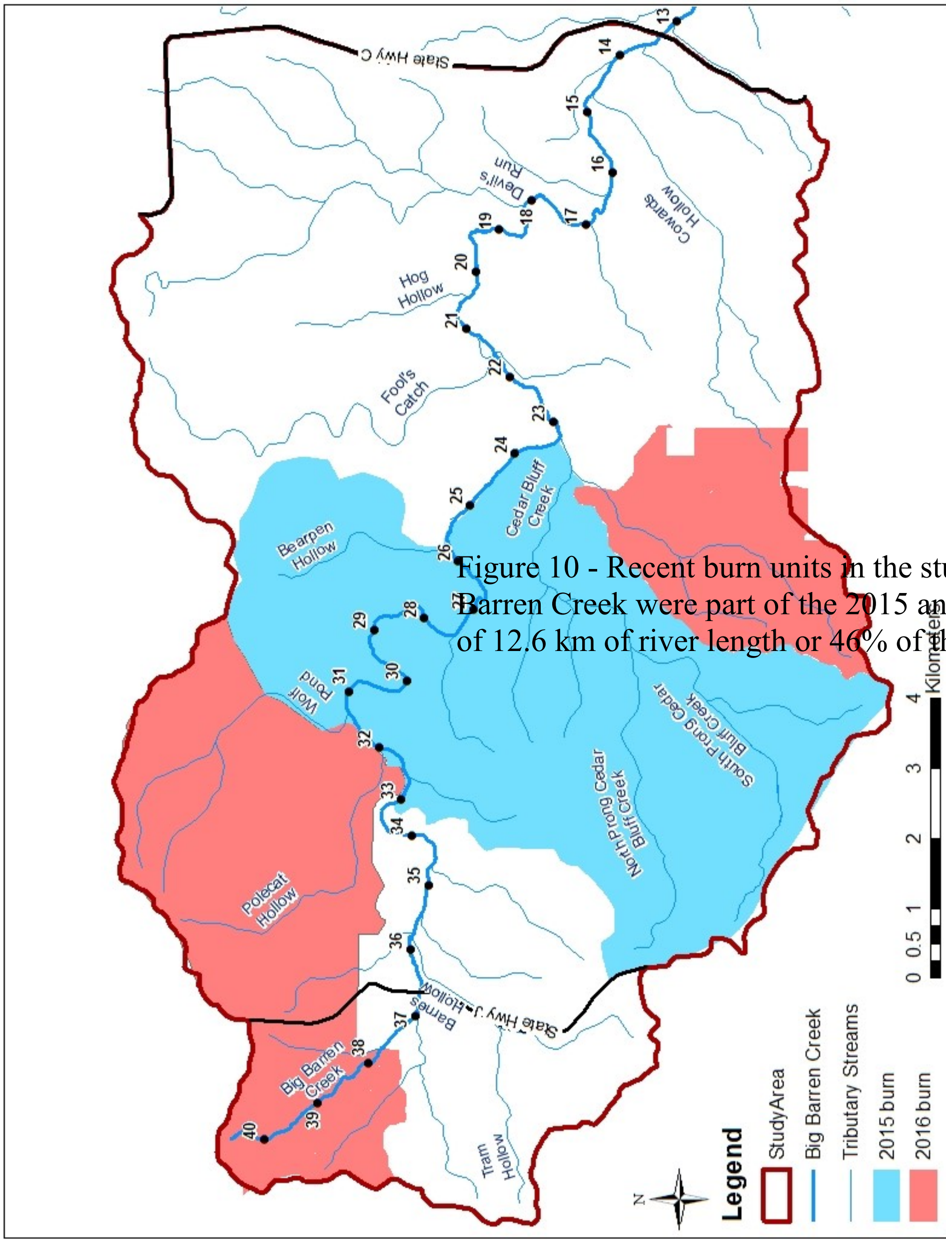

Figure 10 - Recent burn units in the study area. Approximately 9.8 k
Barren Creek were part of the 2015 and 2016 burn units, leaving 14.
of 12.6 km of river length or 46% of the study area was burned betw

Figure 11 - Bulldozer tracks from moving gravel at 23.6 (2013).

METHODS

The main goal of this thesis was to create aerial photograph data sets for Big Barren Creek and then to use those datasets to evaluate changes in the channel and relative influence of land ownership in ArcGIS (version 10.2.2). This study utilizes a multiple year record of aerial photographs to classify planform changes and channel patterns in both private and public managed stream segments. Historical photographs of rivers and streams are useful in quantifying channel change over time (Williamson et al., 1992; Jacobson and Primm, 1997; Perkins, 2007; Martin and Pavlowsky, 2011; Owen et al., 2011). Many aerial photography analysis studies use Geographic Information Systems (GIS) to extract useful information from the photographs (Downward et al., 1994; Martin and Pavlowsky, 2011; Hooke, 2003; Hughes et al., 2006). Using GIS provides increased accuracy and precision of identifying and measuring channel planform changes (Downward et al., 1994). The superimposed sets of historical photographs allows for direct comparisons between photograph years. However, errors associated with georectification and digitization, if not accounted for, can lead to imprecise results when examining planform changes on small scales (Hughes et al., 2006; Martin and Pavlowsky, 2011).

Georectification

Aerial photographs were acquired through the United States Geological Survey's Center for Earth Resources Observation and Science (USGS EROS), the National Agriculture Imagery Program (NAIP), the United States Department of Agriculture U.S

Forest Service (USFS), the Google Earth database, and through the Missouri State University Map Library. Imagery was acquired for the years 1939, 1955, 1956, 1966, 1986, 1995, 2003, 2005, 2007, 2009, 2010, 2013, 2014. Most of the collected photograph series were pre-georectified to UTM Zone 15N base projection. The 1939, 1955, and 1956 photo series were in hardcopy format and had to be scanned at 600 DPI before being brought into GIS for georectification. The 1966, 1986, and 2013 photo series were available in digital format but were not georeferenced. The created aerial photograph datasets for Big Barren Creek were evaluated in ArcGIS to determine spatial resolution, spectral resolution, RMSE, point-to-point error, and total coverage of the creek (Table 2).

Using ArcMap version 10.2.2 georectification of the six photo set years was completed by using ArcGIS's Georeferencing utility. Ground control points (GCPs) are used to georeference one photograph to a base map. For this project, the 2007 aerial photo set was used as the base map for rectification. The 2007 images were determined to be the most appropriate photograph set to be used as a base map due to the fact that the images were acquired during a leaf-off season, represented in true color, had the highest spatial resolution and covered all 40.5 km of Big Barren Creek. A minimum of seven GCPs was needed to rectify each photograph using a second order polynomial transformation (Hughes et al., 2006). In the Big Barren Creek watershed there is a lack of hard GCPs such as houses that are present and consistent throughout the years of this study. Therefore hard GCPs were used when possible, but both hard and soft GCPs were used in georectification. Hard GCPs include structures such as houses or buildings while soft GCPs are "soft-edged" such as trees (Hughes et al., 2006).

Digitization

Extraction of the channel and associated features was accomplished manually in ArcMap version 10.2.2 in the projected UTM coordinate system, NAD 1983, Zone 15N. A centerline for Big Barren Creek was added from the National Hydrography Dataset (NHD) as a reference for locating and digitizing the stream. A shapefile polyline was used to digitize the visible channel boundary, channel widths, and riparian buffers along the length of the main stem of Big Barren Creek from river kilometer 13.3 to 40.5 on every aerial photograph. Bank lines and channel widths were digitized following the appearance of the gravel and sand in the channel bed. In Big Barren Creek, water does not flow perennially throughout the channel and therefore many sections are dry except during storm events or certain times of the year. In aerial photography, these segments appear white, brightly colored, and in stark contrast to the densely vegetated or grazing fields to either side of the channel making it easier to define channel banks and ultimately channel width. One consistency throughout the photo year data sets is the high reflectance of gravel and sand used to define the banks of Big Barren Creek (Figure 12).

Bank Lines. Digitization of channel banks may identify channel planform changes (Turnipseed, 1993; Martin and Pavlowsky, 2011). Bank lines can determine the meander migration of a stream, however, canopy cover of the stream impedes the view of banks especially where riparian vegetation is thick. The channel banks were digitized at a scale of 1:1,500 for the longitudinal length of Big Barren Creek and were ultimately used as a guideline for channel width measurements. Digitization of banks was determined to be too susceptible to error and showed no significant meandering of the channel. Error analysis is described in following sections.

Channel Width. Tracking channel width measurements over time can identify geomorphic changes in a channel (Williamson et al., 1992). However, increases in vegetation during growing seasons may result in inconsistent channel measurements due to canopy cover obstructing the view of the stream (Werbylo et al., 2017). Areas of low canopy cover regardless of season are located on private land where most channelized segments occur. Channelized segments typically have poorer tree buffer so channel width is more visible. Channel width measurements were attained every 100 m interval longitudinally upstream starting at river kilometer 13.3 along the digitized bank lines at a scale of 1:1,500. Similar to bank lines, channel width measurements were also determined to be too error prone to be a reliable comparison from year to year given the nature of vegetation seasons, and historical aerial photograph resolution differences. Errors are discussed in following sections.

Riparian Buffer. For further insight as to channel disturbance causes, land use and management affecting forested riparian buffer width were also considered along the main stem of Big Barren Creek. Riparian buffers serve many important functions, including erosion control (Jacobson and Primm, 1997; Groffman et al., 2003; Zaimes et al., 2004; Richardson et al., 2007) Widths between 10-30 m of vegetation are effective at preventing most soil erodibility (Hawes and Smith, 2005). However, the more impermeable the upland soil, the more vegetated buffer is needed to prevent erosion. Upland soils at Big Barren Creek range from low to moderate permeability, therefore an averaged buffer width of 20 m was used in this study (Hawes and Smith, 2005). The riparian buffer width of forested land cover was evaluated on the left and right banks of the study area. Riparian buffer width was evaluated at every 100 m interval starting at

13.3 km. A 20 m buffer shapefile was added to the previously digitized stream banks. Width was measured if the buffer was 20 m or below, and anything above was noted as greater than 20 m.

Error Assessment

Georectification. There are errors involved in the georectification and digitization of fluvial landforms from aerial photographs. The error in rectification for each aerial photograph was evaluated using Root-Mean-Square Error (RMSE) and error for each photo set year was assessed using point-to-point error (Downward et al., 1994; Hughes et al., 2006; Martin and Pavlowsky, 2011). The RMSE served as a guideline error during the process of rectification (Martin and Pavlowsky, 2011). Point-to-point error is calculated by determining the distance between a point on the rectified image and the corresponding point on the base map (Hughes et al., 2006; Martin and Pavlowsky, 2011). Based on the photograph, two to three point measurements were made on each image as close to the stream as possible. Due to the nature of stream avulsion, movement of gravel beds, development of bars, and channel widening the point-to-point error distances need to be as low as possible. When an acceptable RMSE (3.0 m or below) and point-to-point error is minimized the aerial photographs were georeferenced using the 2007 photographs as the base image. Precision for the RMSE over all of the aerial photographs georectified is 2.27 $\pm$ 0.44 m. Accuracy in georectification can be improved with the use of more GCPs (Hughes et al., 2006). In this study a range of 7-10 GCPs were used for each aerial photograph.

Bank Lines and Channel Width. Errors in bank and channel width measurements can be attributed to georectification, and variations in channel visibility. To account for the errors in rectification, the identification of channel features such as channel banks and width were limited to being larger than the maximum point-to-point error distance found for the aerial photograph (Martin and Pavlowsky, 2011). Identifying channel change this way assures that the largest possible error is accounted for, but will inevitably cause smaller disturbances to be neglected and may lead to over- or under-estimating channel changes (Hughes et al., 2006; Martin and Pavlowsky, 2011). The highest image spatial resolution consistent for the set of photographs is the 2007 aerials at 0.6 m, and the lowest resolution is in 1939 at 1.1 m. The largest point-to-point error occurred in the 1939 photograph set at 10.2 m with an average point-to-point error of 4.05 m. The lowest spatial resolution and greatest error occurs in the oldest photograph set, which is an expected trend in historical aerial photographs. Relief displacement also affects distances measured on aerial photographs.

Inherently, aerial photographs will exhibit to some degree relief displacement. Changes in topography can cause images of features on the ground to be shifted or displaced in photographs (Devi and Veena, 2014). In aerial photographs the displacement due to relief increases displacement from the center of the image to the corners, however over low relief or flat-lying areas aerial photography can more accurately represent true orientations and distances of visible features (Devi and Veena, 2014). Overall, according to Missouri Spatial Data Information Service (MSDIS) the maximum elevation change in Big Barren Creek over the 27.2 km study area is up to 150 m. However, individual aerial

photographs cover small segments of the stream where relief is low which produces a more constant photo scale.

Visibility of the channel varies with the time of year the photo was taken, shadows present in the photo, and the photograph's spectral resolution. All of the NAIP photographs were acquired during vegetative growing seasons and therefore less of the channel is visible from aerial photographs due to the peak growth in canopy cover. Shadows can be cast from vegetation, buildings, or structures and are more apparent in photographs taken early or late in the day when the angle of the sun is more oblique. The spectral resolution of the image acquired can determine the impact of shadow features and vegetation on the visibility of the channel. Approximately half of the historical aerial photographs are panchromatic. All the photographs after 1995 are true, RGB, color images except 2003. The 2003 photo year set is near-infrared false colored image. It is easier to discern vegetation and associated shadows in true or false colored images than from black and white images. Seasonal vegetation obstruction can cause lower measurements than the actual values, and panchromatic images can cause higher measurements than the actual values because near bridges, roads, or cleared land the features will appear to have the same spectral resolution as a gravel bed. Given the error prone nature of channel bank and width measurements, apparent changes in the amount or presence of high gravel reflectance was used to describe relative spatial patterns.

Riparian Buffer Width. Measurement of the riparian buffer width was based off of the bank lines in the 2013 aerial photograph. The Measure Tool in ArcMap (10.2.2) was used every 100 m starting from the bank line to measure length of the riparian buffer up to 20 m. The error in this measurement is not based as much on digitization and

spectral resolution because the 2013 aerial photograph is an RGB image with an average RMSE of 0.84 $\pm$ 0.42 m and a point-to-point standard deviation of 0.72 m. In areas where the canopy cover impedes channel visibility the riparian buffer is greater than 20 m on both the left and right banks.

Geomorphic Channel Classification

Stable Channel Conditions. Photointerpretation of channel conditions in the 2013 recent aerial photographs led to geomorphic channel classification of stable and disturbed channel lengths using longitudinal digitization along the NHD centerline of Big Barren Creek. Photo set year 2013 was used in place of 2014 because the 2013 photographs have a better spatial and spectral resolution. Also, the 2013 photographs cover the entire river kilometer length of Big Barren Creek whereas the 2014 photo set does not. Channel segments were determined to be disturbed or stable based on the 2013 aerials. In general, stable or undisturbed stream segments are defined as channel segments that are not aggrading or degrading, but can be dynamic and change over decades in response to natural variations (Mackin, 1948; Martin and Pavlowsky, 2011). Lack of evidence showing substantial and detectable sediment deposition in stream channels was used as an indicator of stability because no or low gravel bed/bar contrasts means no active entrenchment or bank erosion (Perkins, 2007; USDA, 2008). Stable segments of Big Barren Creek were recognized by exhibiting little to no erosion indicated by the absence of visible gravel bed/bar deposits. Adequate ($\geq$20 m) of riparian vegetation was also used as an indicator of stability in some channel segments because vegetation stabilizes stream banks (Hawes and Smith, 2005). Most channel segments that

were determined to be stable based on the aerial photographs were highly vegetated (Figure 13).

Disturbed Channel Conditions. In contrast, disturbed channel segments are defined as segments that are actively aggrading or incising and are changing at a faster rate than the natural regime (Jacobson, 1995; Surian and Rinaldi, 2003; Simon and Rinaldi; 2006; Martin and Pavlowsky, 2011) (Figure 14). In Ozark streams, disturbance has been identified as bank erosion, aggradation of gravel, and incision of head cuts (Saucier, 1983; Jacobson 1995). Exposed soils and sediments of eroding banks are visible from aerial photography (Washington State Department of Natural Resources, 2004). Unconsolidated alluvium that erodes from channel banks in areas of disturbance accumulate in the stream bed and at the base of the stream banks (Washington State Department of Natural Resources, 2004; USDA, 2008). Lack of riparian vegetation along channel segments was also used as an indicator of disturbance because removal of vegetation leads to bank instability, channel widening, and serves as a sediment source (Hawes and Smith. 2005). Heavy depositional areas along creek valley bottoms with sparse riparian vegetation are areas of disturbance that can be identified in aerial photography (USDA, 2008). Therefore, disturbed channel segments in Big Barren Creek were determined based on the visual detection of obvious gravel bed/bar deposits. Disturbed channel segments were further broken down by apparent cause into segments affected by channelization, headcutting, road crossings, sediment pulses, and other active segments (Table 3). Each of the five disturbance classes were identified for the most recent aerial photographs and longitudinal segments were digitized along the NHD flowline.

Channel segments affected by headcutting are defined as an abrupt knickpoint in the channel profile by the U.S. Department of Natural Resources (2010) and are determined by ground-truthing (Figure 14, Figure 15). Incised channel reaches immediately following a headcut were defined as part of the headcut disturbance. Upstream migration of a headcut creates a steeper slope in the channel bed creating areas of high velocity during flood flows that transports sediment downstream. Headcuts and headcut incision zones can be created by channelization (Landwehr and Rhoads, 2003). Disturbance segments affected by channelization and channel modification were defined as areas of the stream that have experienced straightening, deepening, and an increase in bank height due to human influence (Brookes, 1985). In Big Barren Creek, channelized segments can exhibit temporary sedimentation, widening, and incision that are measured by aerial photographs and ground-truthing (Landwehr and Rhoads, 2003) (Figure 16). During flood flows the exposed finer sediment from channelization construction is winnowed from the channelized reach and transported downstream leaving behind a lag bed comprised of cobbles and boulders (Brookes, 1985). Lack of riparian vegetation is also an indication of channelization and channel modification because less vegetation means more access to the stream for alteration purposes. Road crossings are anywhere along the main stem of Big Barren Creek where a road or bridge structure has been constructed over/in the stream bed. In Big Barren Creek, road crossings were determined by ground-truthing, an Ozark Roads shapefile from Missouri Spatial Data Information Service (MSDIS), and aerial photography (Figure 17). Stream segments categorized as sediment pulses were related to a point source of disturbance such as erosion at headcuts, road crossings, and channelization that caused transit of excess downstream sediment

deposition (Cui et al., 2003) (Figure 16). Conditionally, sediment pulses are stable because mobile sediment such as sand and fine gravel are deposited over a stable bed, but worsening or repeat disturbance, such as continued headward migration of a headcut, can lead to increased downstream sediment transport and instability caused by aggradation (Cui et al., 2003). Other active segments of Big Barren Creek were identified on aerial photographs as areas with accumulated alluvium from eroded banks that show incision and widening that was not directly related to a disturbance source (Washington State Department of Natural Resources, 2004) (Figure 18).

