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Historical Land Use Influence on Fine-Grained Sedimentation in Channel and Floodplain Deposits in a Forested Missouri Ozark Watershed

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HISTORICAL LAND USE INFLUENCE ON FINE-GRAINED SEDIMENTATION IN CHANNEL AND FLOODPLAIN DEPOSITS IN A FORESTED MISSOURI OZARK WATERSHED

A Master's 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
Katy Nicole Reminga
August 2019

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ABSTRACT

Hydrologic disturbances due to land use and climate effects can disrupt river form and increase sediment transport. Ozark streams have been experiencing the effects of accelerated channel erosion on coarse sediment delivery and gravel bar deposition since the onset of early European settlement in the late 1800's. Little attention has focused on understanding the fate of fine-grained sediment released by upland soil and headwater channel erosion and the potential for storage as legacy deposits on floodplains. Legacy deposits are attributed to human disturbances as the result of land clearing and agriculture that increase runoff, soil erosion, flooding, and sediment supply in watersheds. Big Barren Creek (BBC) watershed (191 km^2) drains the Salem Plateau in the Ozark Highlands in south eastern Missouri. The watershed was heavily logged between 1880 and 1920 and stream channelization practices on farmland in the area began as early as 1950. Today about ¾ of the watershed area is within the Mark Twain National Forest. This study assesses the occurrence of fine-grained alluvial deposits along BBC and its tributaries and characterizes the spatial distribution and history of legacy sedimentation on alluvial landforms. There were four conclusions: (i) Fine-grained legacy deposits occur in BBC and are distributed non-uniformly upon channel, floodplains, and terrace landforms; (ii) Rates of post-settlement deposition from 1890-1950 were highest in upper BBC (~0.45 cm/yr) where the effects of historical timber harvest were most prevalent and decreased downstream to 0.29 cm/yr in middle BBC; (iii) Rates of post-1950 sedimentation were highest in lower BBC (~0.80 cm/yr) due to increased sediment supply from upstream head-cutting, channelization, and lateral bank erosion in disturbance zones; and (iv) In response to human-induced watershed disturbance, BBC has generally undergone a transition from a multi-threaded channel to a single channel form over the past century.

KEYWORDS: legacy sediment, disturbance, fluvial geomorphology, sedimentation rates, cesium-137, buried a-horizons, buried root crown dendrochronology, floodplain

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INTRODUCTION

Watershed disturbances due to human activities can lead to hydrologic regime changes that modify channel form and sedimentation process (Knox, 1977; Simon and Hupp, 1986; Simon and Rinaldi, 2006; Wilkinson and McElroy, 2007). As global populations continue to increase, so does the world's demand for food, land, and natural resources. In the wake of this increased global demand for resources, we can expect further and more dramatic changes to both watershed characteristics and hydrologic regimes globally. Some of the most extreme changes may be observed at the local-scale where hydrologic disturbances due to land use and climate effects can disrupt river form and dramatically increase sediment transport and deposition rates within river systems (Meade and Trimble, 1974; Knox, 1977; Knox, 1987; Walling, 1999; Shepard et al., 2011; Ruesser et al., 2015; Pavlowsky et al, 2017). The role of humans as important geomorphic agents is a well-recognized concept in landscape disturbance studies. It was first introduced by George Perkins-Marsh in 1864 who explained how deforestation and subsequent soil erosion were responsible for changes to flooding, channel morphology, and sedimentation patterns in North American rivers, and has since provoked continuing research on the effect of human activity on landscape development and river systems (Meade and Trimble, 1974; Knox, 1977; Knox, 1987; Jacobson and Coleman, 1986; Beach, 1994; Walter and Merritts, 2008; Pavlowsky et al., 2017).

Much of the annual sediment load produced worldwide is the result of anthropogenic activities and modifications to the landscape for urban, agricultural, or natural resource production (Nir, 1983; Hooke, 1994; Wilkinson and McElroy, 2007). Nir (1983) estimated annual global rates of sediment erosion due to anthropogenic activities like forest clearing, grazing, agriculture, mining, and urban construction to be an approximate of 1.73 x10^{-4} G t/yr. In 1994, it was estimated that human contribution to sediment removal and deposition to the world's interior and ocean basins had reached 40-45 Gt annually, or 41% of the current global sediment load at that time (Hooke, 1994). For comparison, previous prehistorical sediment loads have been estimated at 24 Gt per year and largely relate to glacial sediment transported by rivers in the Pleistocene (Hooke, 1994). In 2007, it was reported that erosion rates occurring in response to global agricultural activities alone was upwards of 75 Gt/yr while natural sediment fluxes accounted for only 21 Gt/yr (Wilkinson and McElroy, 2007). Moreover, it has been suggested that the accumulation of post-settlement alluvium in tributary channels and floodplains globally is occurring at a mean annual rate of 12,600 m/my making it the most important erosional/ depositional geomorphic process currently shaping the surface of the Earth (Wilkinson and McElroy, 2007).

Similarly, estimates of human contribution to global landscape change, approximated by terrestrial sediment flux, have been shown to meet (or exceed in some cases) prehistoric sediment fluxes occurring during major geologic transitory periods such as between the Pleistocene and Holocene periods (Wilkinson and McElroy, 2007; Syvitski and Kettner, 2011). Syvitski and Kettner (2011) approximate global coastline sediment fluxes for pre-Anthropocene and Anthropocene (late 21st century) conditions, and found that pre-Anthropocene fluxes averaged approximately 15.1 ± 0.5 Gt/ yr while Anthropocene fluxes averaged about 12.8 ± 0.5 Gt/yr. However, when taking into consideration the amount of global terrestrial sediment unable to reach ocean basins trapped by dams and diversions, the average sediment flux for Anthropocene conditions far exceeds coastal sediment flux during pre-Anthropocene conditions (Syvitski and Kettner, 2011). With Anthropocene conditions defined in this context as the conditions present during a period of geologic time in which the Earth is affected or modified by human activities inducing environmental change on a global scale (Lewis and Maslin, 2015).

In general, changes to watershed characteristics influence the rates and patterns of sedimentation and also govern the distribution of runoff and control channel patterns (Costa, 1975). As a result, human activity is now also widely recognized as a major driver of hydrologic and geomorphic channel adjustments worldwide (Gilbert, 1917; Jacobson and Primm,1997; James, 2013; Pavlowsky et al., 2017; Simon and Rinaldi, 2006). In the U.S. alone, over $1 billion is spent annually to manage and restore streams that are affected by channel instability resulting from land use disturbance (Bernhardt et al., 2005). Most of these channel changes are caused by disturbance-related indirect increases in runoff rate which cascade into increases in soil erosion rate and channel instability. Following increases in erosion and channel instability downstream floodplains and channels will begin to aggrade (Pavlowsky et al., 2017).