Field Assessment and Ground-Truthing

Through the digitization process, recent channel segments exhibiting planform change can verified by visiting those locations. Geomorphic field data collection at main stem included GPS locations of head cuts and road crossings. Ground-truthing was used to evaluate aerial trends and assess stream segments under canopy that cannot be viewed in recent photographs, such as headcuts and subsequent sediment pulses. To further document the presence of bank instability and large gravel formations within the channel, GPS cameras were used. Portions of Big Barren Creek under canopy cover were documented and identified as disturbed by walking along/through the stream using GPS cameras. Ground-truth assessments can only be applied to the most recent aerial photographs, but allow for a vertical and topographic evaluation of the study area not visible by aerial photograph alone.

Table 2- Aerial photograph data set for each photo year.

Photo Set Year	Photo Year/Date	Number of Photos	R-km (0.0-40.5)	Source	Notes	Resolution (m)	RMSE Range (m)	Max P2P Error (m)	Mean P2P Error (m)	Std. Dev. P2P (m)
1939	April 24th, 1939 and July 6th, 1939	2	26.2-40.5	USFS	B&W Geotiff	1.0-1.1	1.51-1.66	10.20	4.05	2.89
1955	October 26th, 1955	1	10.1-14.7	MSU Library	B&W Geotiff	0.7	2.49	3.00	2.00	1.00
1956	1956	3	10.0-20.2, 21.6-24.2	USFS	B&W Geotiff	0.77-0.79	1.42-1.93	5.00	2.50	3.54
1966	March 28th, 1966	8	10.0-40.0	USGS EROS	B&W Geotiff	0.86-1.0	2.05-0.61	5.30	3.26	1.47
1986	September 6th, 1986	9	0.0-15.3, 16.6-40.0	USDA-FS	B&W Geotiff	.67-0.73	0.39-3.37	5.00	1.67	1.65
1995	April 6th, 1995 and February 18th, 1995	6	0.0-37.0, 37.5-40.5	USGS EROS	B&W Geotiff	1.0	pre-rectified	4.91	2.04	1.54
2003	September 2nd, 2003	3	0.0-40.5	NAIP	NIR, leaf on	1.0	pre-rectified	5.20	3.34	1.97
2005	August 17th, 2005	1	0.0-40.5	NAIP	RGB, leaf-on Geotiff	2.0	pre-rectified	4.19	3.15	1.47
2007	March 7th, 2007 to April 16th, 2007	5	0.0-40.5	USGS EROS	RGB, Leaf-off, DOQ Geotiff	0.6	pre-rectified	N/A	N/A	N/A
2009	August 29th, 2009	2	8.7-40.5	NAIP	RGB, leaf-on Geotiff	1.0	pre-rectified	2.54	2.32	0.32
2010	July 23rd, 2010	3	8.7-40.5	NAIP	RGB, leaf-on Geotiff	1.0	pre-rectified	2.44	2.10	0.56
2013	May 13th, 2013	15	13.0-40.5	Google Earth	RGB, leaf-on Geotiff	0.41-1.1	2.13-0.37	3.00	0.76	0.72
2014	October 3rd, 2014	1	0.0-27.2, 27.9-28.9	NAIP	RGB, leaf-on Geotiff	1.0	pre-rectified	4.56	2.85	2.41

Table 3 - Disturbance types and definitions for this study.

Disturbance Type	Definition for this study	Consequences	How disturbance is measured/recognized for this study
Channelization	Human induced channel modification by straightening/deepening channel and raising bank heights (Brooks, 1983; Landwehr and Rhoads, 2003; Simon and Rinaldi, 2006; Hupp et al., 2009)	Causes excess sedimentation, widening, and incision that can lead to upstream headcutting and downstream aggradation (Brookes, 1985; Williamson et al., 1992)	Aerial photography
Headcutting	Channel incision in the form of an abrupt knickpoint in channel profile (Landwehr and Rhoads, 2003; DNR, 2010)	Continuous downcutting of the stream bed that can cause headcutting in the upstream direction and incision downstream (Landwehr and Rhoads, 2003)	Ground-truthing
Road Crossing	Road or bridge is constructed over/in stream bed (Jones et al., 2000)	Causes debris jams upstream and lateral erosion (Jones et al., 2000; Johnson, 2005)	Ground-truthing, MSDIS, and aerial photography
Sediment Pulse	Segment with excess sediment related to a point disturbance (Perkins, 2007)	Disturbance related to a point source can lead to increased sediment transport downstream (Cui et al., 2003)	Ground-truthing and aerial photography
Other Active	Segment with excess sediment not related to a point disturbance (Simon and Rinaldi, 2006)	Accumulation of excess sediment from eroded banks and incision not related to a point source disturbance (Washington State DNR, 2004)	Aerial photography

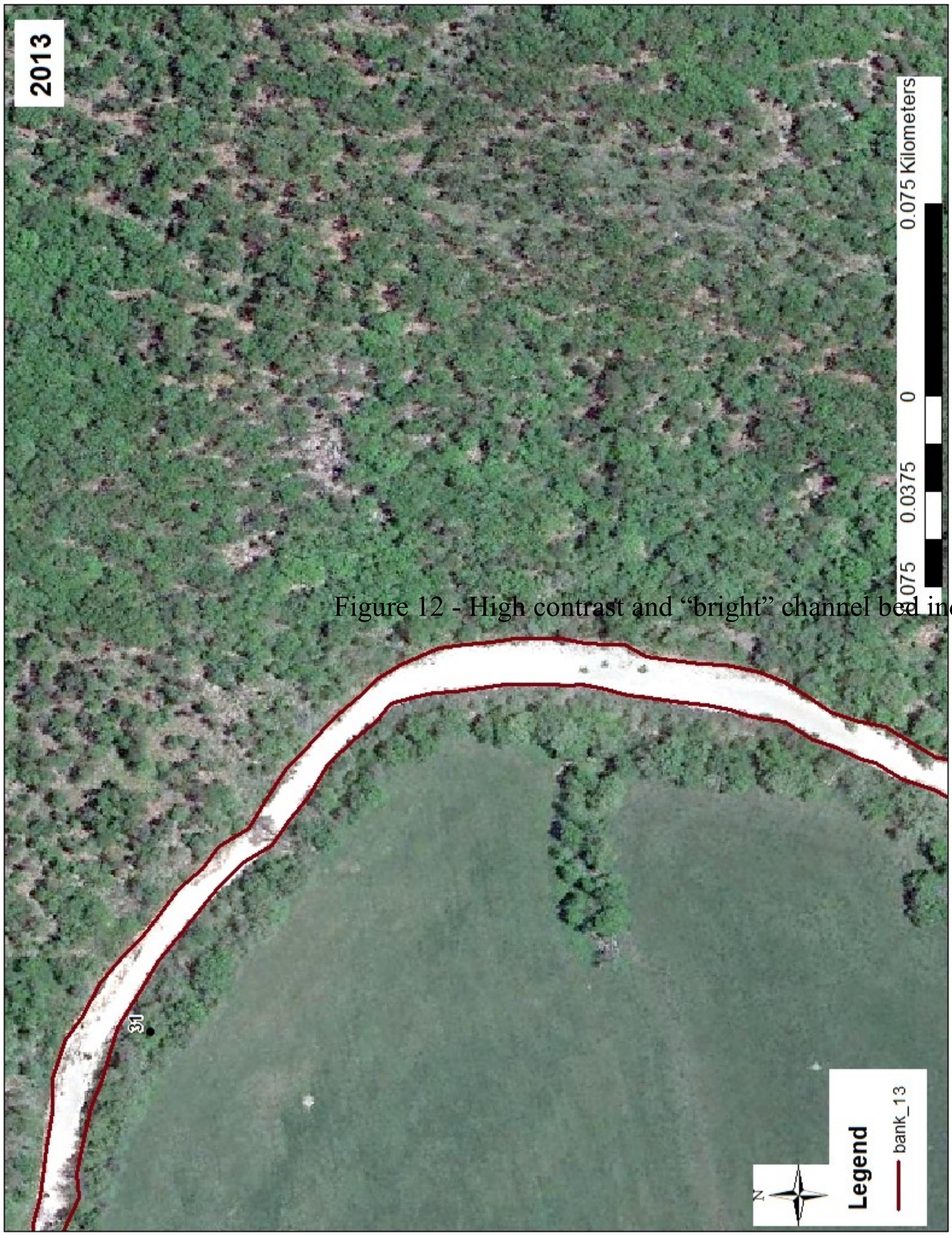

Figure 12 - High contrast and “bright” channel bed indicates disturbed chann

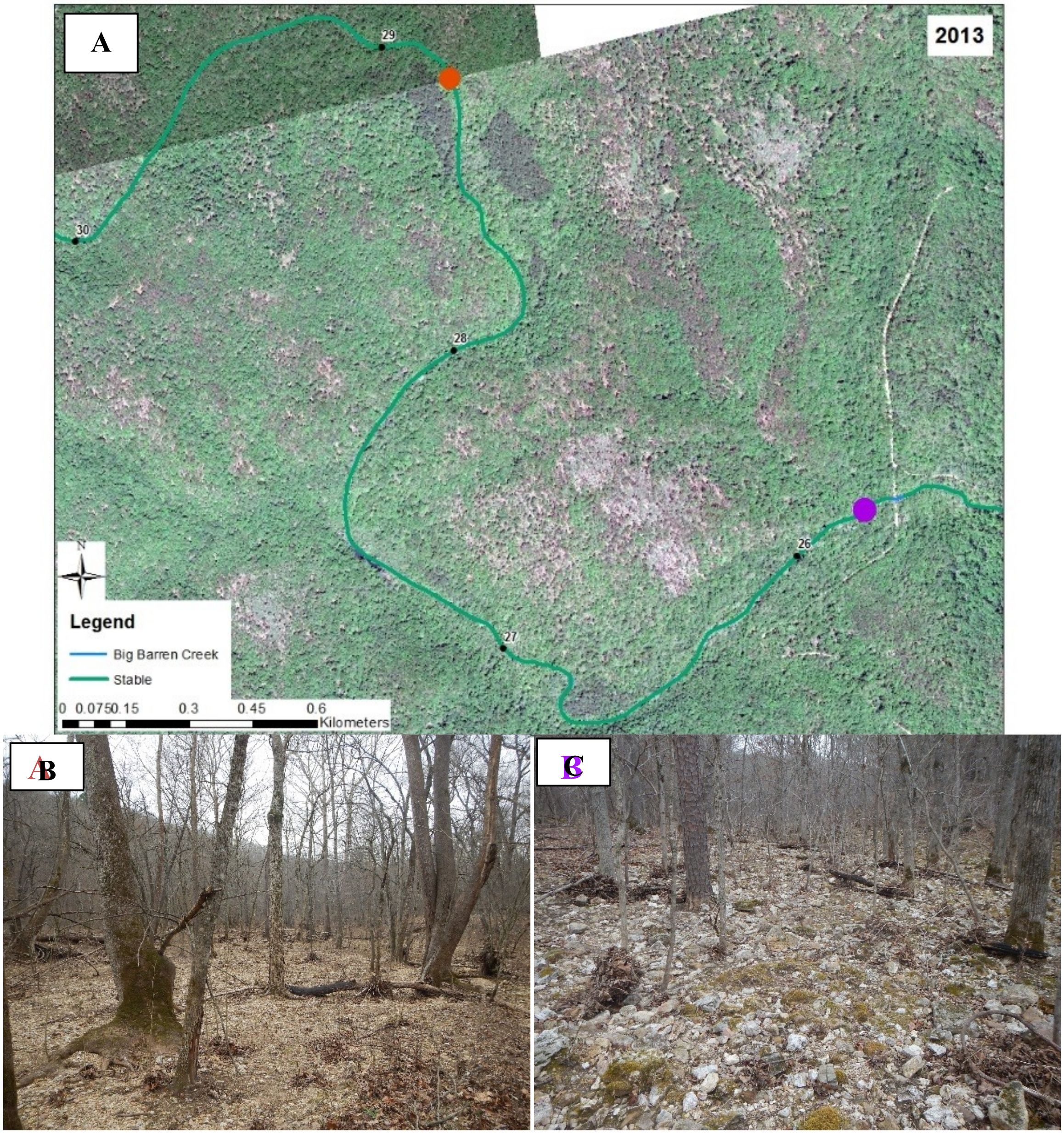

Figure 13A - Ground truthing photographs of stable segments of Big Barren Creek. Aerial photographs (2013) of stable segment 25.5-30.0 km. B: Ground-truthing photo of stable segment at 28.8 km (orange circle) denoted on the map and aerial. C: Ground-truthing photo of stable segment at 25.8 km (purple circle) denoted on the map and aerial images.

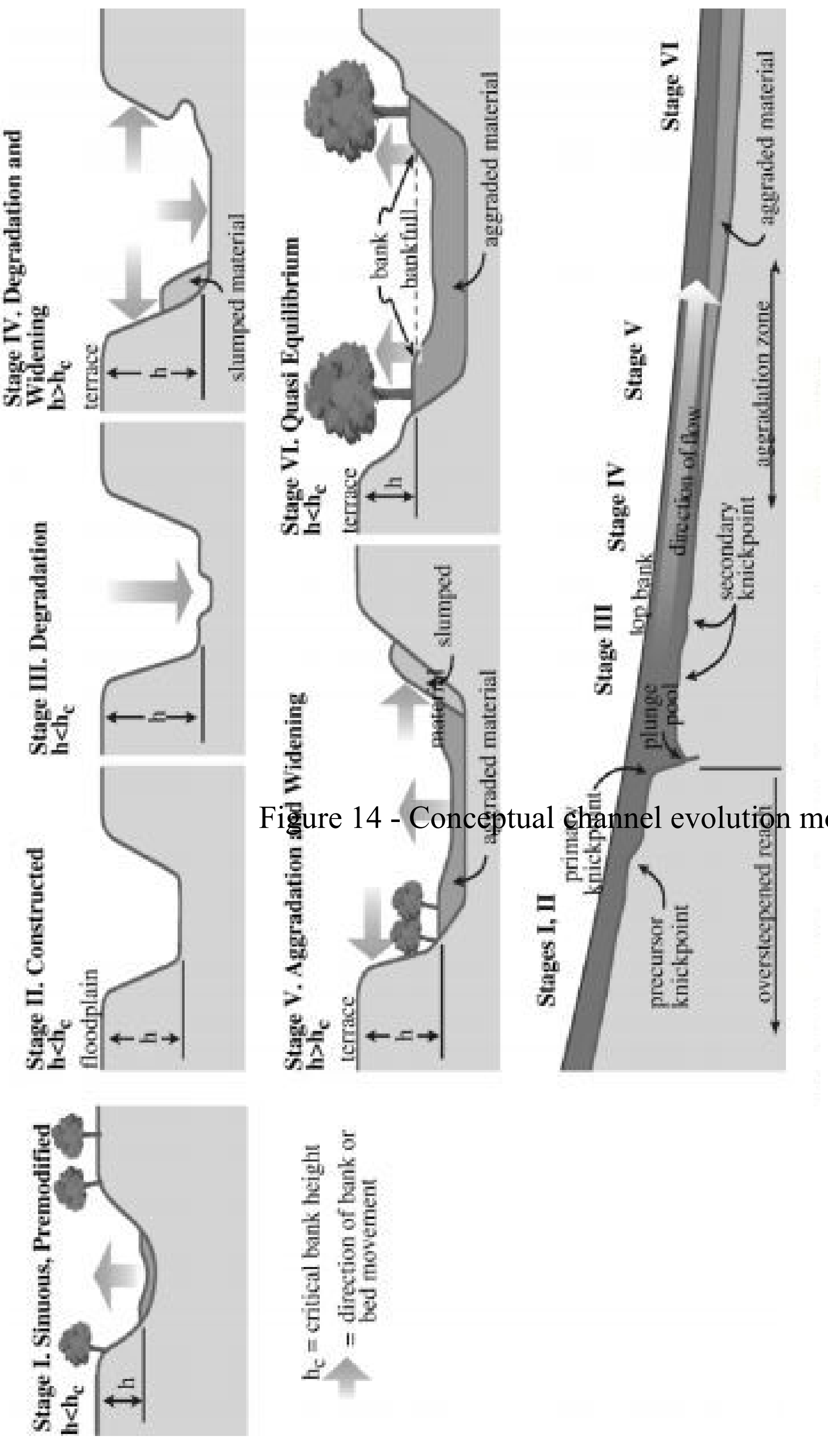

Figure 14 - Conceptual channel evolution model (Simon and Rinaldi, 2006).

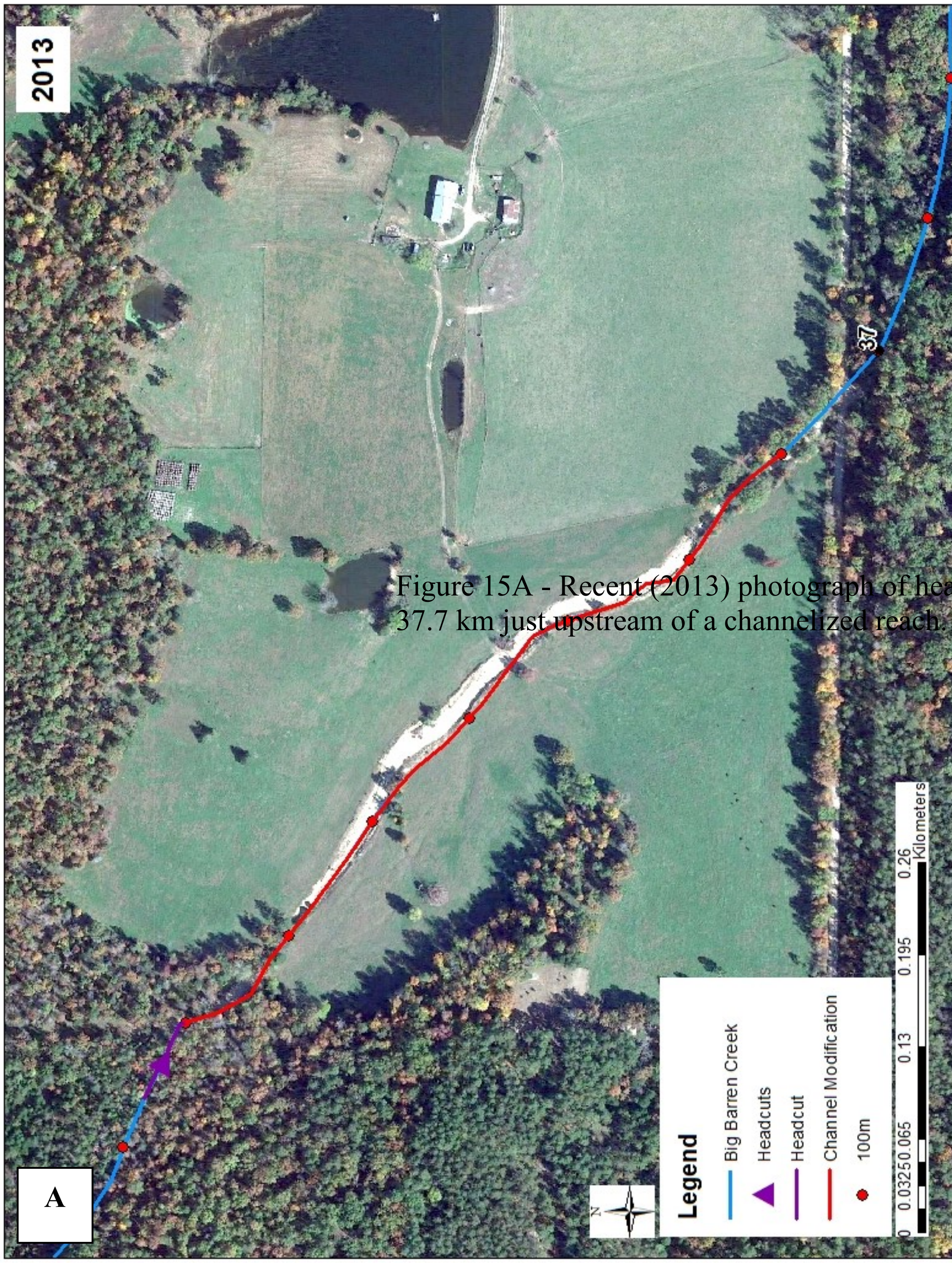

Figure 15A - Recent (2013) photograph of headcut and immediate dow
37.7 km just upstream of a channelized reach.

Figure 15B- Headcuts and headcut incision at 37.7 km. B1&2: Ground-truthing photos (2016) looking upstream of headcut at 37.7 km denoted by a purple triangle in Figure 16A.

Figure 15C - Sediment pulses at 37.7 km. C1: Ground-truthing photos (2016) of sediment pulse looking upstream to headcut at 37.7 km. C2: Photo (2016) of sediment pulse looking downstream of headcut at 37.7 km.

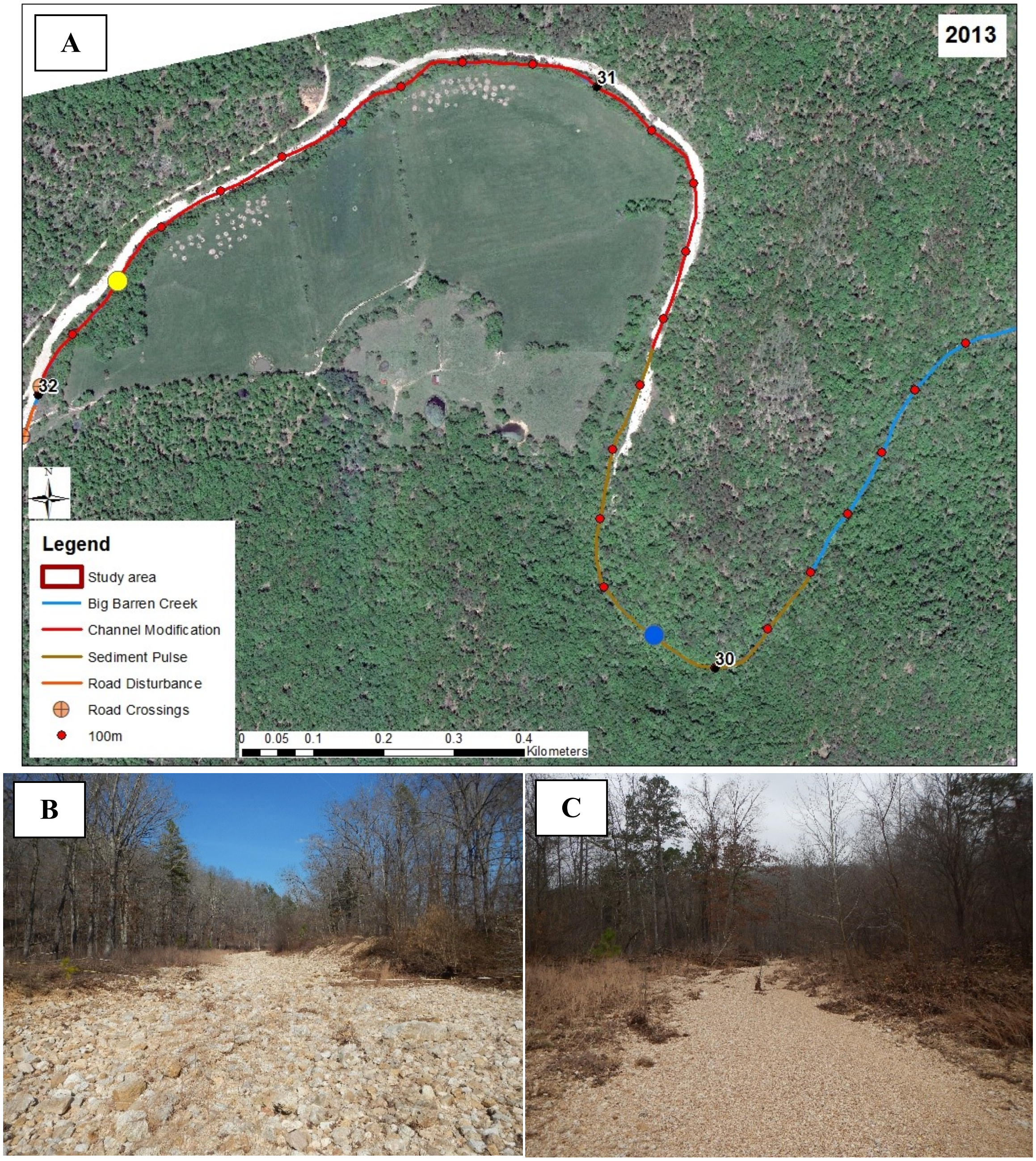

Figure 16 - Map of channelization from 37.7 to 37.1 km. A: Aerial photo (2013) of channelized segment 34.0 to 30.55 km and subsequent sediment pulse to 29.8 km. B: Ground-truthing photo (2016) of channelization 31.8 km denoted as yellow circle in A. C: Ground-truthing photo (2016) of sediment pulse at 30.1 km denoted by blue circle in A.

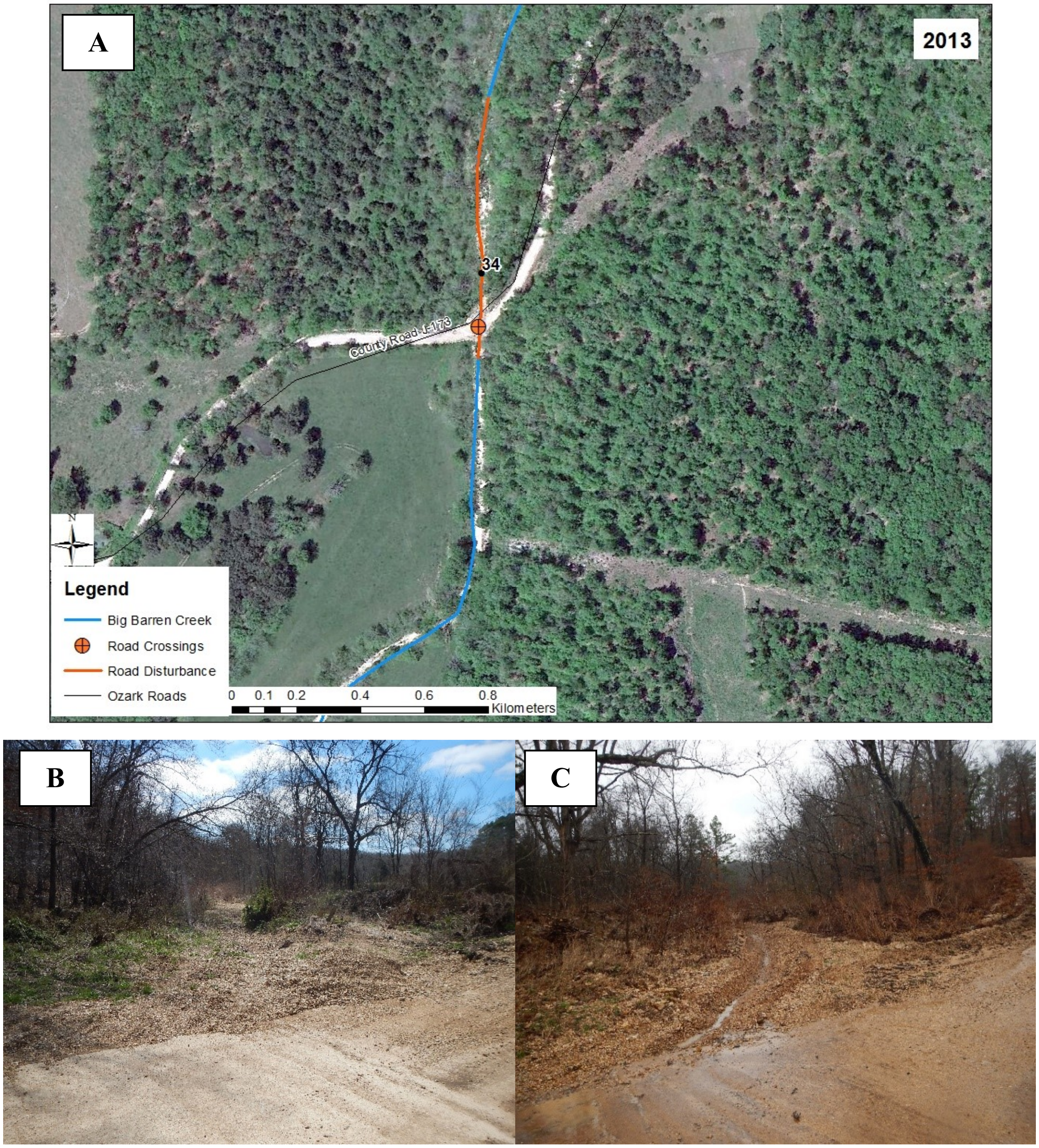

Figure 17 - Map of Ozark roads and road crossings around 34.0 km. A: Aerial (2013) of road crossing from 34.1 to 33.9 km. B: Ground-truthing photo (2016) of road crossing looking upstream of County Road J-173 at 34.05 km denoted by the orange circle on above figure. C: Photo (2016) looking downstream of road crossing at 34.05 km.

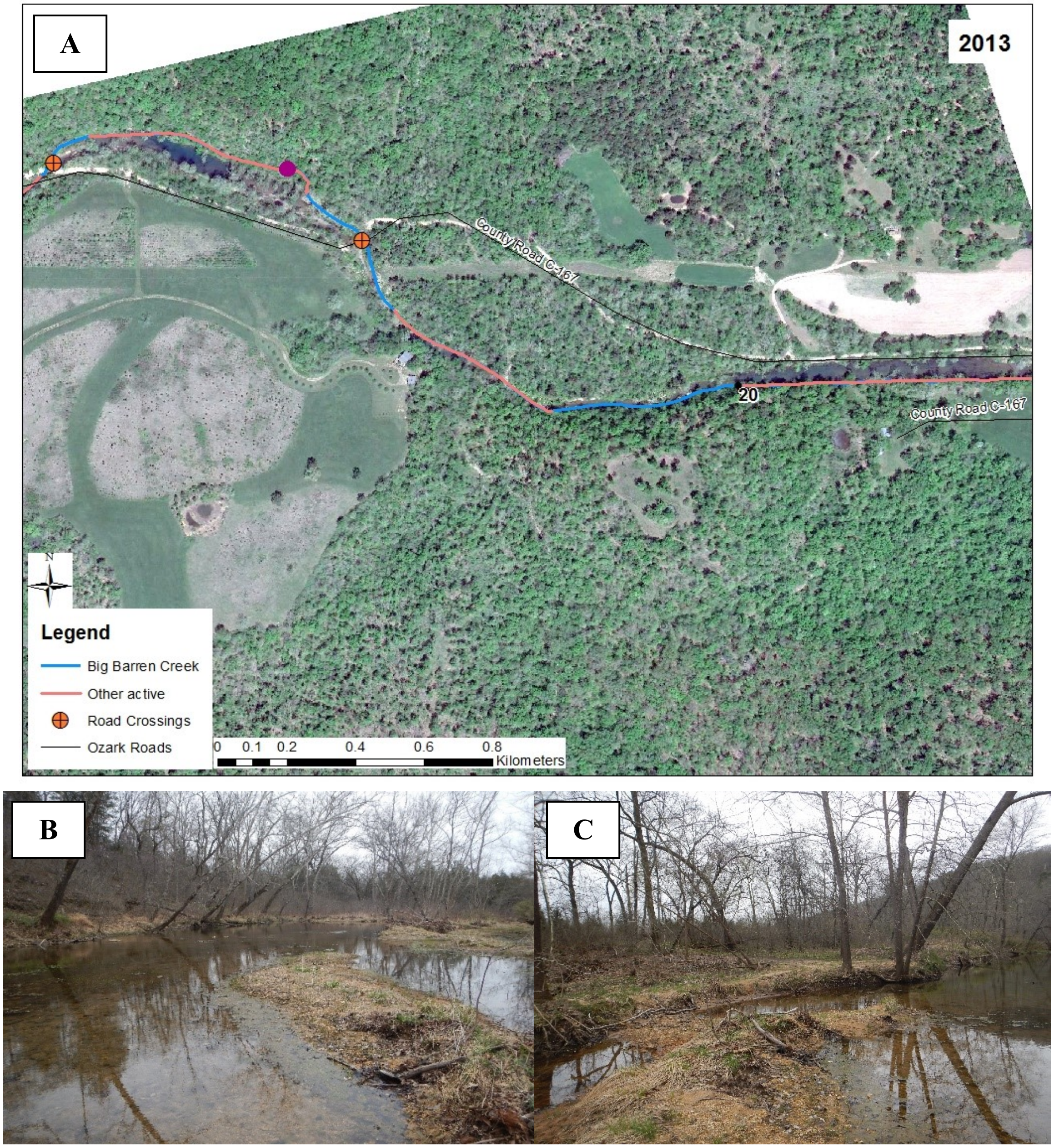

Figure 18 - Map of other active segments caused by the effect of backwater from beaver dams and downstream crossings. A: Aerial photographs (2013) of active areas from 20.8 to 19.9 km. B: Ground-truthing photograph (2016) looking upstream of an active segment at 20.6 km denoted by the dark pink circle in above figure. C: Photo (2016) looking downstream of other active segment at 20.6 km.

RESULTS AND DISCUSSION

The purpose of this chapter is to present and discuss the results of historical aerial photograph analysis. First, the aerial photograph database is described in terms of disturbance for the most recent photo years along with riparian buffer trends. Second, the history of channel disturbances in Big Barren Creek are described. Third, public and private land ownership trends are assessed for the present day channel. Fourth, the influences of prescribed burning on channel disturbance are evaluated. Lastly, climate-change impacts on the future of Big Barren Creek are discussed.

Recent Channel Disturbances

Identification of Visible Segments and Distribution. Longitudinal classification of recent disturbance in the 2013 aerial photographs were only assessed for visible segments of Big Barren Creek. Therefore, ground-truthing information and visible features on 2013 aerial photographs were used to identify locations and lengths of channelized segments, road crossings, headcuts, and subsequent sediment pulse zones (Figure 19, Appendix). Assessment of disturbance by ground-truthing increases accuracy of longitudinal lengths of channel classification of disturbed and undisturbed segments by determining true and false positives and negatives (Bourgeau-Chavez, et al., 2016). True positives are where a disturbance was mapped using aerial photographs and confirmed through ground-truthing, and true negatives are where segments were mapped as not showing disturbance. False positives are segments identified as disturbances through aerial photography, but through ground-truthing were determined to be undisturbed. One

way disturbance zones were identified was by the bright gravel reflectance from bed, bar, and bank sediment. Channel segments that could potentially return a false positive are from photographs being taken after a flood has moved through the stream and remobilized sediment over stable beds and from leaf-off photographs where the bed is visible through vegetation. False negatives are segments where disturbances were not identified through aerial photography, but later added from ground-truthing. For example, headcuts on public land are located under canopy cover and appear stable on the 2013 aerial photographs, but GPS points taken during stream assessment show the location of headcut disturbances.

Approximately 13.05 km or 48% of the length of Big Barren Creek was found to be disturbed within the 27.2 km study area (Table 4). Disturbance types were classified into headcuts, sediment pulses, road crossings, channelization, and other active segments (Table 3). Of the total 13.05 km of the disturbed segment length 0.88 km, or 7%, is attributed to headcuts and their immediate incised reaches, 1.74 km, or 13% is attributed to road crossings, 2.62 km, or 20% is effected by sediment pulses, 3.46 km, or 27% is due to other active segments and, 4.35 km, or 33% is from channelization.

Private and Public Channel Trends. There is almost an even split of land ownership and management along the riparian corridor of the main stem of Big Barren Creek. Of the 27.2 km, 14.17 km, 52%, are managed by private landowners, and 13.03 km, 48%, is publicly owned and managed by the U.S. Forest Service (Figure 3). Disturbance zones occur in both the private and publicly owned stream segments. Approximately 10.6 km, or 81%, of the total disturbance length occurs in sections of private land ownership. Thus, only 2.4 km, or 19%, of the total disturbance length occurs

on public land ownership. These disturbance lengths were further broken down into potential causes by land ownership (Figure 20).

On public land, 0.31 km, or 12%, of disturbance is attributed to headcut erosion, 0.46 km, or 18%, is attributed to road crossings, 0.77 km, or 31%, is from sediment pulses generated from headcuts, road crossings, and winnowing of channelized reaches on private land, and 0.95 km, or 38%, is due to other causes of active disturbance. Two headcuts located in tributary streams also contribute to the sediment pulses identified on public land (Figure 21). The first headcut on public land is located on an unnamed north Big Barren tributary that joins Big Barren Creek around 37.7 km where channel modifications are occurring just downstream on private land. The second tributary headcut occurs on the Upper Big Barren tributary that joins Big Barren Creek around 37.0 km where County Road 174 crosses the stream. Tributary headcuts may be contributing to the excess sediment in the river channel and maintaining disturbance segments near confluences (Rice et al., 2011). Therefore it is probable that the downstream channelization may have contributed to migrating headcuts on the tributaries as well as the main stem. Together, 62% of longitudinal disturbance length on public land is attributed to road crossings, headcuts and subsequent sediment pulses. The other 38% of the longitudinal length on public land is due to other causes of active disturbances. Stream segments leading up to and after bluff pool areas as determined by the 2013 aerial photographs such as 17.59-17.11 km, account for 51% of the other active longitudinal length on public land. The other 49% of other active areas occur between 20.87 to 20.56 km and 19.2 to 19.1 km where backwater effects from beaver dams and downstream road crossings create disturbance.