Human-derived sediment is distinct from naturally deposited sediment and is commonly referred to as legacy sediment (Donovan et al., 2015; Fitzpatrick et al.,2007; James, 2006, 2010, 2013; Niemitz et al., 2013; Novotny, 2004; Pavlowsky et al., 2010; Pavlowsky et al., 2017). Legacy sedimentation is broadly defined as intense episodes of accelerated floodplain or channel deposition resulting from anthropogenic activities that increase runoff and erosion (James, 2013; Pavlowsky et al., 2017). Legacy deposition, also referred to as anthropically-derived alluvium, is formed by landscape disturbances during the post-colonial age (Niemitz et al., 2013). Anthropogenic activities known to produce legacy sediment include land clearing and settlement, deforestation, large-scale agricultural practices/ row-cropping, mining, urbanization, and the construction of mill dams (James, 2013; Pavlowsky et al., 2017).

Anthropogenic sedimentation does not occur uniformly across landscapes and does not exhibit laterally extensive characteristics, but rather it collects intermittently atop of older landform surfaces associated with adjacent streams (James, 2013). These anthropically-derived deposits often reside as: (i) alluvial deposits on floodplains (Knox, 1972); (ii) as ponded water deposits upstream of dams (Walter and Merritt, 2008); or (iii) as colluvial deposits at the base of valley slopes (Happ et al., 1940; Costa, 1975; Pavlowsky et al., 2017). Variations in the spatial pattern of legacy sediment deposition and storage is affected by differences in sediment production, valley floor accommodation space, and relative transport capacity of the stream (Magilligan, 1985; James, 2013). Legacy deposits can also be categorized according to texture and storage potential as either: (i) fine-grained legacy deposits typical of the long-term storage of sand, silt, and clay fractions on valley floodplains or (ii) coarse-grained legacy deposits typically characterized by short-term storage of fine to coarse-grained gravel confined to bank-full channels (James, 1999). The study of legacy sedimentation and storage has important implications for river-restoration, water quality, flood risks, and aquatic and riparian habitats as the introduction of these sediments can degrade water quality and ecosystem health as well as alter channel form (James, 2013; Donovan et al., 2015).

Early work done in the western U.S. focused specifically on processes of valley aggradation of coarse sediment and changes to channel hydraulics following land use periods of intensive mining practices. Gilbert in 1917 was one of the first researchers to report the influence of hydraulic mining on sediment production and geomorphic response using catchment-scale sediment budget techniques in the Sacramento Valley of the Sierra Nevada Range in northern California (James, 1989). Gilbert constructed three time series of low- flow stage elevations for three locations, two at the Yuba River, and one along Sacramento River in California. He related the channel stages to bed elevation at each of the gauge sites and effectively equated them with sediment loads at the respective gauge sites (James, 2013). Following these findings, Gilbert (1917) was able to generate a sediment wave model which described alluvial response to disturbance in terms of the movement of waves of sediment and debris following mining periods. This wave can be described by the characteristic raising and lowering of channel bed elevations through processes of aggradation and incision that mimic the overall input of water and sediment introduced during a disturbance period (James, 1999).

Research documenting the influence of historical land disturbance on the production and storage of what would later be referred to as legacy sediment generally began in the United States in the 1930s-1940s with USDA studies on soil erosion and valley sedimentation (Happ et al., 1940). Primary influential studies focused on the effect of large-scale agricultural practices and resulting accelerated alluvial deposition into river valleys of the upper Midwest Driftless area and the southern Appalachian Piedmont regions (Knox, 1972; Costa, 1975; Trimble, 1974; Magilligan, 1985; Jacobson and Coleman, 1986; Beach, 1994; Walter and Merritts, 2008; Wilkinson and McElroy, 2007; Wolman, 1967).

Some research drew early connections between increases in alluvial sedimentation and shifts in channel morphology characteristics exhibited by rivers in the north-eastern U.S following colonial settlement. It was suggested that the infill of large volumes of legacy sediment into once stable, multithreaded, pre-colonial channels caused a transition in channel morphology to the incised, single-threaded channels that are seen today (Trimble, 1974; Walter and Merritt, 2008; Cluer and Thorne, 2013). Walter and Merritt (2008) found that pre-settlement streams in the eastern United States were characterized by laterally extensive, small, multi-threaded, or anastomosing streams which were contained within wet woodland environments.

Flow through these woodland environments was heavily influenced by small, stable, vegetated islands rather than deep single-threaded channels. Later, the idea of a multi-threaded, pre-settlement channel morphology in some regions was included as a pre-disturbance reference condition in a Stream Evolution Model developed for use in stream restoration (Cluer and Thorne, 2013).

The gradual transition from pre-settlement, multi-threaded streams, to single-threaded streams, has allowed for a dominant pattern of contemporary legacy sedimentation to occur. This classic model of legacy sedimentation commonly referred to as "over-bank deposition", is the archetypal model of fine-grained floodplain deposition experienced by most major single-threaded river systems. This occurs where transported fine-grained sediment will over top channel banks during flood conditions and accrete vertically on channel floodplains in downstream valleys (Fig. 1) (Knox, 1972; Donovan et al., 2015). Increases in sedimentation rates and changes to channel morphology are largely associated with changes to the transport and/or carrying capacity of the channel in response to hydrologic disturbances. Specifically, legacy sediments will be deposited and stored when transport capacity of the stream is exceeded by the amount of sediment delivered to the channel reach, commonly expressed in terms of a sediment storage potential ratio (James, 2013). The sediment storage potential ratio can be used to predict whether legacy sediment will be recruited and transported ($D_s/T_c < 1$), or deposited and preserved with longer residency times ($D_s/T_c >> 1$), where D_s is sediment delivery and T_c is transport capacity (James, 2013). As a result, fluctuations in rates of runoff and erosion, influenced by land use, are mirrored in changing rates and volumes of historical sediment storage in river valleys (Costa, 1975).

The composition, distribution, and magnitude of legacy deposits on floodplains can be used as an indicator of watershed disturbance. Fine-grained legacy deposition is frequently associated with contemporary overbank floodplain features and riparian zones along stream channels (Knox, 2006; Owen et al., 2011). The study of accelerated legacy sediment deposition remains a valuable means for understanding the severity and level of land use related disturbance (James, 2013; Knox, 2006). Historical floodplain deposits contain sedimentary records of both vertical and lateral channel adjustments reflecting variations in watershed conditions caused by past disturbances (Jacobson and Coleman, 1986; Knox, 1972, 1977, 1987; Macklin and Lewin, 2008, Owen et al., 2011). Legacy floodplain deposits can be interpreted to understand watershed response to historical land use by using stratigraphic markers and horizons to date the deposits (Walling and He, 1997). Floodplains are very susceptible to upstream watershed changes and often serve as either long-term or temporary sinks for contaminated soil and disturbance-derived sediment (Knox, 2006). Disturbance-derived sediment deposited on floodplains ultimately ends up preserved as legacy sediments within the floodplain where residence times are on the order of decades to thousands of years (Owens, 2005).