On private land, 0.57 km, or 5%, of disturbance is due to headcut erosion, 1.28 km, or 12%, is attributed to road crossings, 1.85 km, or 18%, is due to sediment pulses generated by road crossing and headcuts, 2.51 km, or 24%, is due to other causes of active disturbance, and 4.35 km, or 41%, is from channelization. Together, 76% of the longitudinal disturbance length on private land is attributed to road crossings, headcuts, channelization, and subsequent sediment pulses. Four headcuts located in tributary streams also contribute to the sediment pulses identified on private land. Two headcuts are located on the Barnes Hollow tributary that joins the main stem of Big Barren Creek at 35.9 km where a current headcut and sediment pulse segment exist. The other two headcuts are located on Polecat Hollow and Wolf Pond. The confluences of the tributaries Polecat Hollow at 32.0 km, and Wolf Pond at 31.3 km are located where current channelization is occurring (Figure 21). Therefore it is possible that channelization influenced the development and headwater movement of the tributary headcuts.

Sediment pulses in Big Barren Creek are segments related to point disturbances such as headcut erosion, road crossings, and winnowing of sand and gravel from beds of channelized reaches (Perkins, 2007). Channelization exposes sand and fine gravel to flood scour which transports finer sediment downstream and leaves a coarser bed lag surface. Downstream sediment transport of excess sand and fine gravel from headcuts, road crossings, and channelization give the appearance of disturbance on aerial photographs due to high contrast and bright channel beds (Jacobson and Primm, 1997). However, stable reaches in Ozark streams can transport excess sediment without substantial cross-section and planform changes (Jacobson, 1995). Therefore, segments

classified as sediment pulses can be conditionally stable. Sediment pulse zones are used in this study to show the downstream effects of sediment deposition resulting from headcuts, road crossings, and channelization.

Riparian Buffer Width. Riparian vegetation and width of the riparian corridor are dependent on land use and management (Richardson et al., 2007). Based on the most recent aerial photographs, of the total study area length, 75% of the left bank has a riparian corridor greater than 20 m, and the right bank has 70% greater than 20 m. Longitudinally, 63% of the study area has a riparian corridor of greater than 20 m on both sides. Longitudinal segments of less than 20 m of riparian buffer on the left and/or right bank occur in both private and public lands (Table 5, Figure 22). The sections of less than 20 m riparian buffer on public land occur on the left bank at 15.1 and 15.2 km due to cleared land behind a buffer of 14 m, and on the right bank at 20.5 and 24.0 km due to road crossings and cleared land adjacent to the crossing.

Areas of less than 20 m of riparian buffer, however, almost exclusively occur on private land holdings. On private land holdings, land clearing for agriculture and pasture typically have left 20 m or less of riparian buffer, and in some cases no tree buffer. In channel segments that are classified as channelized, 53% of the riparian buffer width is less than 20 m. On the left bank of channelized segments, 42% of the riparian buffer is below 20 m with 23% at or below 10 m. On the right bank of channelized segments, 42% of the riparian buffer is below 20 m with 29% at or below 10 m. In channelized segments there are five instances where both the right and left bank have zero meters of riparian buffer width. Removal of the riparian zone can contribute to excess sediment observed in

Big Barren Creek because without the effects of anchoring vegetation, banks are more susceptible to erosion and instability (Jacobson and Pugh, 1997).

History of Channel Disturbance

Using the 2013 aerial photographs as the most recent year, comparison of previous channel conditions were evaluated (Table 6). Disturbed segments of Big Barren Creek were identified in aerial photographs and ground-truthing by excessive sediment from bank widening, lack of riparian vegetation, increases in bank height, deepening of the channel, and headcut and road crossing locations. The first period of channel disturbance in Big Barren Creek extends to the beginning of the study in the 1939 aerial photographs in the post logging period. Of the 14.3 km, 40.5- 26.2 km, covered by 1939 aerial photographs, 2.1 km show disturbance, and 1.65 km are attributed to channel modification. Most modified segments of Big Barren Creek have experienced little change throughout the photograph record after the first disturbance (Table 6). Channel segments that have experienced change are areas that have shown channel recovery. Recovered channel segments shown a reduction in disturbance over the photograph years. The observed recovery of a channel segment in aerial photographs may include the regrowth of riparian vegetation and the dissipation of excess gravel deposits (Shields et al., 2003). The average time for a channel to recover in this study was approximately 46 years, with the shortest recovery time of 27 years from 1939 to 1966 and the longest recovery time of 70 years from 1939 to 2009 (Table 6).

From the aerial photograph record, 10 instances of historical channelized segment disturbances were identified (Table 6, Figure 23). Of the 10 channelized segments, 8

segments have persisted to the most recent aerial photograph (2013) record. Repeated disturbances can be seen throughout photo set years where high gravel reflectance is easily identified, and the maximum channelization length for the record was recorded. Average channel width was also included in the channelization assessment to show the morphological nature of disturbance by modification. Widening and sedimentation can result from channel modification changing the channel shape and sediment mobility regime (Landwehr and Rhoads, 2003; Hupp et al., 2009).

The historical channelization shows a general trend of channelized segments in the headwater or upland portions of Big Barren Creek beginning earlier than in the downstream portions (Table 6). The date of initiation of channelization tends to increase downstream (Figure 24). On the main stem of Big Barren Creek up to the C7 segment, the first channelization years occur on or before 1966 with the exception of levee and channelization construction at the C3 segment by 1986. From C8 to C10 segments the first channelization years occur starting in 2005. This pattern of the timing of channelization in Big Barren Creek may be related to downstream effects of early channelization and levee construction. Channelized segments can accelerate floods through the channelized segment increasing stream velocity causing winnowing of channelized reaches and downstream aggregation (Brookes, 1985; Hupp et al., 2009). Upstream channelization can cause more flood water to move downstream thus causing more flooding resulting in downstream construction of levees. Over time, the erosional and depositional downstream effects of channelization can perpetrate the perceived need for channelization and levee construction. In regions where banks are susceptible to instability such as privately owned land where riparian vegetation is sparse or lacking,

bank erosion and subsequent release of sediment into the stream can augment downstream effects of channelization (Brookes, 1985).

Channelized Segments. Channelization site numbers C1, C3, C4, C5, C8, C9, and C10 show repeat or consistent disturbance throughout the available photograph record after the initial year of disturbance. The C1 segment was cleared land by 1939 but was fully channelized by 1966 and extends from 37.7 to 37.1 km with an average channel width of 10.9 m and a coefficient of variation (CV) of 33%. A headcut is located 0.1 km upstream of the C1 segment and has lacked riparian vegetation for the photographic record (Figure 25). Channelization of segment C3 from 36.2 to 35.75 km began by 1966, and construction of segment C4 from 35.75 to 35.1 km began by 1986 (Figure 26). The average channel width and CV for segments C3 and C4 are 13.3 m and 9% and 11.9 m and 36%, respectively. The C5 segment from 34.7-34.0 km was channelized by 1939 and is bookended by road crossings at 34.9 km and 34.0 km. Gravel reflectance has worsened upstream of the 34.0 km crossing over the aerial record (Figure 27). The average channel width and CV for the C5 segment are 8.4 m and 34%. The C8 segment from 32.0-30.55 km begins at a road crossing around 32.0 km where levee construction began by 1966 but channelization is visible as early as 2005 (Figure 28). The average channel width and CV for the C8 segment are 16.1 m and 33%. Two tributary streams, Polecat Hollow and Wolf Pond, with upstream headcuts join the C8 segment of Big Barren Creek at 32.0 and 31.3 km, respectfully. Segment C9 from 24.6 to 24.1 km began as early as 2007 and has an average channel width of 19.4 m and a CV of 24%. A headcut is located at 24.9 km, just 0.3 km upstream of the C9 segment and a road crossing is located downstream at 24.1 km (Figure 29). Segment C10 from 23.9-23.2 km has visible bulldozer tracks in the 2007 and

2013 aerial photographs around the road crossing at 23.5 km (Figure 29). The average channel width and CV for the C10 channelized segment are 18.4 m and 44%.

Recovered Segments. Only C2, C6, and C7 segments out of the 10 channelized locations showed recovery. The C2 segment from 37.1-36.45 showed channelization along County Road 174 and across State Hwy C in 1939 but recovered by 1966 (Figure 30). The average channel width for the C2 segment is 8.2 m in 1939. Segment C6 was channelized by 1939 from 34.0-33.4 km, but has remained recovered since 2003 and is now stable on the 2013 aerial photographs (Figure 31). The C7 segment from 32.77 to 32.0 km recovered from earlier (1939) channelization by 1986, but showed repeat disturbance in the 1995 photographs (Figure 32). The average channel width and CV for segment C7 is 9.8 m and 41%.

Channel Disturbance Patterns on Private and Public Lands

Private Land Ownership. Given the almost equal division of land ownership and management of the riparian corridor of Big Barren Creek, it is interesting that approximately 81% of channel disturbances occur in privately owned sections of Big Barren Creek. These channel disturbances are mainly attributed to land management. Since 1939, private land owners have modified the channel, mined gravel from the stream to use on roads, constructed levees using excess gravel to protect their fields, and have actively or passively altered the riparian vegetation. All of these factors lead to disturbance and instability in Big Barren Creek. Most of the disturbances listed are not one time events with initial channelization periods around 1939, 1966, 2005, and 2007. Private landowners will reconstruct levees and mine stream gravel as needed to protect

their fields or provide fill for roadways. Repeat disturbance effects like gravel mining to repair roadways and build levees creates a headcut, or abrupt increase in slope each time and can augment already disturbed zones. The highest percentage of disturbance on private land is attributed to channel modification and sediment pulses that are generated from channelized segments, headcuts, and road crossings.

Public Land Ownership. Approximately 19% of land disturbance occurs on publicly owned and managed land. Road crossings, other active segments, and sediment pulses make up most of the disturbances on public land. The stream bed is even utilized as a road at some crossing locations such as 17.4, 18.3, 18.7, 20.9, and 24.6 km (Figure 33). The small percentage of headcut disturbances on public land contribute to downstream sediment pulses. Of the two headcuts that occur on public land at 24.9 km and 37.8 km, each headcut is 0.3 and 0.1 km upstream from private landownership where channel modification is and has been occurring before burning began (Figure 34). Downstream of the 37.8 km headcut channel modification began as early as 1939, and downstream of the 24.9 km headcut channel modification began as early as 2007. Therefore, there is reason to believe that due to channel modifications on private land, headcuts may have originated on privately owned segments of Big Barren Creek and migrated upstream due to repeated disturbance.

Prescribed Burning Influence on Channel Disturbance

Of the 12.6 km of Big Barren Creek directly in a burn unit, 7.6 km, 60%, is stable based on the most recent photographs. Of the 14.6 km not directly in a burn unit, 5.9 km is stable based on the 2013 aerial photographs. Most of the burn units follow road lines or

use roads as boundaries. So, in places where the road runs along the stream or there is a road crossing, burn units follow along. Disturbance areas due to road crossings, headcuts, and subsequent sediment pulses have existed in the privately owned channel segments downstream of burn units before burning began in 2011. The 2016 burn unit directly on Big Barren Creek ends at 37.7 km (Figure 35). Disturbance due to channel modification in the downstream segment from 37.7-37.1 km began occurring as early as 1966, but was cleared as early as 1939. The 2015 burn unit directly on Big Barren Creek starts at 33.1 km and ends at 23.3 km (Figure 36). Disturbance due to channel modification in the downstream segment from 23.9-23.2 km began as early as 2007 with a sediment pulse downstream that continues to 22.22 km. Prescribed burning patterns do not correlate with channel disturbance trends. It is likely that burning has had very little influence on channel disturbances on the main stem of Big Barren Creek.

Climate-Change Impacts

The increased precipitation regime in the Ozarks may be contributing to flooding and subsequent sediment movement (Angel and Huff, 1997; Villarini et al., 2013). Daily rainfall events over 7.5 cm have increased in the Big Barren Creek watershed from 6 occurrences between 1955-2005 to 10 occurrences between 2005-2015 (Pavlowsky et al., 2016). Reported increases in heavy precipitation events have also occurred across the Midwestern region (Angel and Huff, 1997;Villarini et al., 2013).

Rainfall amounts in Big Barren Creek have been increasing over the past 10-20 years and therefore climate change may be playing a role in the perception of channel sediment problems (Pavlowsky et al., 2016). Increases in intense rainfall events lead to

flooding that may cause channel disturbances (Knox, 2000). Increased precipitation regimes and increases in heavy rainfall events lead to more erosive and damaging floods (Pielke and Downton, 1999). Therefore, the recent increases in intense rainfall events in Big Barren Creek watershed would be expected to contribute to the degradation of modified and disturbed channel segments. Erosive flooding as a result of heavy precipitation in Big Barren Creek would also allow headcut and sediment pulse problems to persist or possibly get worse if the precipitation trend continues.

Table 4 - Summary chart of disturbance types and lengths overall for the main stem of Big Barren Creek and by land ownership.

Channel segment	Length (km)	Percent (%)
Main stem	27.20	100
No disturbance	14.15	52
Disturbance	13.05	48
Disturbance types		
Headcut	0.88	3
Sediment pulse	2.62	10
Road crossing	1.74	6
Channel modification	4.35	16
Other active	3.46	13
Ownership by Channel Length		
Public	13.03	48
Private	14.17	52
Disturbance by Land Ownership		
Total	13.05	100
Public	2.49	19
Private	10.56	81
Public Land Disturbance		
Total	2.49	100
Headcut	0.31	12.4
Sediment pulse	0.77	30.9
Road crossing	0.46	18.5
Channel modification	0.00	0.0
Other active	0.95	38.2
Private Land Disturbance		
Total	10.56	100
Headcut	0.57	5.4
Sediment pulse	1.85	17.5
Road crossing	1.28	12.1
Channel modification	4.35	41.2
Other active	2.51	23.8

Table 5- Average percent riparian vegetation buffer and number of road crossings for public and private land.

Segment				Forest buffer within 20 m of bank (Avg. %)		
Land Ownership	River km	Total km	Road crossing #	L Bank	R bank	Total
Public	40.5-37.8	2.8	0	100	100	100
Private	37.7-37.1	0.7	0	26	22	23
Public	37.1-36.7	0.4	2	100	100	100
Private	36.7-30.4	6.3	6	80	73	75
Public	30.4-25.7	4.7	3	100	100	100
Private	25.7-25.4	0.3	0	78	100	88
Public	25.4-24.6	0.8	1	100	100	100
Private	24.5-24.1	0.5	1	64	100	82
Public	24.1-23.9	0.2	1	100	85	98
Private	23.9-23.2	0.7	1	100	84	91
Public	23.1-23.0	0.2	0	100	100	100
Private	22.9-21.9	1.1	0	100	88	93
Public	21.8-21.4	0.5	1	100	100	100
Private	21.3-21.1	0.3	0	70	100	86
Public	21.0-20.5	0.6	1	100	92	96
Private	20.4-19.2	1.3	2	100	97	98
Public	19.1-18.1	1.1	2	100	100	100
Private	18.0-17.9	0.2	0	100	100	100
Public	17.8-17.3	0.6	1	100	100	100
Private	17.2-17.1	0.2	0	100	100	100
Public	17.0-16.5	0.6	0	100	100	100
Private	16.4-16.3	0.1	0	100	100	100
Public	16.2-15.9	0.4	0	100	100	100
Private	15.8-15.6	0.3	0	100	100	100
Public	15.5-15.4	0.2	0	100	100	100
Private	15.3	0.1	0	65	100	85
Public	15.2-15.1	0.3	0	70	100	85
Private	15.0-13.3	1.7	1	74	72	73
Total		27.2	23	90.2	88.7	89.1

Table 6- History of channel disturbance by public and private ownership.

	Segment					Date/ years				% Segment disturbed 2013
Sub-reach	River km	Owner-ship	Length (km)	1st Available photo	1st disturbance	Channelization/ modification	Channelized segment #	Recovered by	Other disturbance	%
2	37.8-37.7	Public	0.1	1939	1966	N/A		N/A	N/A	100
3	37.7-37.1	Private	0.6	1939	1966	1966, 1989, 2003, 2005, 2007, 2009, 2010, 2013	C1	N/A	N/A	100
4,5	37.1-36.7	Public	0.4	1939	1939	1939	C2	1966	N/A	18
6	36.7-36.6	Private	0.1	1939	1939	N/A		N/A	N/A	100
7	36.6-36.0	Private	0.7	1939	1939	N/A		2009	N/A	0
7	36.0-35.8	Private	0.2	1939	1966	N/A	C3	N/A	N/A	100
8,9,10	35.8-34.9	Private	0.9	1939	1986	N/A	C4	N/A	N/A	100
11, 12	34.9-34.0	Private	0.9	1939	1939	1986, 1995, 2003, 2005, 2007, 2009, 2010, 2013	C5	N/A	N/A	100
13,14	34.0-33.1	Private	0.9	1939	1939	1939, 1966, 1986, 1995	C6	2003	N/A	22
15, 16, 17, 18, 19	33.1-32.0	Private	1.1	1939	1939	1966, 1995, 2007, 2013	C7	1986	1995	82
20, 21	32.0-30.4	Private	1.6	1939	2005	2005, 2007, 2009, 2010, 2013	C8	N/A	N/A	100
29	24.9-24.6	Public	0.3	1966	2007	N/A		N/A	N/A	100
30	24.6-24.1	Private	0.5	1966	2007	2007, 2009, 2010, 2013	C9	N/A	N/A	100
31	24.1-23.9	Public	0.2	1956	2007	N/A		N/A	N/A	100
32, 33, 34	23.9-23.2	Private	0.7	1956	2007	2007, 2009, 2010, 2013	C10	N/A	N/A	100
35	23.2-23.0	Public	0.2	1956	2009	N/A		N/A	N/A	100
36, 37	23.0-21.9	Private	1.1	1956	2009	N/A		N/A	N/A	100
41, 42	21.3-21.1	Private	0.2	1966	2007	N/A		N/A	N/A	100
44, 45, 46, 47, 48	21.1-20.5	Public	0.6	1966	2007	N/A		N/A	N/A	100
49, 50	20.5-20.2	Private	0.3	1966	2007	N/A		N/A	N/A	100
52, 53, 54	20.0-19.1	Private	0.9	1966	2007	N/A		N/A	N/A	100
60	16.7-16.6	Public	0.1	1966	1966	N/A		1995	N/A	100
67, 68, 69	15-13.3	Private	1.7	1955	1955	N/A		N/A	N/A	100

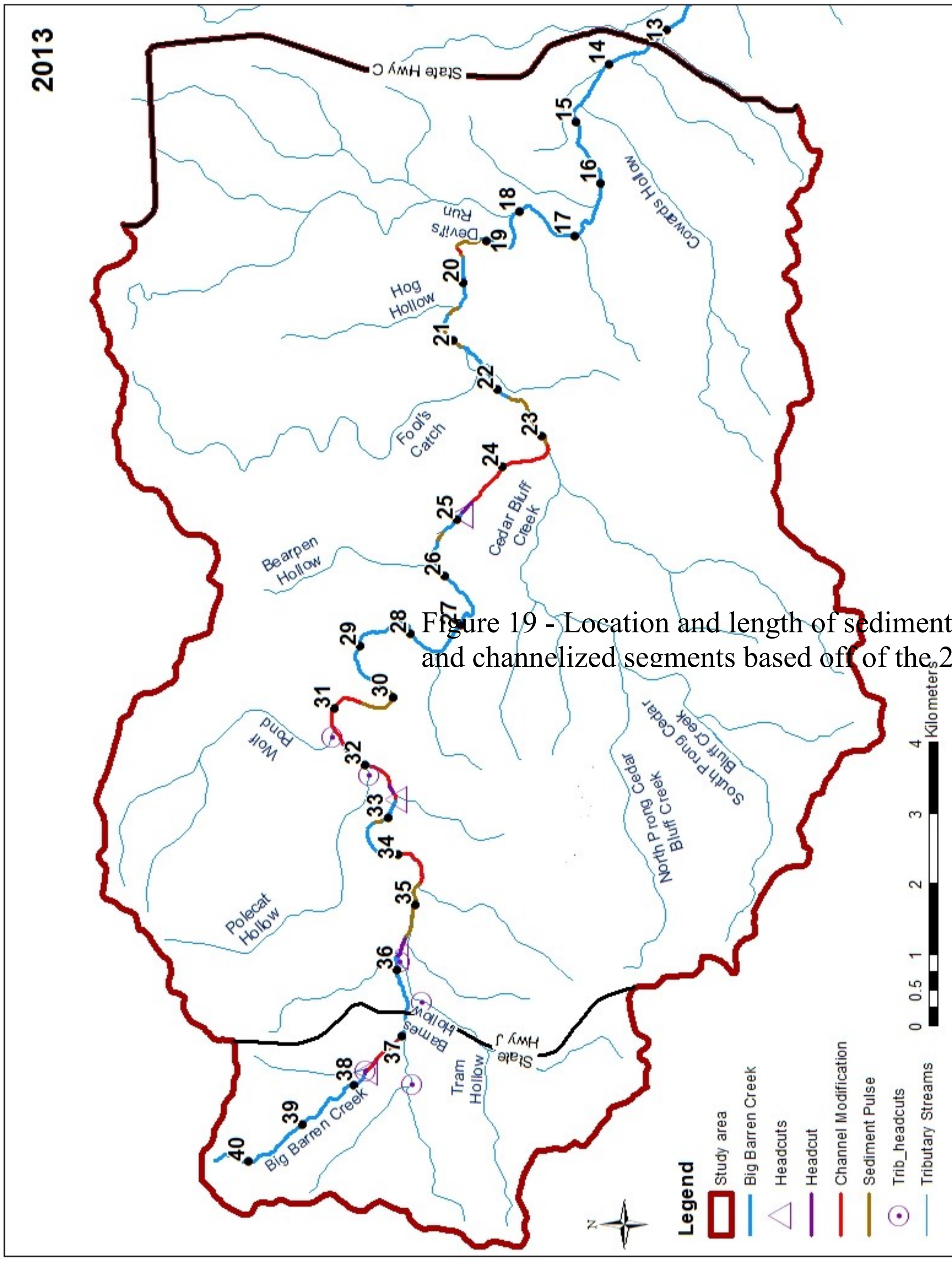

Figure 19 - Location and length of sediment pulse segments and rela
and channelized segments based off of the 2013 aerials.

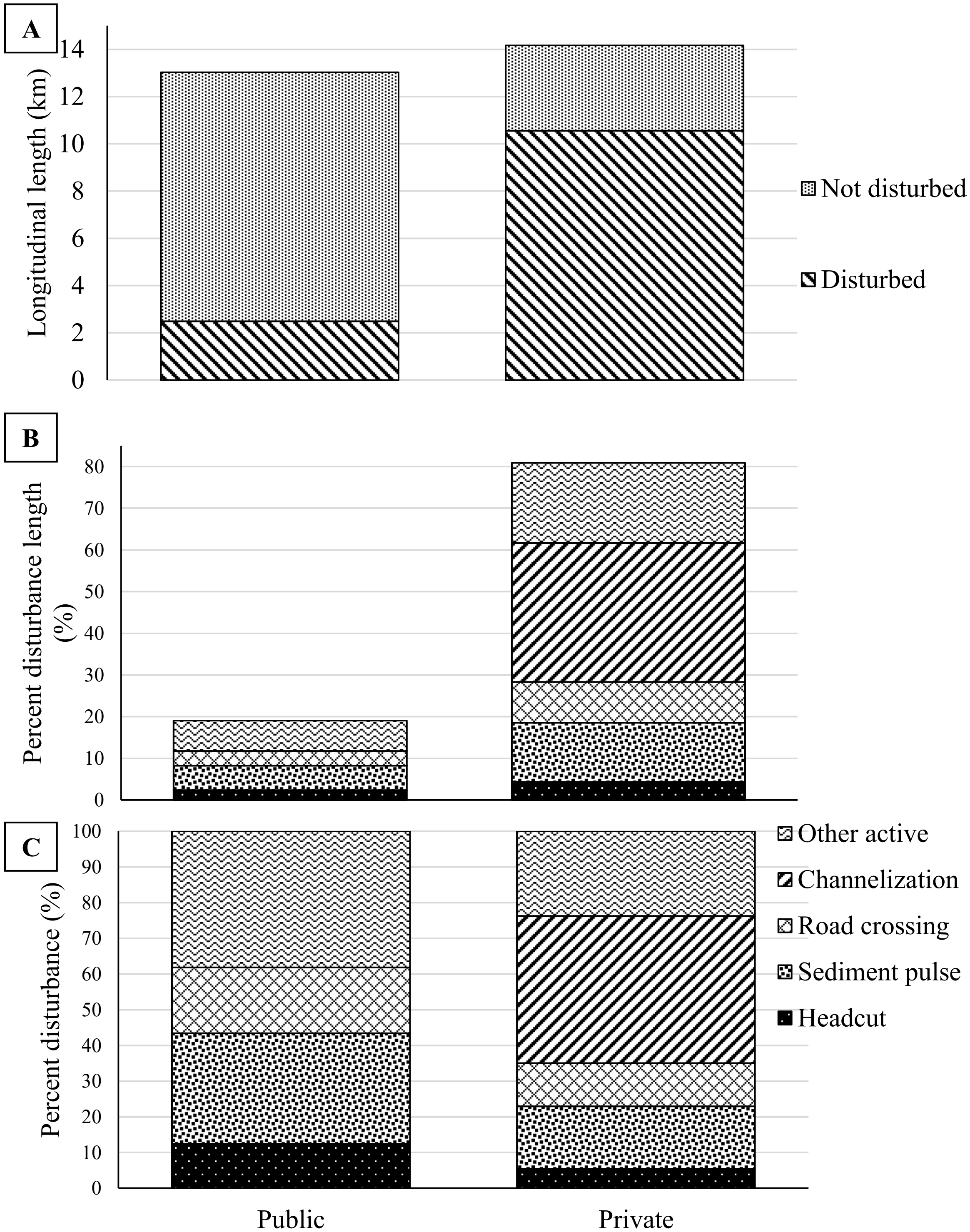

Figure 20 - Disturbance of Big Barren Creek by private and public ownership. A: Total lengths of disturbance and no disturbance by private and public ownership. B: Disturbance on public and private lands as a percent of total disturbance length for Big Barren Creek. C: Types of disturbance as a percent of total disturbance length by land ownership.

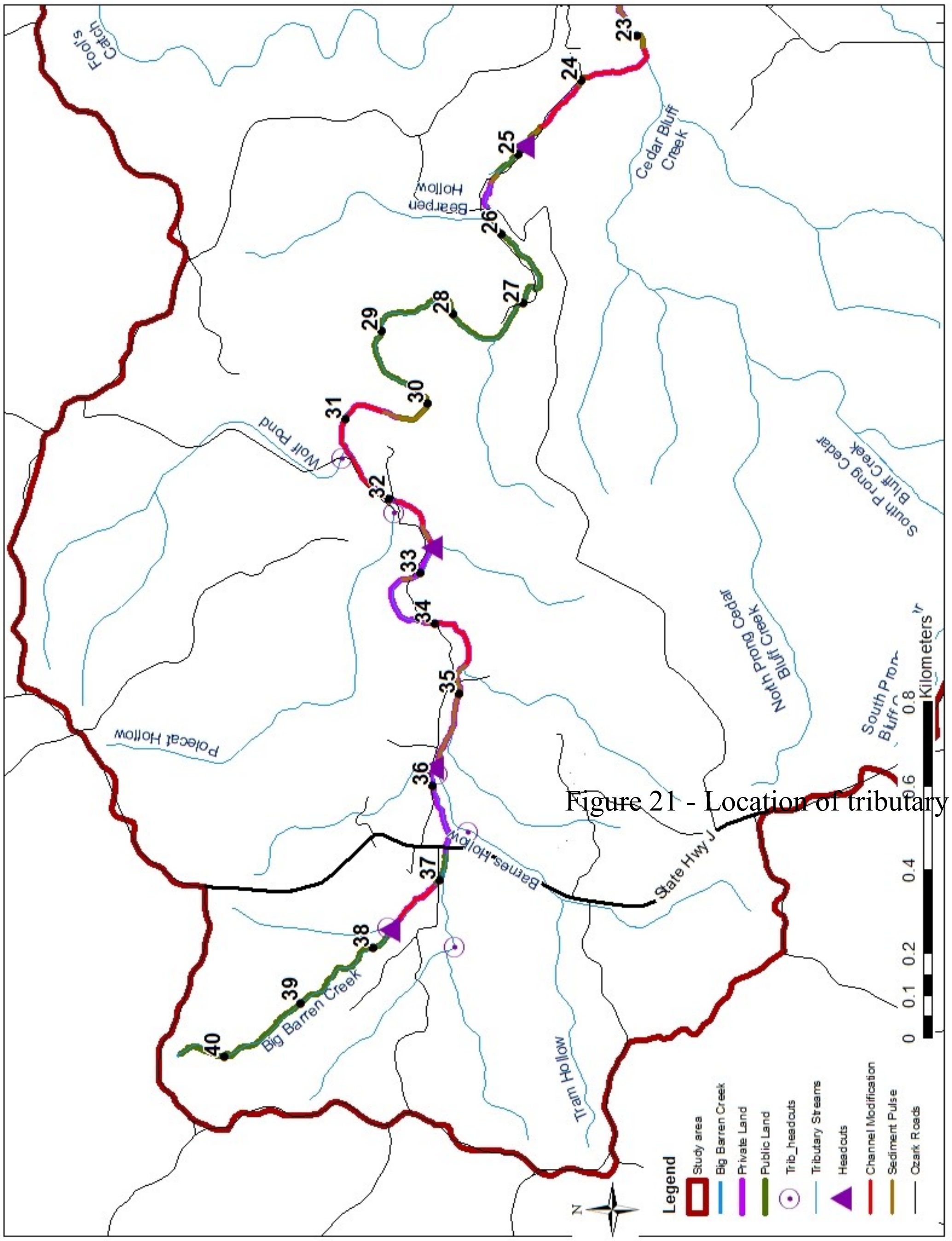

Figure 21 - Location of tributary headcuts on private ar

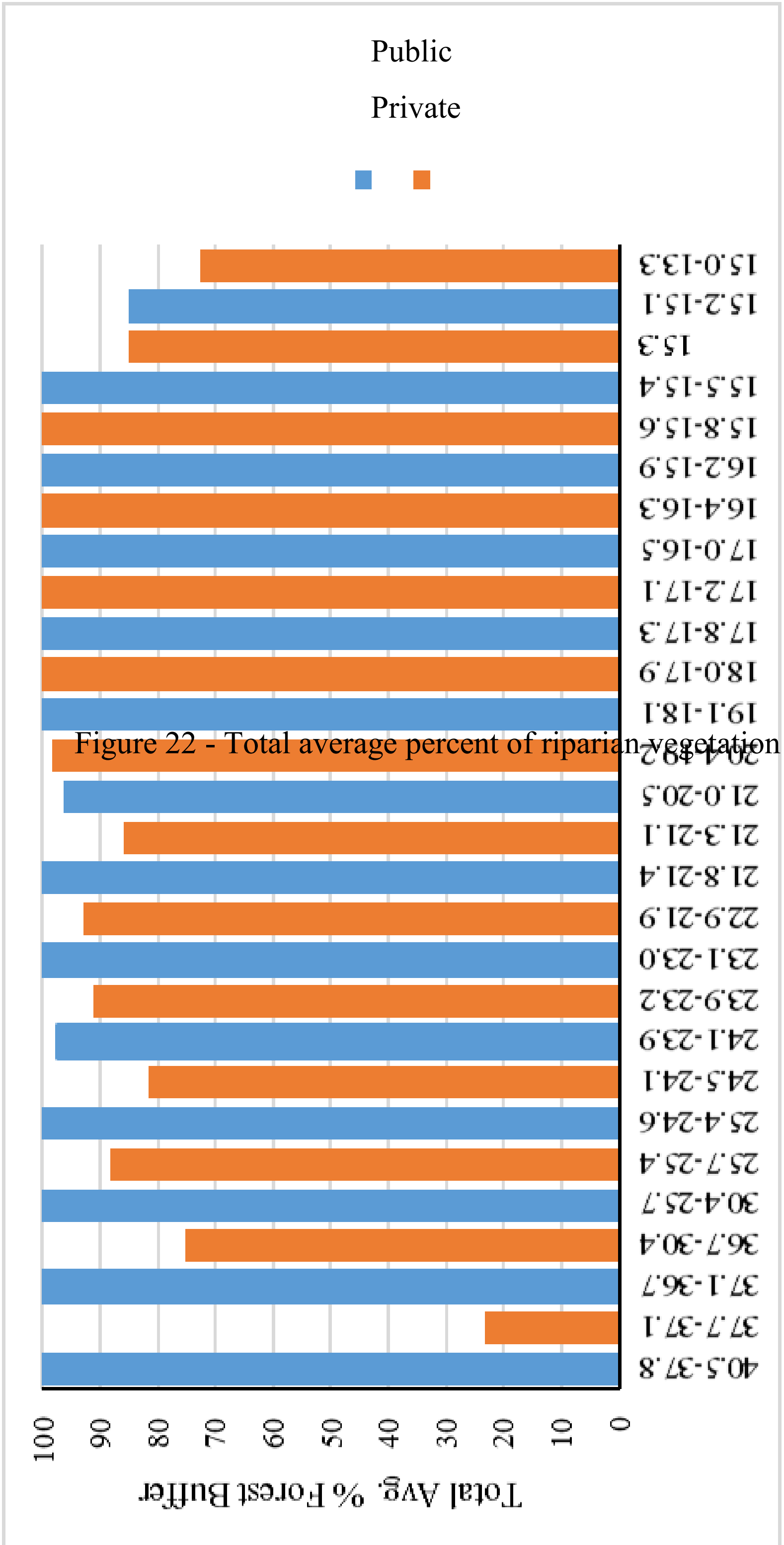

Figure 22 - Total average percent of riparian vegetation by river-kilometer by ownership.

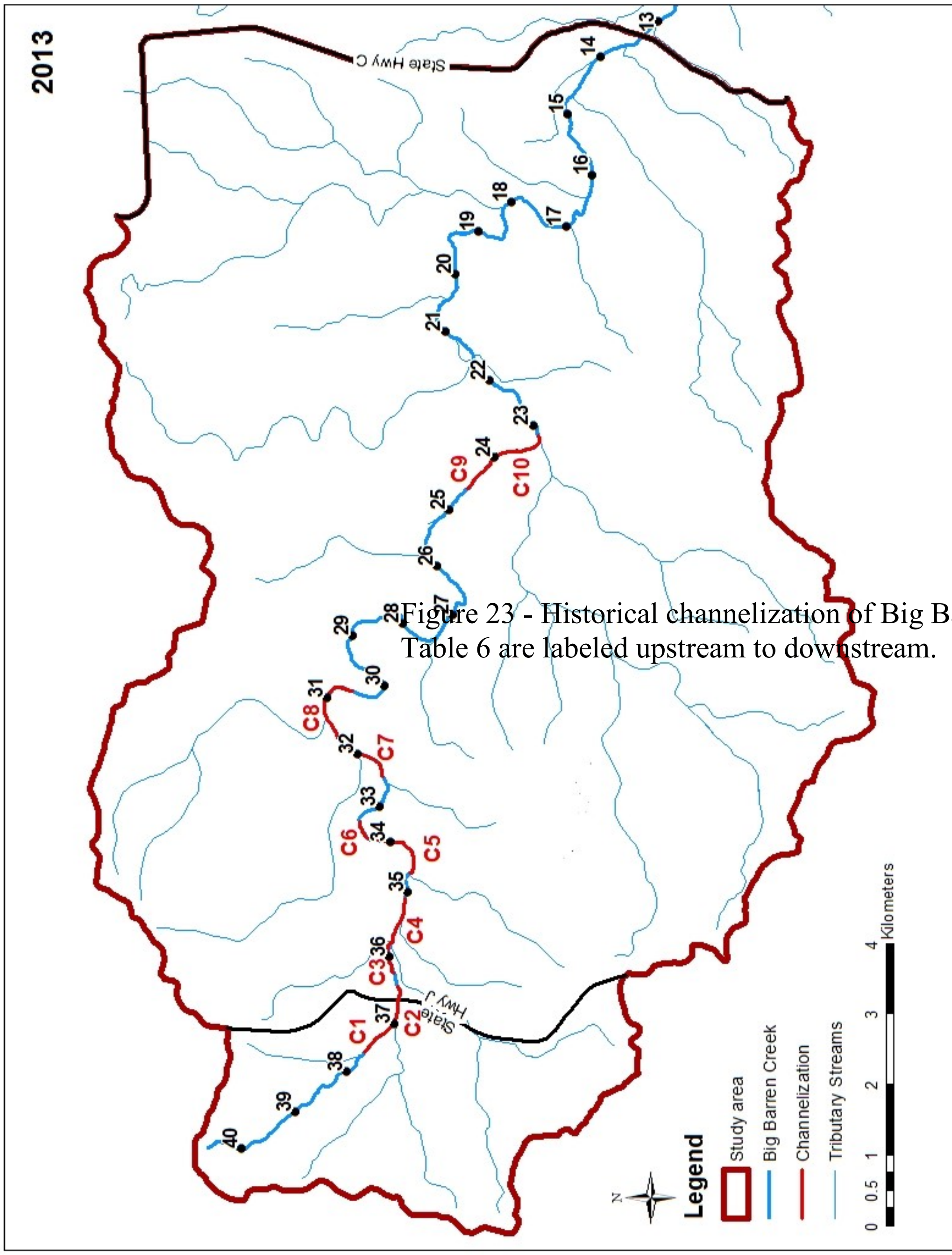

Figure 23 - Historical channelization of Big Barren Creek. Each of the
Table 6 are labeled upstream to downstream.