Forest Controls on Hydrology

Forest canopies act as shelter to upland soils and shield them from the effects of intense rainfall, runoff, and erosion (Leigh, 2016). Under ideal forest conditions the processes of surface erosion are minimal due to increased capacity for infiltration and the inability for Hortonian flow processes to occur (Hewlett et al., 1977; Leigh, 2016). In mature, forested, watershed systems, precipitation is instead infiltrated and passed through subsurface pathways as saturation overland flow (Leigh, 2016). However, in many areas this is simply not the case due to the influence of both natural and anthropogenic disturbances that work to disturb forest cover. Disturbances in forest cover subsequently result in increased exposure of bare soil, the reduction of infiltration capacity, and the accelerated erosion and deposition of sediments to downstream floodplains (Leigh, 2016). As a result, floodplains within these watersheds serve to store and record episodes of past forest disturbance via fluctuations in sedimentation patterns (Leigh, 2016). In general, it is known that large scale timber harvest and clear-cutting drastically increase floodplain sedimentation patterns due to mass vegetative loss that would otherwise prevent soil loss from processes of rain drop impact, sheet flow, and rilling processes (Walling, 1987; Knox, 2006; Leigh, 2016).

Review of Overbank Legacy Deposits by Region

The influence of human activities on the landscape and its subsequent release of anthropogenic sediment has been a well-studied topic in the United States (Table 1). Historically, methods to measure the effect of such activities on the landscape have included watershed-scale sediment budgets (Happ, 1944; Owens, 2005), measurements of terrestrial sediment flux (Hooke, 1994; Syvitski and Kettner, 2011; Wilkinson and McElroy, 2007), and the calculation of legacy sedimentation rates (Donovan, 2015; Jacobson and Coleman,1986; Knox, 1987, 2006; Lecce and Pavlowsky,2014; Magilligan,1985; Meade and Trimble,1974;Trimble and Lund,1982).

As previously mentioned, Gilbert (1917) attempted to quantify the effects of hydraulic mining on alluvial sedimentation and valley aggradation. He reported an enormous rate of post-mining valley aggradation of approximately 5.8 x 10^7 cubic meters of sediment in 27 years which equated to nearly a 1.7 ft net elevation gain of the water surface of the ship channels feeding into the San Francisco Bay.

Some of the major contributions to watershed disturbance studies stem from the legacy sediment research done in the Midwest Driftless Area occurring after the 1800's (Knox, 1972, 1977, 1987, 2006; Magilligan, 1985; Lecce and Pavlowsky, 1997; Lecce and Pavlowsky, 2001) (Table 1). Happ (1944) provided some of the first examples of post-settlement sedimentation occurring in the Midwest Driftless Area. His estimates of agricultural-induced sedimentation in the Coon Creek basin in the northern Driftless Area of Wisconsin calculated legacy rates for in channel and floodplain aggradation of over 1.52 cm/ yr. Later, Trimble and Lund (1982), reported rates of post-settlement legacy sedimentation occurring in the same area of the Coon Creek basin of Wisconsin ranging from 1.5-15 cm/ yr suggesting an increase in overall disturbance induced sedimentation.

In response to agricultural and land management practices in the eastern Appalachian Piedmont, significant accumulations of anthropogenic-derived sediment were deposited as reworked deposits on floodplains and aggraded channels (Donovan, 2015; Jacobson and Coleman, 1986; Lecce and Pavlowsky, 2014; Meade and Trimble, 1974; Walter and Merritts, 2008). Research by Jacobson and Coleman (1986) in the Loch Raven, Prettyboy, Atkisson, and Lake Roland reservoirs in the Appalachian Piedmont region of Maryland revealed historical rates of post-settlement deposition occurring before 1963 at 0.5- 20.1 thousand tonnes/km^2/yr and rates of historical deposition occurring after 1963 at 0.2-30.0 thousand tonnes/km^2/yr. Walter and Merritts (2008) investigated the effect of historical mill dam emplacement in the United States and found that approximately 1-5 m of sediment collected upstream of tens of thousands of 17th - 19th century mill dams. Estimates of post-settlement alluvium in other watersheds in the Appalachian piedmont include the Little Buffalo and Dutch Buffalo creeks in North Carolina. Short term rates of sedimentation estimated in these basins averaged 2.7 cm/yr during the most intensive gold mining period (1864-1856) and nearly tripled the long-term average rate of 0.9 cm/yr (Lecce and Pavlowsky, 2014).

The Ozark Highlands Region of the central United States has been subject to a long history of land use changes dating as far back as the late 1700's when the first waves of European settlers moved into the area (Jacobson and Primm, 1997) (Table 2). The geology of the Ozarks encouraged frequent settlements in the low-lying fertile valleys, below the higher relief, carbonate ridges overlain by a thin layer of soil (Jacobson and Primm, 1997). Valley bottoms were clear cut and developed for agricultural purposes, while forested ridges were economically lucrative timber producing areas throughout much of the late 1800's to early 1900's (Jacobson and Primm, 1997). Smaller-scale, managed, logging practices persist today on private and federal Ozark forest lands. In addition, research involving repeat aerial photography in areas of the Ozarks indicate that stream channelization practices along private-inholdings have occurred since at least 1960 and still persist today (Bradley, 2017b) (Fig. 2). Changes to subsequent stream morphology have also mimicked the transition from wide, natural channels to deeper, narrower stream channels lined by levees (Fig. 3).

More recently, the release of legacy deposits in response to post-colonial anthropogenic activities has been investigated in the Ozark Highlands of the central U.S, but mainly focus on agricultural induced land disturbance (Owen et al., 2011; Pavlowsky et al., 2017; Ray et al., 1998). Previous studies on human influence on channel morphology and sedimentation in the Ozarks have primarily focused on historical gravel waves in channel bed and bar deposits produced by land disturbance during the European settlement periods from 1850 to 1900 (Jacobson, 1995; Jacobson, 2004; Jacobson and Gran, 1997; Jacobson and Pugh, 1992; Jacobson and Primm, 1997; Jacobson and Pugh, 1997; Martin and Pavlowsky, 2011; Shepard et al., 2011).