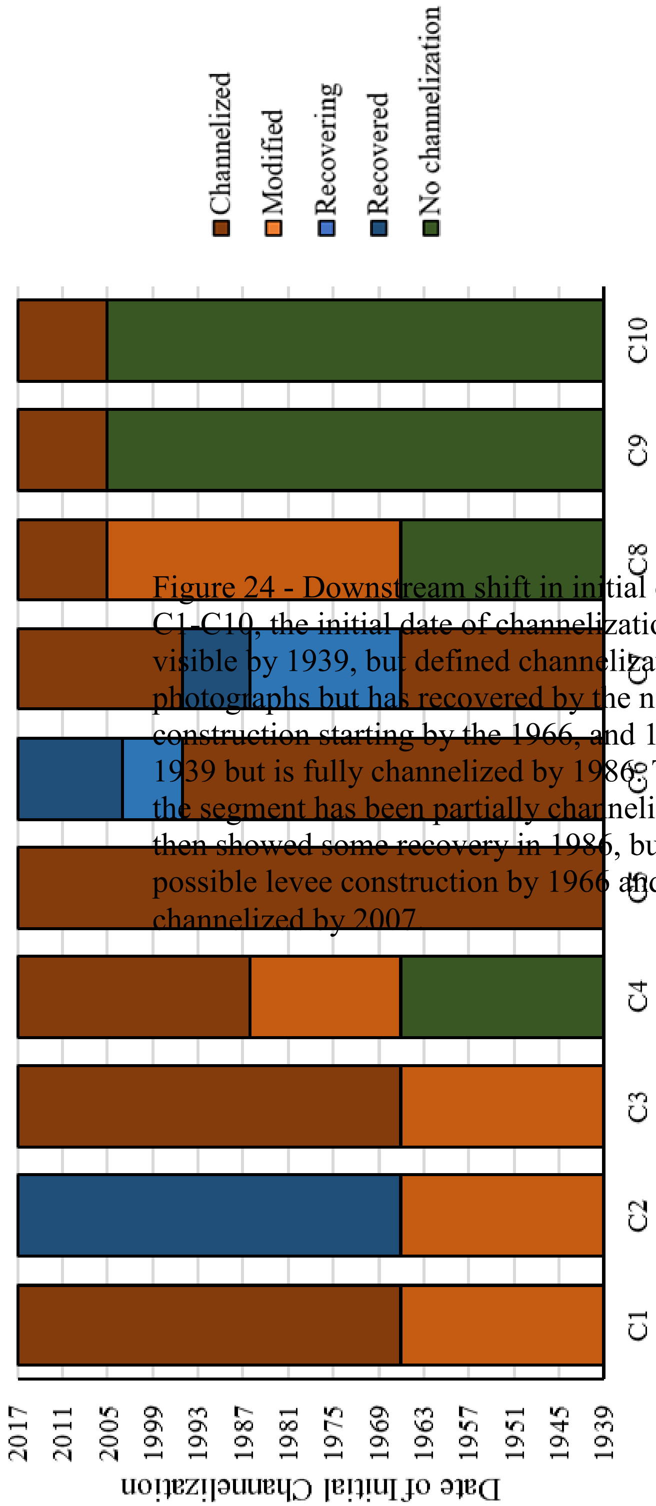

Figure 24 - Downstream shift in initial channelization and leveed year. Generally, from u
C1-C10, the initial date of channelization increases. At C1 cleared land and possible char
visible by 1939, but defined channelization was occurring by 1966. Segment C2 is chann
photographs but has recovered by the next photo year. The C3 and C4 segments show cha
construction starting by the 1966, and 1986 photographs. At C5 part of the channel segme
1939 but is fully channelized by 1986. The C6 segment is channelized by 1939 and has re
the segment has been partially channelized by 1939 and reached full channelized extent b
then showed some recovery in 1986, but channelization was reactivated by 1995. At C8 t
possible levee construction by 1966 and full channelization of the segment by 2005. The
channelized by 2007

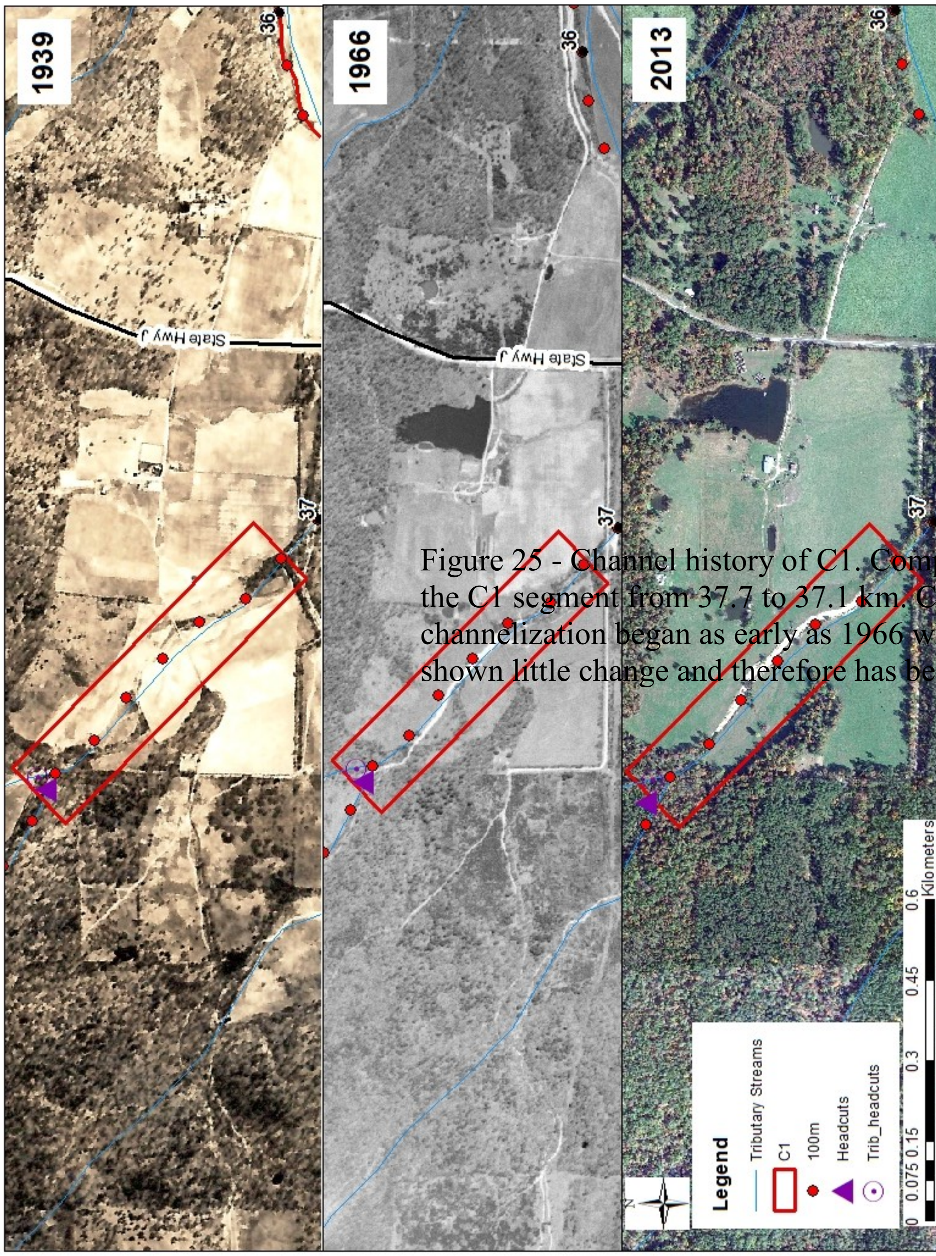

Figure 25 - Channel history of C1. Comparison of 1939, 1966, and 201
the C1 segment from 37.7 to 37.1 km. Cleared land is visible in the 19
channelization began as early as 1966 where there is a prominent grav
shown little change and therefore has been continuously disturbed for

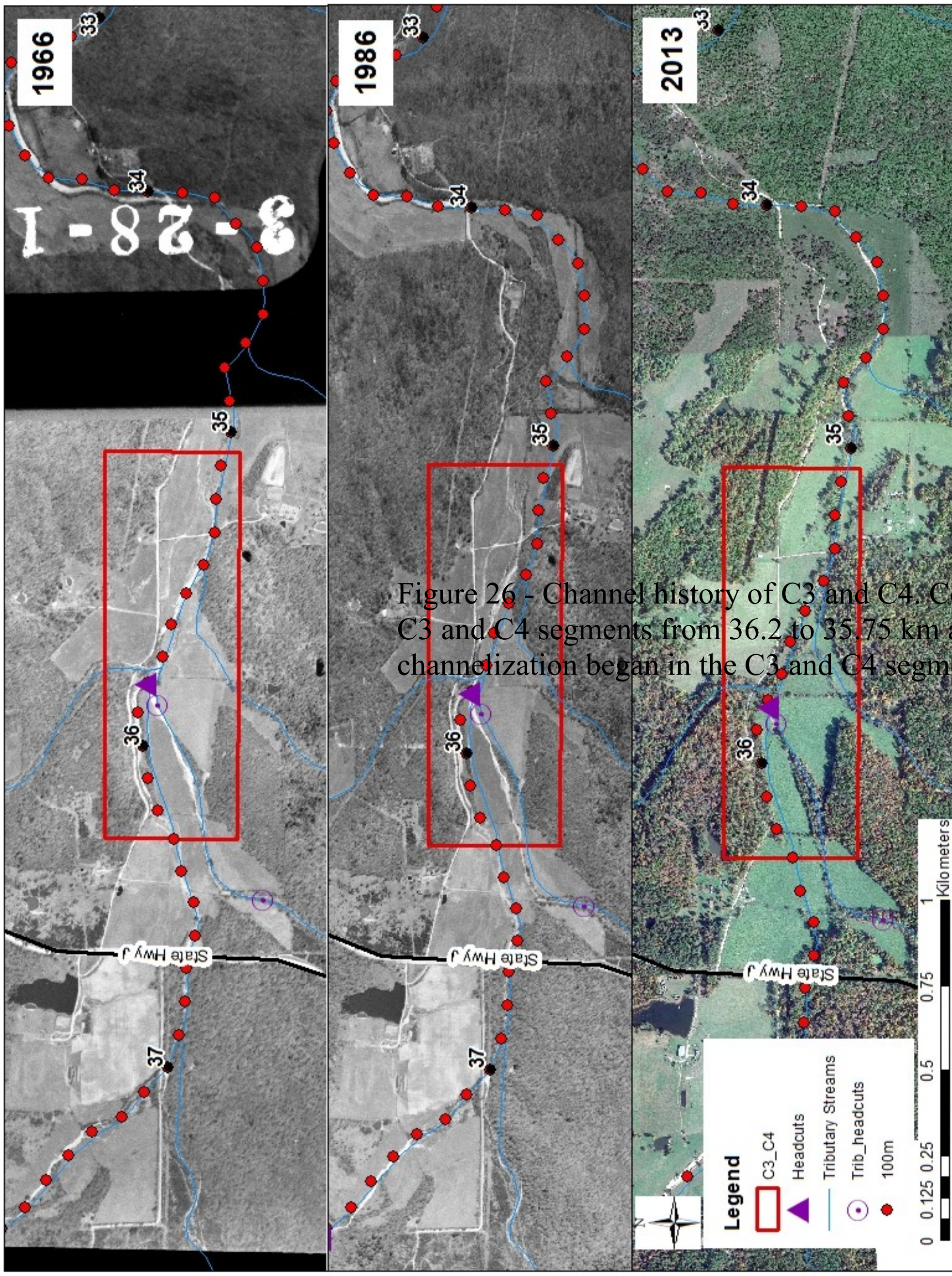

Figure 26 - Channel history of C3 and C4. Comparison of 1966 and 19
C3 and C4 segments from 36.2 to 35.75 km and from 35.75 to 35.1 km
channelization began in the C3 and C4 segments starting from 1966 an

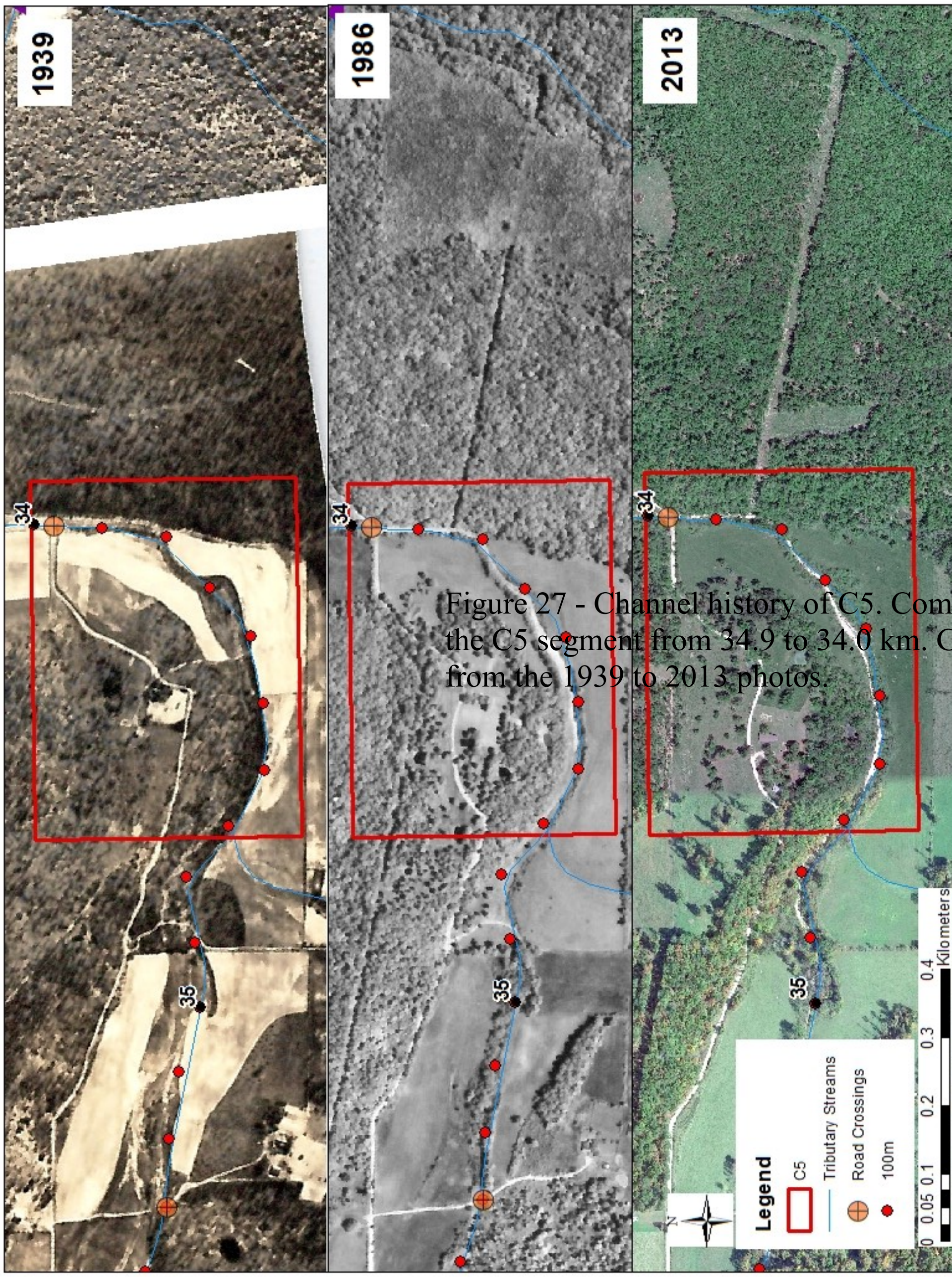

Figure 27 - Channel history of C5. Comparison of 1939, 1986, and 2
the C5 segment from 34.9 to 34.0 km. Gravel reflectance has grown
from the 1939 to 2013 photos.

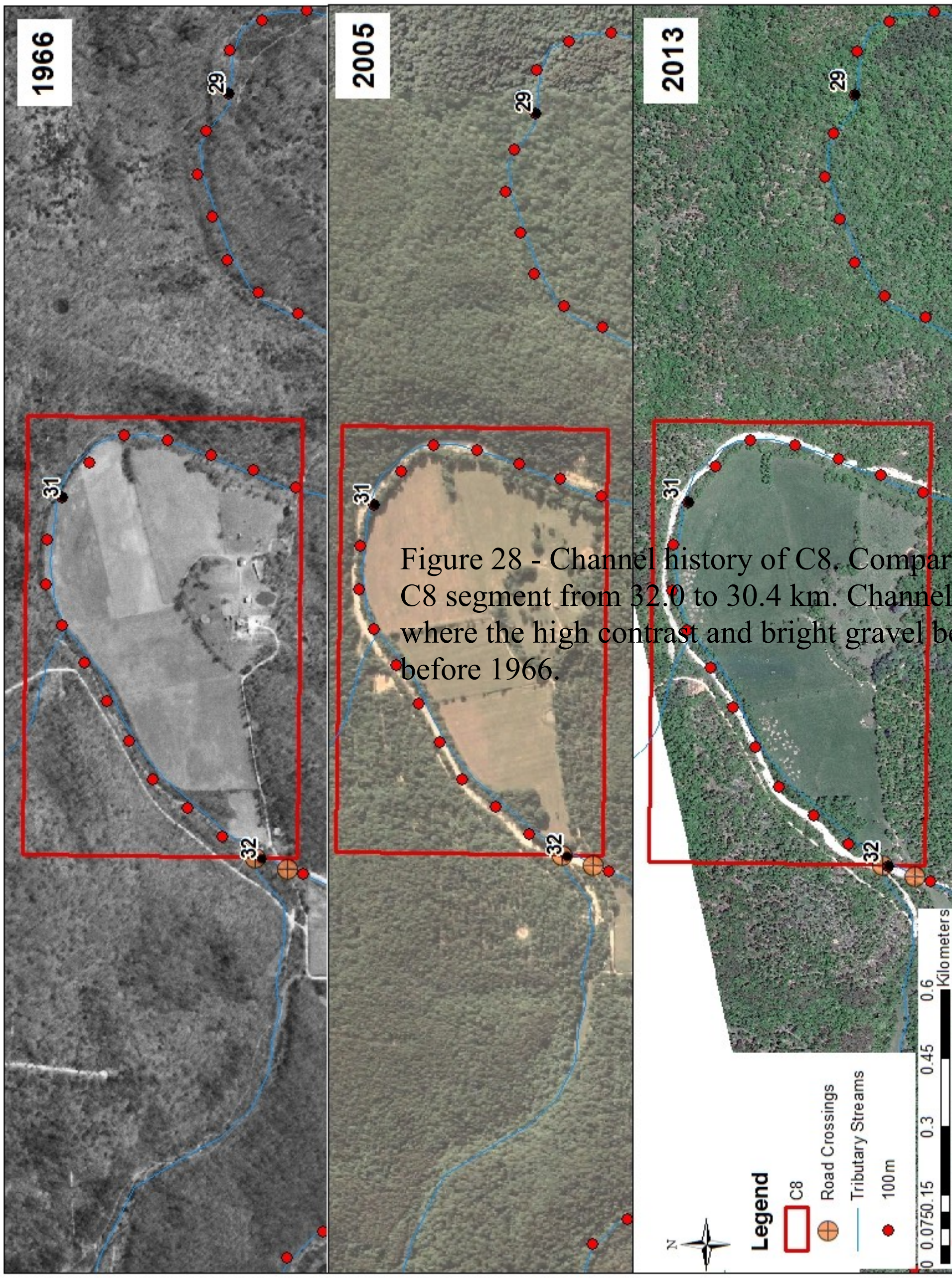

Figure 28 - Channel history of C8. Comparison of 1966, 2005, and 201
C8 segment from 32.0 to 30.4 km. Channelization in first seen in the 20
where the high contrast and bright gravel bed are visible, but levee cons
before 1966.

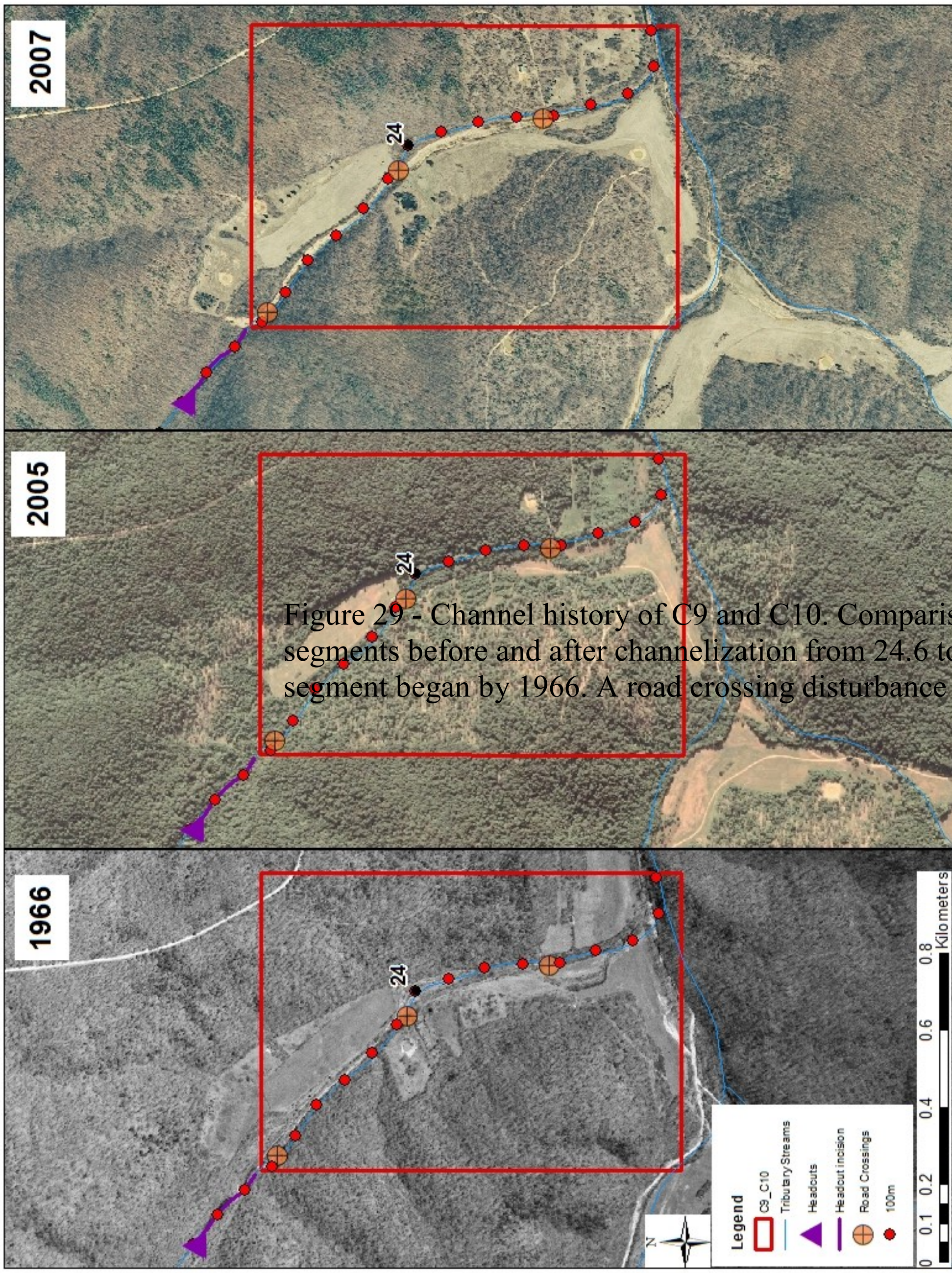

Figure 29 - Channel history of C9 and C10. Comparison of 1966, 2005, and 200
segments before and after channelization from 24.6 to 24.1 km, and 23.9 to 23.2
segment began by 1966. A road crossing disturbance around 24.07 separates the

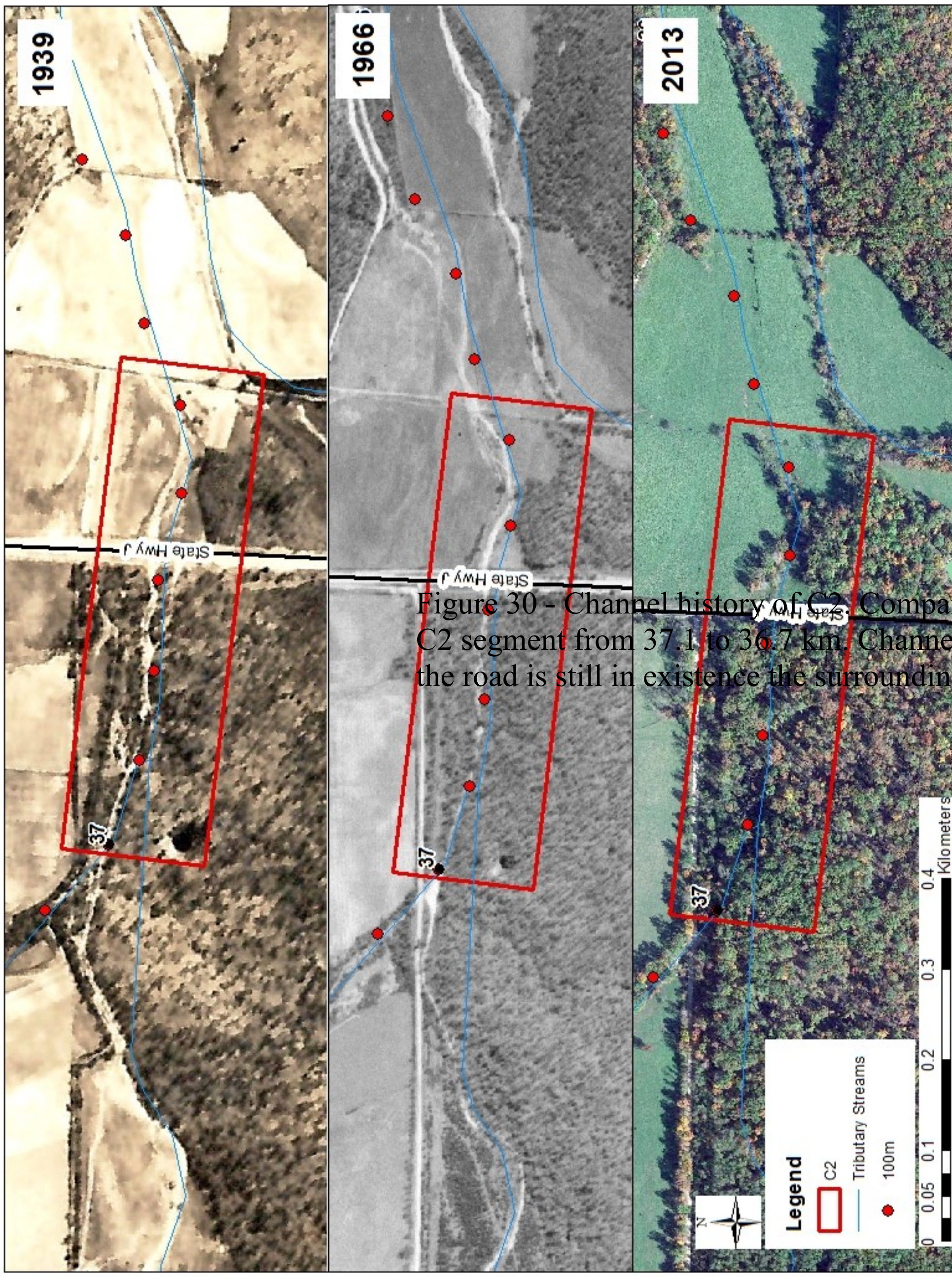

Figure 30 - Channel history of C2. Comparison of 1939, 1966, and 20
C2 segment from 37.1 to 36.7 km. Channelization in 1939 is along Co
the road is still in existence the surrounding area has recovered startin

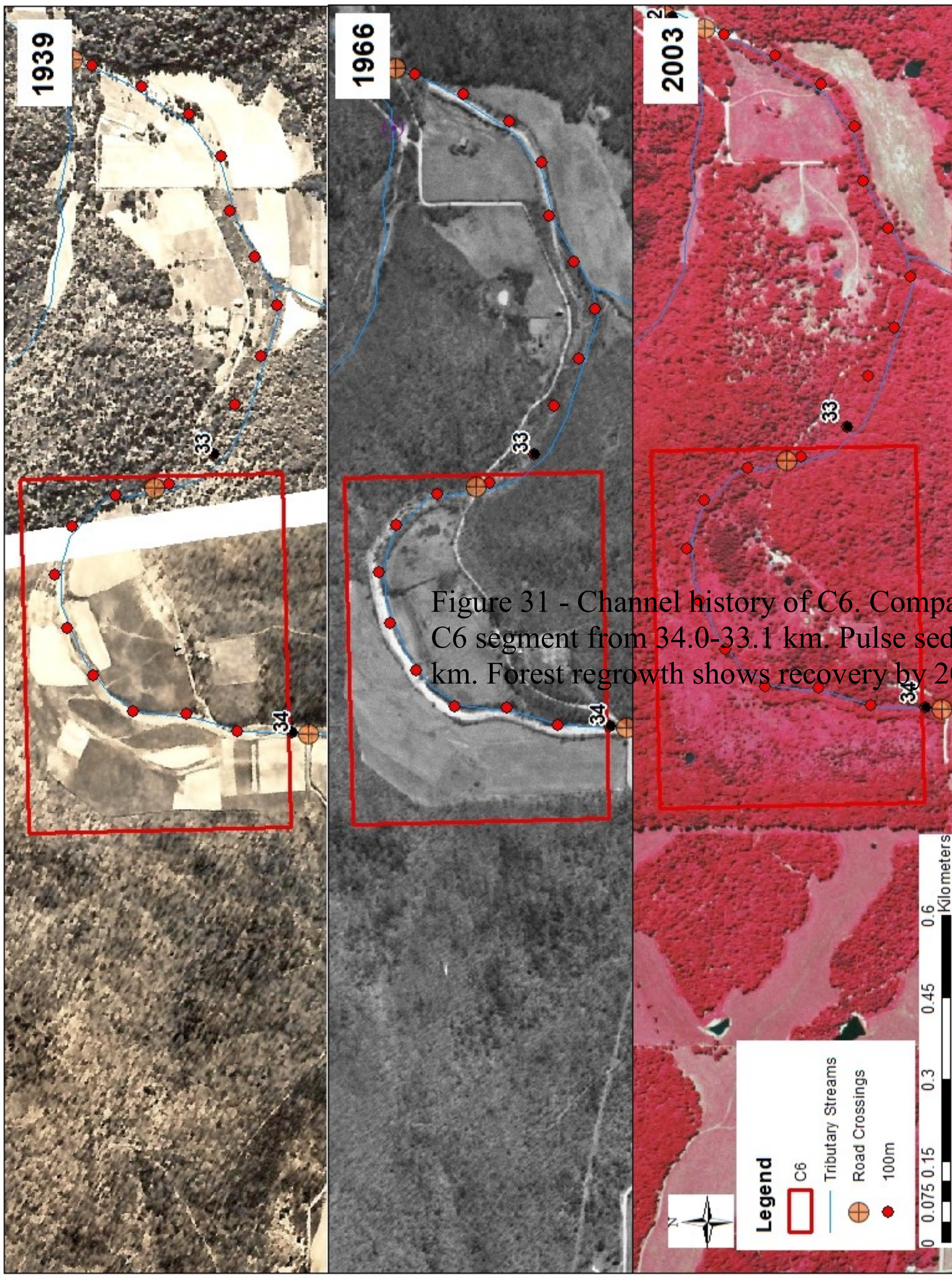

Figure 31 - Channel history of C6. Comparison of 1939, 1966, and 2
C6 segment from 34.0-33.1 km. Pulse sediment is visible on the 196
km. Forest regrowth shows recovery by 2003.

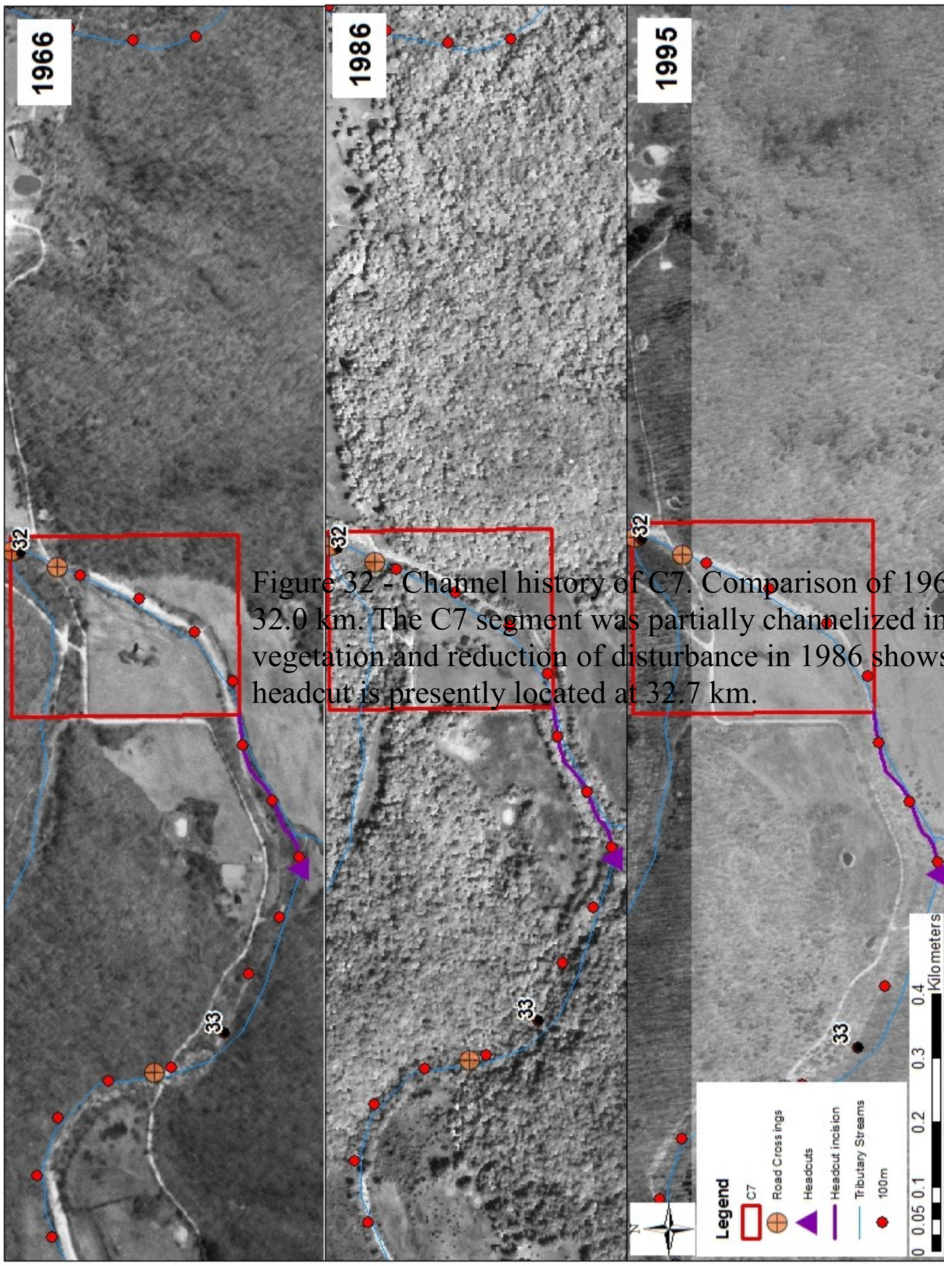

Figure 32 - Channel history of C7. Comparison of 1966, 1986, and 1995 aerial phot
32.0 km. The C7 segment was partially channelized in 1939, but reached full extent
vegetation and reduction of disturbance in 1986 shows recovery, but by the 1995 ae
headcut is presently located at 32.7 km.

Figure 33 - At 20.9 km on public land the stream bed is part of a road

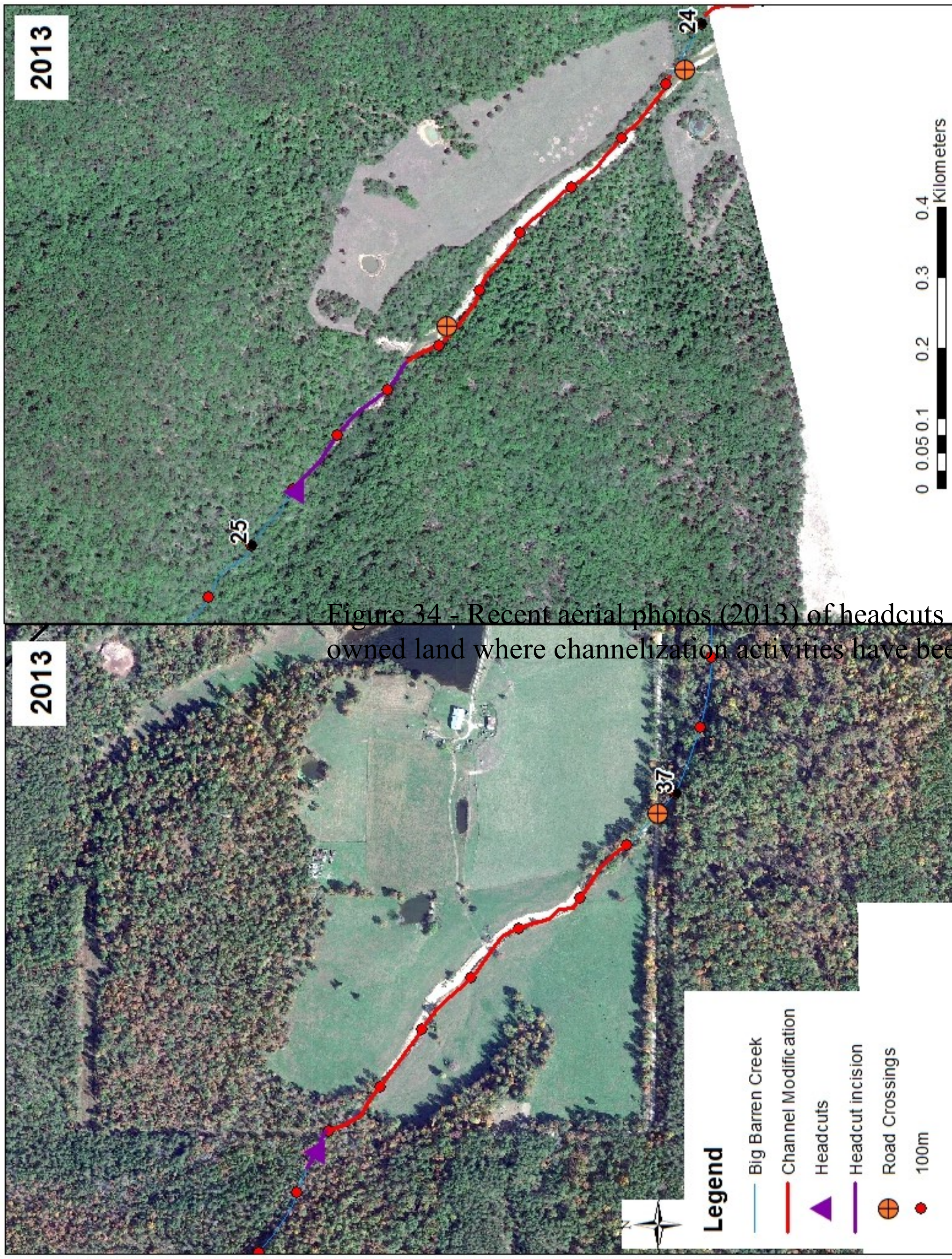

Figure 34 - Recent aerial photos (2013) of headcuts located 0.1 km (left) and
owned land where channelization activities have been occurring.