Only a few studies have documented overbank floodplain legacy deposits along main channel segments associated with historical agricultural disturbance (Carlson, 1999; Owen et al. 2011; Pavlowsky et al., 2017; Ray, 2009; Trimble, 2001; Womble, 2009) (Table 3). Owen et al. (2011) investigated historical deposition in the James River basin of southwest Missouri and found post-settlement agricultural-induced deposition rates of 0.41cm/yr and 0.34 cm/yr following the land management era after the 1950's. Pavlowsky et al. (2017) used mining tracers to investigate rates of historical overbank deposition resulting from the agricultural period in Big River, southeast Missouri. They found rates of post-settlement deposition ranging from 1.3- 3.0 cm/yr. Fewer studies have addressed legacy sedimentation associated with urban disturbance (Rodgers, 2005; Shade, 2003). However, no studies in the Ozarks have yet addressed (1) the possibility of legacy sediment on floodplains of headwater tributaries and (2) the production of legacy deposits associated with historical logging practices.

This study investigates the effects of historical land use disturbance within the Big Barren Creek watershed in southeast Missouri on the occurrence and spatial distribution of fine-grained legacy deposits. Big Barren Creek watershed is a heavily forested headwater tributary to the Current River drainage basin. This area has undergone a long series of land use changes since the onset of European Settlement, the most notable of which began in the mid 1800's with historical exploitive logging practices (Jacobson and Primm, 1997). During this time, large expanses of pine and oak forest were cut and transported via extensive networks of constructed tram beds and logging roads. Since 1935, The U.S. Forest Service has managed over 78 % of Big Barren Creek watershed as a part of the Eleven Point Ranger District of Mark Twain National Forest. The remaining 22% of land is made up of private-inholdings with most properties located along Big Barren Creek. Local landowners eventually began channelizing the stream as early as the 1960's in some areas of Big Barren Creek to mitigate the negative effects of increasing flood frequency in the area (Bradley, 2017b). It is for this reason that this watershed provides a suitable natural laboratory to assess the impact of historical land use on watersheds characterized by heavy forest cover. Jacobson (2004) suggested the effects of logging and localized farming practices on the response of channels in heavily forested areas were associated with alterations in hydrologic characteristics, degraded water quality, and changes to sediment budget characteristics. Nevertheless, these aspects of forest and channel change in the Ozarks have not been studied in detail. To better understand these effects, it is necessary for long-term, qualitative assessments of stream response to disturbances like historical logging at the drainage-basin scale (Jacobson, 2004).

PURPOSE AND OBJECTIVES

Legacy deposits have previously been used to determine sedimentation rates in response to historical watershed disturbance (Knox, 1997, 2006; James, 1999; Reusser et al., 2015; Schuller et al., 2004). Interpreting the sedimentary record contained within floodplain legacy deposits has proven to be a useful tool in assessing and constraining the extent and degree of watershed disturbance following historical land use periods. The purpose of this study will be to investigate the possibility of legacy sedimentation occurring as in-channel aggradational fill or fine-grained deposition on floodplains of main stem and headwater tributaries in Big Barren Creek, and to determine the sedimentation rates of legacy deposits associated with historical logging and recent channelization practices.

This study will address the following three questions: 1) What is the form, distribution, and rate of deposition of fine-grained floodplains in an Ozark forest watershed? 2) Are legacy sediments deposited on floodplains due to logging, agriculture, and channelization disturbance? And 3) If legacy deposits occur, how do they affect present day geomorphic and ecologic processes? Furthermore, this study will emphasize human effects on headwater stream sedimentation and related channel response in a forested, relatively mountainous watershed in the Ozark Highlands.

BENEFITS OF RESEARCH

This study will be the first to investigate the effects of historical logging and farming activities on fine-grained legacy deposition and associated geomorphic changes in river systems in the Ozarks Highlands. Additionally, this research will help to broaden our understanding of human impacts on river systems and build on the knowledge reflecting the degree to which forest disturbance can affect channel form, stability, and floodplain function (Jacobson, 2004). Understanding geomorphic and hydraulic channel responses to disturbance can be important predictors for continued channel recovery and help in creating solutions to reduce the influence of channel instability (Letapie et al., 2014). By bettering our understanding of the cause-effect relationships on the watershed in response to disturbance, more sustainable land use practices can be implemented in the Ozark Highlands. Continuing research on both historical and current land use practices and their long-term effects on the watershed will help to create a dialogue with public and private landowners alike on the health and stability of the local streams and the important ecosystems they provide.

Table 1. Midwest and Eastern U.S. Legacy Deposition Rates

Geographic Area		Drainage Area (km^2)	Land use Legacy Deposition Rates (cm/yr)		Methods Used	Reference Cited
			Historical Period Row cropping: (post 1890-1950)	Recent Time Land Management: (post 1963)		
Midwest Driftless Area	Kickapoo Valley, WI	1,989	1.52 ^{C}	N/A	Sediment Budget techniques	Happ (1944)
	Galena River, WI, IL	340-400	1.9	0.75	organic carbon-buried soil	Magilligan (1985)
	Shullsburg Branch, WI, IL	26	1.3	0.3	Mining tracers, organic carbon- buried soil	Knox (1987)
	Coon Creek, WI	~350	1.5-5.8 ^{C}	1.6-15.0^{C}	Universal soil loss equation	Trimble and Lund (1982)
	Galena River, WI, IL	700-170,000	0.5- 2.0 ^{C}	1.8-3.4^{C}	^{14}C, ^{137}Cs, Mining tracers, soil texture, buried soil	Knox (2006)
Eastern U.S.A. Appalachian Piedmont	MD	10.6-215	17.7 (1000 tons/km^2/yr)^{D}	30.0 (1000 tons/km^2/yr)^{D}	organic carbon, soil texture, pollen analysis	Jacobson and Coleman (1986)
	NC	39-254	2.7	0.9	Mining tracers	Lecce and Pavlowsky (2014)
	AL, SC, GA	3,600	0.73	0.10	Sediment load modeling	Meade and Trimble (1974)

^{A} *Deposition rate not delineated by disturbance era*

^{B} *Maximum/ minimum rate reported*

^{C} *Average rate varied by watershed size*

^{D} *Erosion rate reported in place of deposition rate*

Table 2. Ozark. Legacy Deposition Rates

Geographic Area	*Drainage Area (km^2)*	*Land use Legacy Deposition Rates*		*Methods Used*	*Reference Cited*
		Row-cropping (1850-1950)	*Land Management (1950)*		
James River, SW MO	637	0.41 cm/yr	0.34 cm/yr	Mining tracers, organic carbon, ^{137Cs}	Owen et al. (2011)
Big River, SE MO	626-2500	1.3-3.0 cm/yr^A	1.3-3.0 cm/yr^A	Mining tracers	Pavlowsky et al. (2017)
Honey Creek, SW MO	174.35	0.82 cm/yr^C	0.60 cm/yr^C	Mining tracers	Carlson (1999)
Chat Creek, SW MO	32	929 Mg/yr^D	929 Mg/yr^D	Sediment budget techniques	Trimble (2001)

^{A} *Deposition rate not delineated by disturbance era*
^{B} *Maximum/ minimum rate reported*
^{C} *Average rate varied by watershed size*
^{D} *Floodplain Erosion Rate*

Table 3. A timeline of the history of land use practices in the Missouri Ozarks.