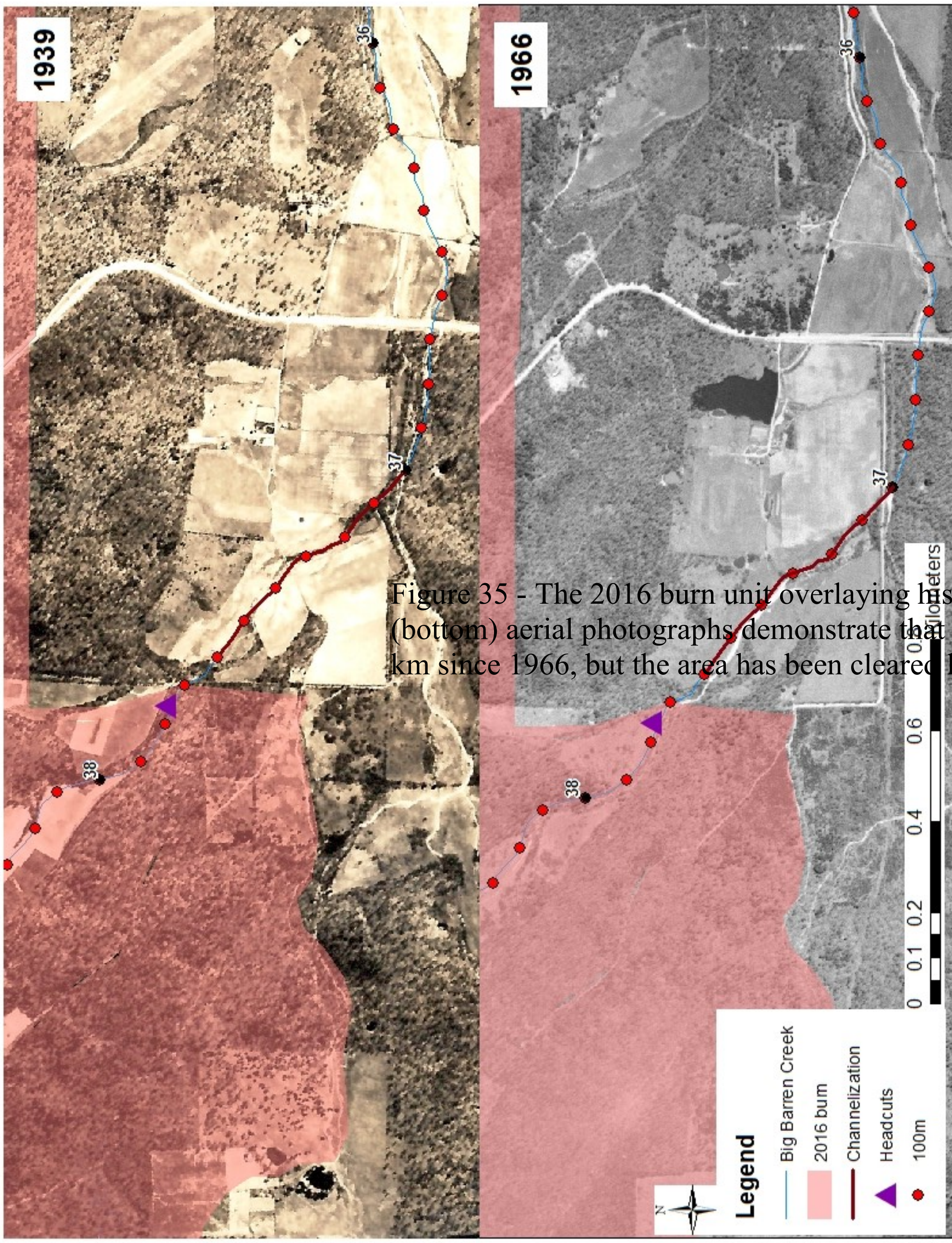

Figure 35 - The 2016 burn unit overlaying historical aerial photographs. (bottom) aerial photographs demonstrate that channel disturbance has be km since 1966, but the area has been cleared land starting from 1939, lo

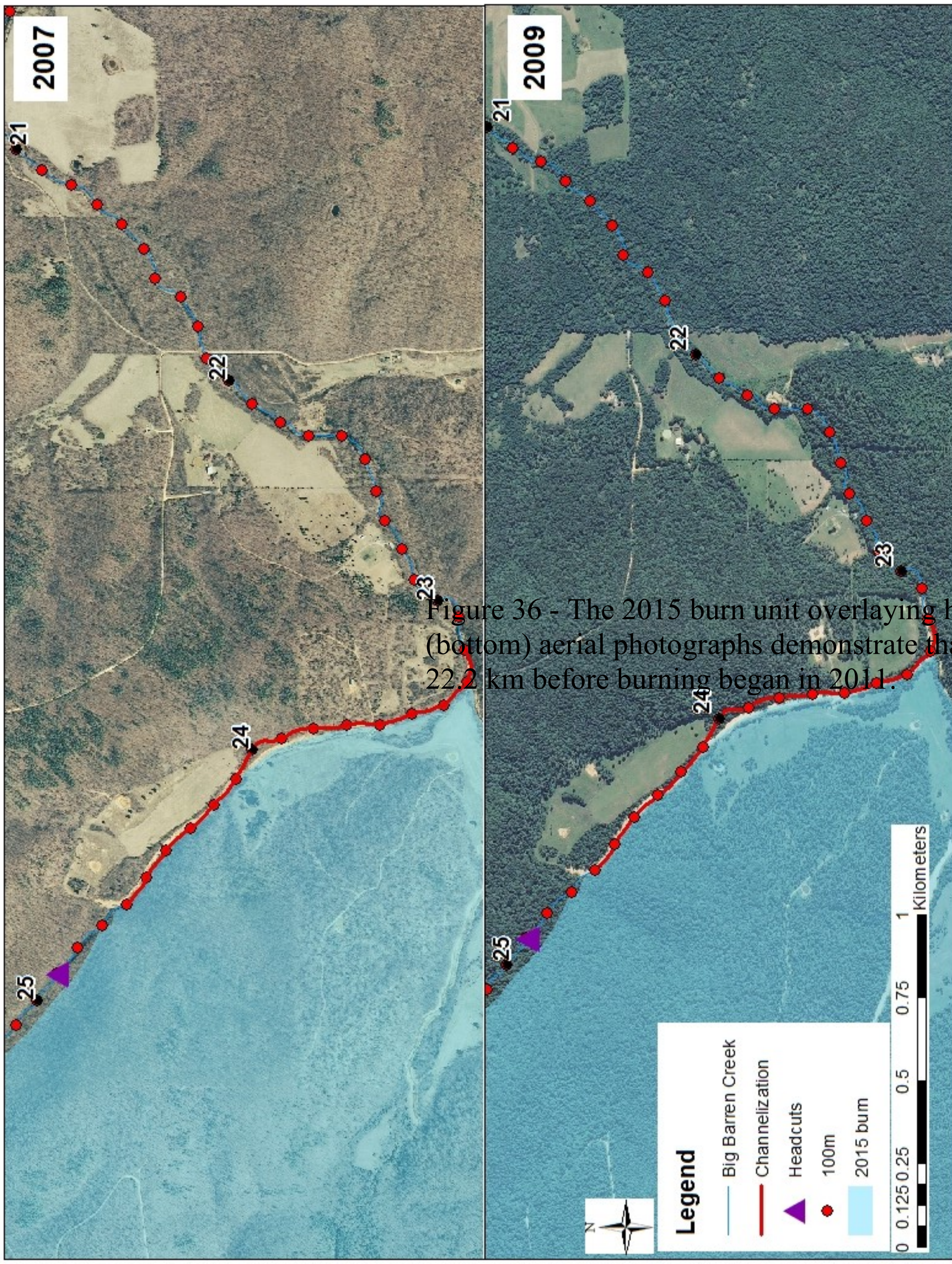

Figure 36 - The 2015 burn unit overlaying historical aerial photograp
(bottom) aerial photographs demonstrate that channel disturbance has
22.2 km before burning began in 2011.

CONCLUSIONS

This study fills a gap in the understanding of historical channel geomorphology of Big Barren Creek in the Ozark Highlands. Channel disturbance has existed in Big Barren Creek starting from 1939. The formation and continuation of channel disturbance is, in large parts, due to the effects of private land management practices. The purpose of this study was to assess historical channel disturbance in association with human modifications and land ownership from river kilometer 13.3 to 40.5 along the main stem of Big Barren Creek. The findings of this study have implications for future land use management and understanding their influence on other headwater streams in the Ozarks.

There are seven main findings:

1. Anthropogenic channelization accounts for over half of the disturbed channel length on Big Barren Creek. Approximately 48% of the study area length of 27.2 km of Big Barren Creek shows signs of channel bed and bank disturbance based on 2013 aerial photographs. Disturbed channel length is distributed as follows: 33% by channel modification; 13% by road crossings; 7% by head-cuts/incised beds; 20% by aggraded beds due to sediment pulses generated at channel modifications, road crossings, and headcuts, and 27% by other disturbances. Therefore, anthropogenic channelization and headcuts and aggraded beds generated by channelization accounts for at least 60% of the disturbed channel length of Big Barren Creek. Monitoring the extent of disturbance caused by direct human modifications in headwater streams such channelization is crucial to understanding implementation of channel stabilization measures (Guneralp and Rhoads, 2009).

2. Channel disturbances occur more often on privately-owned land than on publicly-owned land. Big Barren Creek is distributed with 52% of its length on private holdings and 48% within public land managed by the US Forest Service. Private land disturbance accounts for 81% of the total disturbed channel length. Of the 19% of disturbed channel length on public land, 43% is associated with channelization on private lands (upstream incision and downstream aggradation) and 18% due to road crossings. Channelization on private lands has resulted in upstream head-cut migration and bed incision to a maximum of 300 m from private land boundaries and downstream sedimentation and aggradation to 1000 m below. The extension of geomorphic disturbance both up and downstream of

channelized reaches has been reported for other regions (Brown et al., 1998; Johnson, 2005; Hupp et al., 2009).

3. Historically, ten distinct segments were affected by channelization in Big Barren Creek, and eight of those segments are still visibly disturbed by channelization practices in 2013 photographs. Evidence of human modifications of Big Barren Creek were observed in aerial photographs from 1939 to 2013, with the most recent episode of initial channelization occurring in 2007. Since 1939, three of the ten channelized segments showed signs of recovery with increased bed stability and vegetation growth. However, one recovered segment was re-channelized recently. This result can provide management guidance in deciding whether or not human influence is needed to aid recovery of local segments of Ozark headwater streams because if given the opportunity, Big Barren Creek can naturally recover from instability (Guneralp and Rhoads, 2009).

4. Channelization activities have shifted downstream over time, possibly in response to higher channel flows being progressively transferred downstream by constructed levee systems and enlarged channels. Channelization for upstream reaches (C1-C7) was first noticed in 1939 or 1966 aerial photographs. However, in downstream reaches (C8 to C10) channelization first started in 2005 or later. Levee construction and channelization leads to channel instability, sediment problems, and increased flooding so that continued maintenance is required including gravel mining and vegetation clearing as well as levee repair and these practices create long-term problems (Brookes et al., 1983).

5. Big Barren Creek has shown the ability to recover to some degree from channelization. Channel recovery time ranged from 27 to 70 years with an average period of 46 years. Channel recovery was indicated by the revegetation of the channel and lack of active gravel beds (Shields et al., 2003). However, field inspections indicated that pre-disturbance channel morphology has not recovered in most cases.

6. Segments of <20 m riparian buffer occur most often on private land. Forested stream buffers of >20 m on both banks occur along 63% of the creek. On public land, 97% has a forest buffer >20 m on both banks, while private land only has 53%. Channel segments with <20 m forest buffer occur where land has been cleared for agriculture and grazing. In channelized segments 58% of the forest buffer on both banks is <20 m. There were five instances in channelized sections where both the right and left banks have no tree buffer. The average forest buffer percent on public land is 99% and the average buffer percent on private land is 78%. The average buffer percent for channelized reaches is 75%. For management evaluation of bank instability, lack of wooded riparian vegetation is an important indicator of bank segments at risk of eroding (Brookes, 1985).

7. It is unlikely prescribed burning is responsible for much, if any of the disturbance zones. Segments directly below burn units have been disturbed continuously since 1939 and 2007. These disturbances started before the implementation of the Missouri Pine-Oak Woodlands Restoration Project in 2011. Segments of Big Barren Creek located directly in burn units have shown stability and even recovered over the study. It is possible that increased frequency of intense rainfall over the past decade may have produced more out-of-bank floods which have increased channel erosion and remobilized previously stored sediment (Knox, 2000; Pavlowsky et al., 2016).

Channel disturbance along Big Barren Creek occurred most frequently along private land holdings. Channelization including levees, channel enlargement, and gravel mining affect both private and public channel segments. If these land management practices continue or increase, bank instability and channel length affected by disturbance will continue, or possibly increase, in the future. Channel segments under U.S. Forest Service management showed considerably less disturbance (19%) than segments under private ownership (81%). Areas of disturbance under U.S. Forest Service management were mainly attributed to sediment pulses and headcuts caused by channelization and road crossings, and other active reaches including areas effected by beaver dams and valley bluff obstruction and bar formation.

To improve and protect channels in the future, restoration goals should focus on maintaining natural bank and bed stability and sediment management (Wohl et al., 2005; Darby and Sear, 2008). Levees may have been installed prior to channel bed enlargement, therefore future research to determine levee ages by dendrochronology will improve the temporal history of channelization along Big Barren Creek. This study of the chronology and history of channel geomorphology in Big Barren Creek is limited by photograph availability, quality, and access to stream segments during ground-truthing. A more in depth inspection can further refine timing of initial channelization.

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APPENDIX

Subreach	Ownership	Upstream Km	Downstream Km	Disturbance type	Length (km)
1	Public	40.5	37.76	No disturbance	2.74
2	Public	37.76	37.7	Headcut	0.06
3	Private	37.7	37.06	Channel modification	0.64
4	Public	37.06	37	Road crossing	0.06
5	Public	37	36.68	No disturbance	0.32
6	Private	36.68	36.65	Road crossing	0.03
7	Private	36.65	35.81	No disturbance	0.84
8	Private	35.81	35.52	Headcut	0.29
9	Private	35.52	35.32	Sediment pulse	0.2
10	Private	35.32	35.27	Road crossing	0.05
11	Private	35.27	34.67	Sediment pulse	0.6
12	Private	34.67	34.04	Channel modification	0.63
13	Private	34.04	33.93	Road crossing	0.11
14	Private	33.93	33.16	No disturbance	0.77
15	Private	33.16	33.1	Road crossing	0.06
16	Private	33.1	32.88	No disturbance	0.22
17	Private	32.88	32.73	Other active	0.15
18	Private	32.73	32.45	Headcut	0.28
19	Private	32.45	32.09	Channel modification	0.36
20	Private	32.09	31.98	Road crossing	0.11
21	Private	31.98	30.56	Channel modification	1.42
22	Private	30.56	30.4	Sediment pulse	0.16
23	Public	30.4	29.8	Sediment pulse	0.6
24	Public	29.8	25.74	No disturbance	4.06
25	Private	25.74	25.7	Road crossing	0.04
26	Private	25.7	25.42	No disturbance	0.28
27	Public	25.42	25.3	Road crossing	0.12
28	Public	25.3	24.9	No disturbance	0.4
29	Public	24.9	24.65	Headcut	0.25
30	Private	24.65	24.09	Channel modification	0.56
31	Public	24.09	23.97	Road crossing	0.12
32	Private	23.97	23.65	Channel modification	0.32
33	Private	23.65	23.62	Road crossing	0.03

34	Private	23.62	23.2	Channel modification	0.42
35	Public	23.2	23.1	Sediment pulse	0.1
36	Private	23.1	22.22	Sediment pulse	0.88
37	Private	22.22	21.9	Other active	0.32
38	Public	21.9	21.87	Road crossing	0.03
39	Public	21.87	21.4	No disturbance	0.47
40	Private	21.4	21.29	No disturbance	0.11
41	Private	21.29	21.2	Other active	0.09
42	Private	21.2	21.11	Road crossing	0.09
43	Private	21.11	21.1	Sediment pulse	0.01
44	Public	21.1	21.03	Sediment pulse	0.07
45	Public	21.03	20.89	No disturbance	0.14
46	Public	20.89	20.82	Road crossing	0.07
47	Public	20.82	20.56	Other active	0.26
48	Public	20.56	20.5	Road crossing	0.06
49	Private	20.5	20.39	Road crossing	0.11
50	Private	20.39	20.22	Other active	0.17
51	Private	20.22	19.95	No disturbance	0.27
52	Private	19.95	19.65	Other active	0.3
53	Private	19.65	19.25	Road crossing	0.4
54	Private	19.25	19.2	Other active	0.05
55	Public	19.2	19.11	Other active	0.09
56	Public	19.11	18.1	No disturbance	1.01
57	Private	18.1	17.9	No disturbance	0.2
58	Public	17.9	17.3	No disturbance	0.6
59	Private	17.3	17.1	No disturbance	0.2
60	Public	17.1	16.5	No disturbance	0.6
61	Private	16.5	16.3	No disturbance	0.2
62	Public	16.3	15.9	No disturbance	0.4
63	Private	15.9	15.6	No disturbance	0.3
64	Public	15.6	15.4	No disturbance	0.2
65	Private	15.4	15.3	No disturbance	0.1
66	Public	15.3	15.1	No disturbance	0.2
67	Private	15.1	14.98	No disturbance	0.12
68	Private	14.98	13.55	Other active	1.43
69	Private	13.55	13.3	Road crossing	0.25

Total 27.2