Time Period	Historical Land use Events and Practices
Early 1800's	European Settlement
1850	Large-scale land clearing and agricultural practices
1870	Introduction of railroads
1879	Missouri Lumber and Mining company opens (Carter, Co, MO)
1880's-1920's	Timber Boom Period
1880-1930	Open-range grazing
1930-1963	Modern row-crop cultivation
1939	Creation of the Missouri National Forest System
1950	Implementation of "cyclic' timber harvesting
Mid 1960's	Stream channelization on private-in holdings
1976	Induction of Mark Twain National Forest
2000	Implementation of prescribed fire management

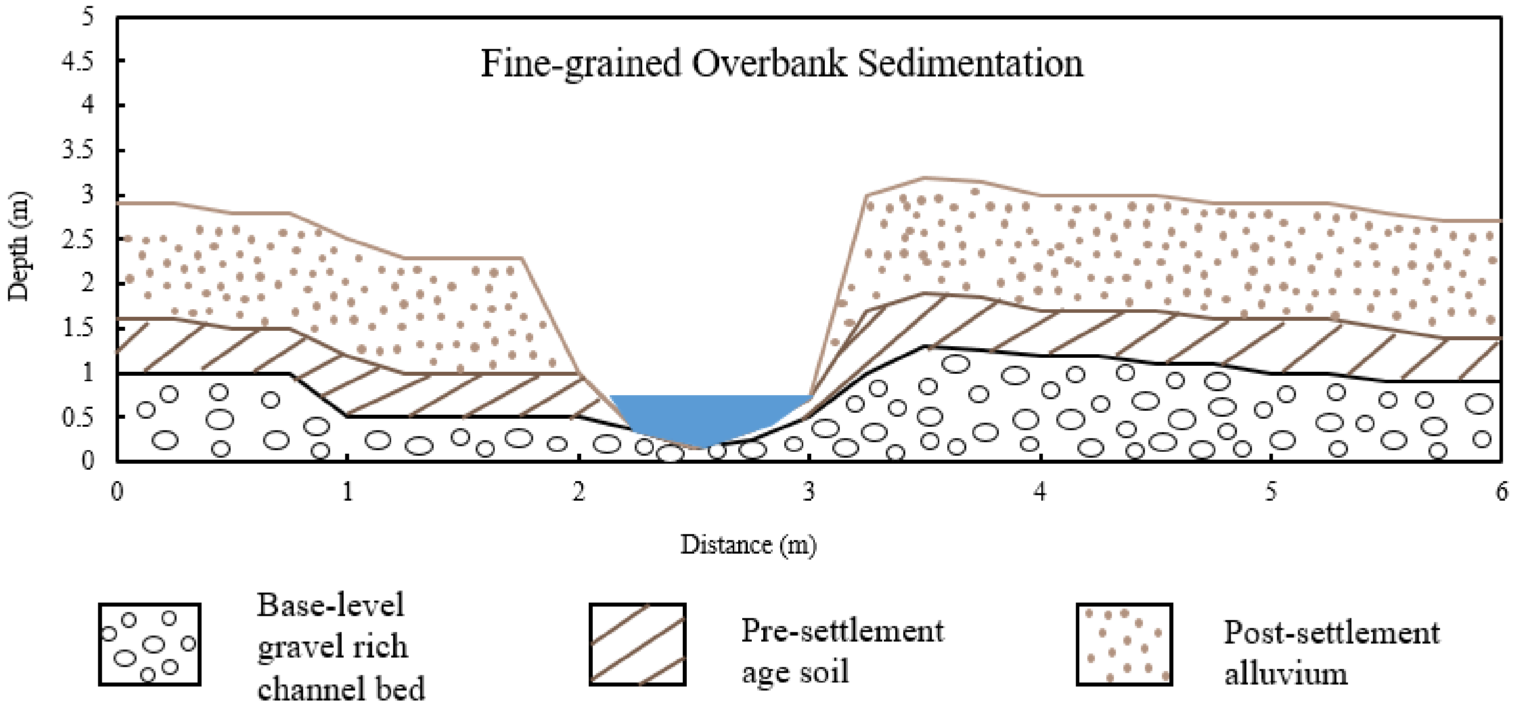


Figure 1. A conceptual diagram depicting fine-grained overbank sedimentation.

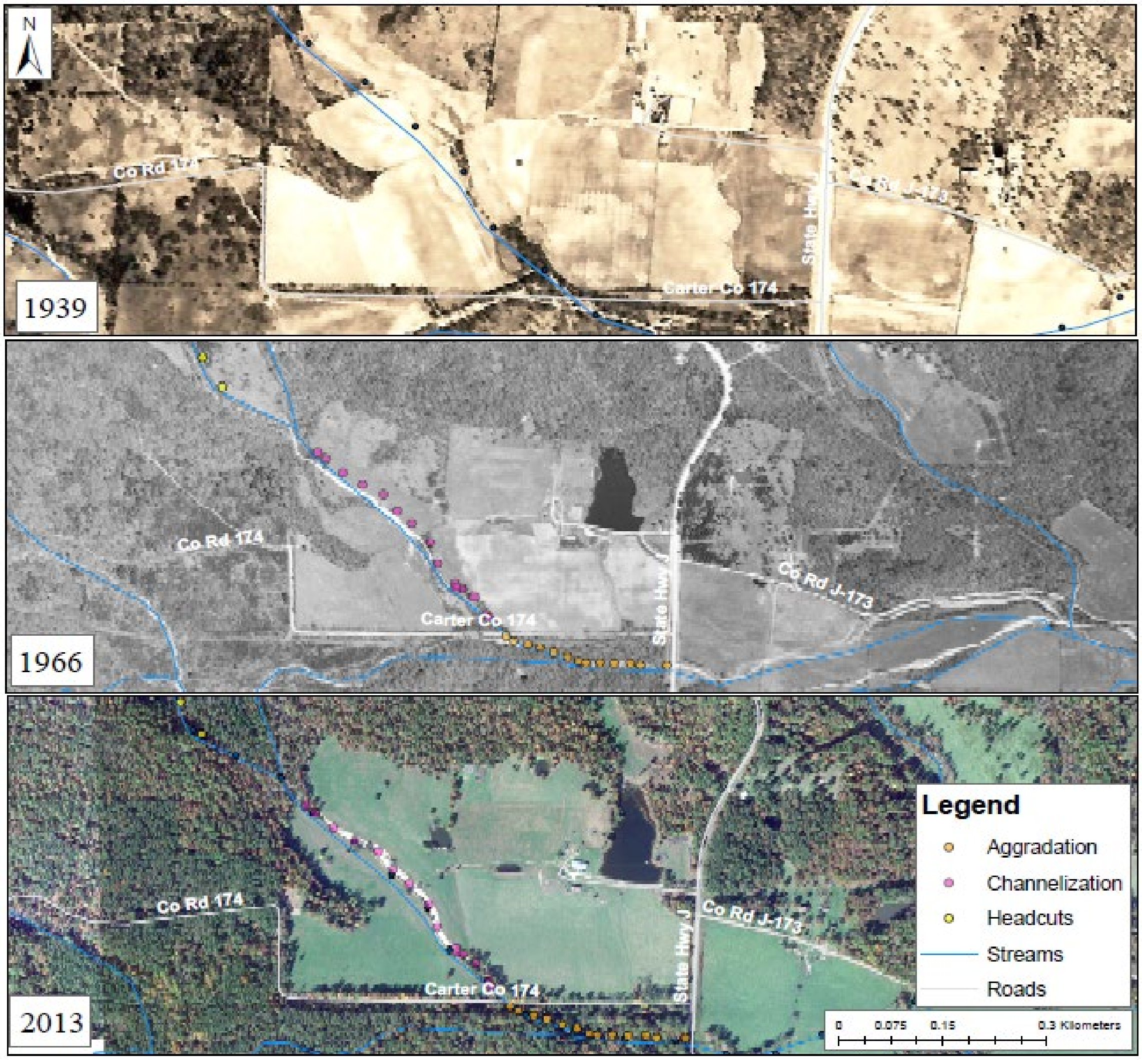
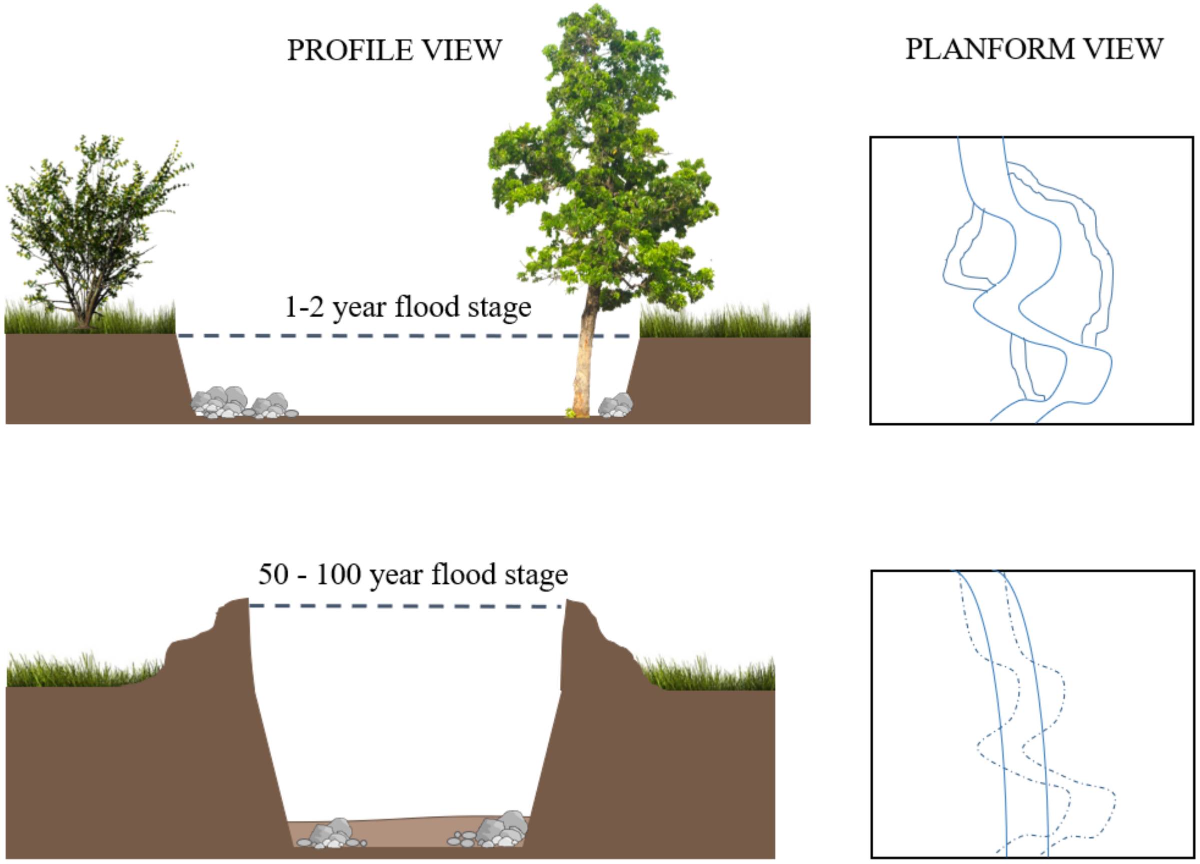


Figure 2. Channel history of Big Barren Creek. Comparison of 1939, 1966, and 2013 aerial photographs of the upper Big Barren Creek stream segment. No disturbance to the stream is detected in the 1939 photograph, but channelization is indicated as early as 1966 where there is a prominent gravel reflectance. The 2013 aerial photo shows a continuation of channelized stream disturbance.

DESCRIPTION

PROFILE VIEW

PLANFORM VIEW



Natural Stream:
Low banks, shallow, wide channel with flow obstructions and vegetation, high level of connectivity to floodplain, multi-threaded channel.

Channelized Stream:
High banks, often accompanied by levees, narrow, deep channel, low level of connectivity to floodplain, deep single-thread.

Figure 3. Conceptual models of natural and channelized stream morphologies in BBC

STUDY AREA

Regional Location and Physiography

Big Barren Creek drainage basin is 40 km in length and drains 191km^2 of the Ozark Highlands in SE Missouri. It covers parts of Carter (80%), Oregon (3.5%), and Ripley (15.5%) Counties and is within the Eleven Point Ranger District of Mark Twain National Forest (Fig. 4). Big Barren Creek is located within the Salem Plateau, a region dominated by vast rolling uplands and large resistant carbonate ridges (Panfil and Jacobson, 2001). The Salem Plateau is the central most province of the sub-divided Ozark Highlands lying north of the Boston Mountains, east of the St. Francois mountains, and west of the Springfield Plateau (Panfil and Jacobson, 2001).

Geology and Soils

The Big Barren Creek drainage basin is underlain by the Gasconade Dolomite, Jefferson City Dolomite, and Roubidoux formations as shown in (Fig. 5). The Jefferson City Dolomite is the uppermost formation capping the regional geologic sequence and is comprised of dolomitic carbonate rocks interbedded by sandstone and chert (Panfil and Jacobson, 2001). Underlying the Jefferson City Dolomite is the Roubidoux formation. This formation is characterized by its ridge forming resistant sandstone units interbedded by lesser units of dolomite and chert (Panfil and Jacobson, 2001; Thies, 2017). Beneath the Roubidoux formation lies the Gasconade Dolomite. The Gasconade is the lowest carbonate unit in the Ozark Upland geologic sequence and is known for its extensive karst development throughout the region (Panfil and Jacobson, 2001). Big Barren Creek lies within the Wilderness-Handy Fault Zone, an assemblage of northeastsouthwest trending faults which control the formation of steep bedrock bluffs in the lower and middle parts of the watershed (Weary et al., 2015). Where jointed and fractured limestone and dolomite are exposed at the surface, rill development and headward channel migration facilitate the initiation of stream channels. Chert rich limestone and dolomite within the Ozark Highlands may have helped the initiation of stream channels and directly influenced drainage patterns and densities within these watersheds (Splinter et al., 2011).

In 1973, the U.S. Forest Service completed a detailed 1:253,440 scale soil map of Mark Twain National Forest that included parts of Carter, Oregon, and Ripley counties which included detailed representations of the soils specific to Big Barren Creek. Big Barren Creek (BBC) drains four main soil associations (Table 4, Fig. 6). Over 55% of the watershed is covered by the Captina-Clarksville-Macedonia association (Fig. 7). The soils in this association are gently-sloping to moderately-steep soils, some of which have a fragipan, and others gently-sloping to very steep soils that are cherty throughout (Gott, 1975). The Clarksville-Poynor-Doniphan association covers over 25% of the lower portion of Big Barren Creek watershed and is characterized by gently sloping to very steep soils that have a cherty surface layer and a cherty/ clayey subsoil (Fig. 8) (Gott, 1975). Approximately 16.8% of the soils belong to the Clarksville-Coulstone association which can be described as gently sloping to very steep soils that are cherty throughout. These soils are commonly found in the northern most extents of the watershed (Gott, 1975). The remaining 2.6% of soils in Big Barren Creek belong to the Poynor-Macedonia-Captina association and are isolated to a small area in the lower central locations of the watershed near the Carter and Ripley county border. These soils are typically gently sloping to very steep soils that have a cherty surface layer and a clayey subsoil, and gently-sloping to moderately steep soils, some of which have a fragipan (Gott, 1975).

The main soil types found within the Salem Plateau were formed by the intense weathering of carbonate and chert-rich bedrock units and are classified as varying alfisol and ultisol units (USDA, NRCS 2006). Most soils in Big Barren Creek are upland ultisols which cover over 86% of the watershed. These soils are mature silty soils with a thin- A-horizon and shallow depth to bedrock on most hillslope and flat upland areas. Alfisols are the second most dominant soil type at 10% of the total soil cover and occur in stream valleys and forested headwater tributaries (Table 5, Fig. 8). Floodplain soils are characterized by mostly alfisols with smaller amounts of entisols nearest to streams. These two soil orders describe most of the alluvial soils series in BBC.

There are 20 different soil series in Big Barren Creek with seven of those described as fine-grained alluvial soil series (Table 6, Fig. 9). The alluvial soil units include floodplain units such as the Secesh, Sandbur-Wideman-Relfe, Tilk-Secesh, Relfe-Sandbur, and the Midco, and terrace units such as the Bearthicket and Higdon (Table 7). The majority of the watershed's mapped alluvial soil acreage is characterized by the Tilk-Secesh Complex at over 29.8% of the total alluvial soil series and is typical of Big Barren Creek's tributary regions that feed into the main stem. This unit is occasionally flooded (ponded > 5 to 50 times in 100 years) and the E horizon indicates leaching of the upper soils and formation of more mature horizons beneath it including the Bt horizon. The presence of the Bt horizon in this series indicates it has been developing for roughly a few thousand years. Approximately 24.4% of the watershed is described by the Secesh silt loam and can be found as rarely flooded floodplain and terrace units surrounding the Tilk-Secesh and Midco floodplain units. This series has a high level of solum differentiation with an A/BE/B horizon profile containing 5 different Bt horizons underneath it's BE horizon. The Midco is a gravel rich occasionally flooded floodplain unit that covers approximately 13.9% of the watershed. This unit is under differentiated with an A/C1/C2/C3 profile with an extremely thin solum layer under 10 inches. The Bearthicket silt loam covers approximately 17.5% of the watershed and can be found on terrace units in along the mainstem and headwater tributary regions. This unit is rarely flooded and highly differentiated with an A/B horizon profile containing 5 different Bt horizons. The Relfe-Sandbur is a frequently flooded, excessively drained floodplain unit typically comprised of sand and gravelly alluvium. Due to its landscape position it is highly under differentiated with a Ap/C1/C2/C3/C2/C5 profile. Lesser units such as the Sandbur-Wideman-Relfe and Higdon contribute to the total alluvial soil series cover at 0.7% and 0.6% respectively. Examples of typical alluvial chrono-sequences for the above units are given for upper and lower Big Barren Creek in (Fig. 10).

Most alluvial soil units classified as frequently flooded can be found in the tributary regions of Big Barren Creek and are classified as varying silt and sand units (Fig. 11). The majority of occasionally flooded alluvial units are characterized by gravel rich units predominately surrounding the main stem regions of Big Barren Creek with some found in the tributary regions in the lower portion of the watershed. Lastly, the alluvial soils classified as rarely flooded were primarily characterized by silt rich units which often surround the floodplain units along the main stem of Big Barren Creek. According to USDA soil series descriptions, no buried soils were associated with any of the alluvial soil series common in Big Barren Creek.

Climate and Hydrology

Big Barren Creek is subject to a temperate continental climate characterized by eastward traveling storm systems and northward moving moist air masses off the Gulf of Mexico (Panfil and Jacobson, 2001). Seasonal weather patterns often include powerful thunderstorms and intense rain events that account for much of the area's annual rainfall totals (Panfil and Jacobson, 2001; Pavlowsky et al., 2016). Southeastern Missouri experiences a mean annual precipitation of approximately 112 cm/ yr and has an average annual temperature of approximately 14.4°C (Adamski et al., 1995; Pavlowsky et al., 2016). In a recent study done by Pavlowsky et al. (2016), it was reported that flood frequency and intensity and frequency of storms in Big Barren Creek have increased dramatically in the last 30 years when comparing rainfall records from the two most recent 30-year rainfall records from six nearby weather stations. More specifically, the number of days of intense rainfall with greater than 3 in of rainfall per day has increased. Seasonal analysis of the 60-year rainfall period indicates that higher magnitude rain events tend to occur in the months of spring and fall. However, the frequency of high magnitude rainfall events has been increasing for the spring, winter, and summer months over the last ten years. Overall, rainfall records show a general increase in annual rainfall totals over the last decade suggesting a historical wet period. This research suggests climate shift-induced increases in frequency and intensity of rainfall events over the past decade may be causing more overbank flooding events, channel instability, and excess gravel aggradation in streams in Big Barren Creek (Pavlowsky et al., 2016). Recently in 2017, the National Weather Service reported that the Current River in Van Buren, experienced the largest flood event in 100 years, cresting at over 37.2 ft high, a full 8 ft higher than the record stage of 29 ft set in 1904.

Most of the Ozark Highlands contains expansive karst aquifer systems within the thick sequences of Paleozoic carbonates covering the region (Jacobson, 2004). The region's karst dominated lithology creates a unique hydrologic setting characterized by abundant ephemeral or under-drained stream networks (Panfil and Jacobson, 2001). Much of the water received by precipitation in the Ozark Uplands infiltrates into the subsurface karst system and travels via conduits to reemerge as springs in valley bottoms (Jacobson, 2004).

Settlement and Land Use History

Pre-settlement Vegetation. Prior to European Settlement, approximately 70 percent of the state of Missouri was covered by vast expanses of forested land with over 6.6 million acres of forest belonging to regions of the Missouri Ozarks (Cunningham, 2006; Liming, 1946). The most noteworthy of these areas was known as the Courtois Hills, an extensive area of rugged, pine-covered hills in the southeastern Ozarks covering Big Barren Creek watershed in parts of Carter, Oregon, Ripley, Shannon, Reynolds, Crawford, Dent, Iron, Wayne, Butler, and Madison Counties (Cunningham, 2006). Pine lands were fairly open, containing little to no underbrush except for the occasional plot of native bluestem grass *(Schizachyrium scoparium)* or oak sapling (Martine and Presley, 1958). Pine volumes averaged 4,000 board feet per acre, while particularly well-established stands contained up to 25,000 board feet per acre (Hill, 1949; Cunningham, 2006).

Fire History. Before the onset of early European settlement in the Ozarks, Native American peoples had been routinely setting fires to the land to maintain open grassland ranges and reduce fuel loads (Jacobson and Primm, 1997; Stambaugh and Guyette, 2006). After European settlers migrated to the Ozarks, they began implementing fire suppression techniques to combat the detrimental effects of destructive wild fires on their fields, pastures, and crops (Jacobson and Primm, 1997). In addition, timber production in Ozark counties was starting to boom and wildfires threatened the fast-growing industry. Controlled burns were reintroduced as a forest management technique after the decline in timber production in the 1920’s left much of the economically viable timber stores depleted and much of the land unfit for agriculture and grazing (Jacobson and Primm, 1997). Fire records show that forest fires occurred at a mean interval of approximately 17.7 years in the pre-population period, 12.4 years in the Native American population period, and 3.7 years in the early European Settlement period up through the early 20th century until cultural values changed again to favor fire suppression (Guyette and Larsen, 2000; Stambaugh and Guyette, 2006). Historical accounts recorded by Jacobson and Primm (1997) reveal overall increases in the amounts of erosion and frequencies of larger floods that occurred in burn years in comparison to non-burn years. Since 2000, the U.S. Forest Service began implementing prescribed burning of Mark Twain National Forest burning over 30,000 acres of forest per year for ecological restoration and hazardous fuel load reduction.

Clearcutting and Agriculture. The Ozark Mountains have a long history of land use changes dating as far back as the late 1700's when the first waves of European settlers moved into the area (Jacobson and Primm, 1997). The geology of the Ozarks encouraged frequent settlements in the low-lying fertile valleys, below the topographically high, rugged, carbonate ridges (Jacobson and Primm, 1997). Valley bottoms were clear-cut and developed for agricultural purposes, while forested ridges and slopes were economically lucrative timber-producing areas during the late 1800's to early 1900's when increasing populations started implementing large-scale agrarian practices, grazing, and clear-cutting operations (Jacobson and Primm, 1997). Populations in Ripley and Oregon counties didn't start to grow until around the 1880's when populations grew to around 5,000 people (Cunningham, 2006). Populations in Carter county were slower to take off and reflect the success of the timber industry in the area. Populations in Carter county grew to around 5,000 people in 1890 (Cunningham, 2006).

Timber Harvesting. Timber production in the Ozarks began following the introduction of rail car transportation in the 1870's and peaked from the 1880's until approximately 1920 Table 8 (Jacobson and Primm, 1997). Timber production began to take off significantly in 1879 following the Missouri Lumber and Mining Company's decision to open its first large sawmill operation in the city of Grandin in Carter County, Missouri (Cunningham, 2006). After the Railroad had finished constructing lines into Grandin, this mill was the primary timber producer in the region (Cunningham, 2006). The Missouri Labor Bureau reported that in 1904, over 60 million board feet of lumber was harvested from Reynolds County alone just north of Big Barren Creek watershed (Guyette and Larsen, 2000). Reynolds County was just one of the three primary timber production counties in the Ozarks including both Carter and Shannon counties (Guyette and Larsen, 2000). The Ozarks was responsible for over 71 percent of the state of Missouri's round wood tree production (Jacobson, 2004). During the height of the Timber Boom in 1899, Carter County MO was clear-cutting over 70 acres of forest a day at maximum capacity (Jacobson and Primm, 1997).

By the early 1900's timber production in Carter County began to slow down and eventually in 1909 the Grandin Mill closed and moved to West Eminence in Shannon County Missouri (Cunningham, 2006). By the 1920's, most of the marketable shortleaf pine in the Ozarks had been exhausted (Jacobson and Primm, 1997). At the end of the Grandin-based sawmill's final year of operation in 1909, it had cut over 213,017 acres of forest land (Galloway, 1961; Cunningham, 2006). Throughout the main logging period, loggers constructed extensive networks of tram lines that were needed to transport logs and materials to and from cutting sites. These tram bed features persist to this day and can be found throughout the headwater regions of Big Barren Creek. Work done by Bradley (2017a) reported that the extensive tram construction occurring during the logging period still influences the channel morphology and stability of tributaries in Big Barren Creek today.

Forest Management. The U.S. Forest Service controls approximately 78% of the Big Barren Creek watershed. Management of this land by the Forest Service followed the 1935 purchase of over 3.3 million acres of land designated as the Mark Twain National Forest in Missouri. In the 1950's forest managers began implementing cyclic timber harvesting. This practice was a much less intense form of logging, a process where many trees and branches were left to serve as ground cover to reduce the effects of raindrop impact, runoff, and erosion. Since 2000, the Forest Service, as a part of the Missouri Pine-Oak Woodlands Restoration Project, has been using prescribed fire management in combination with tree planting to help restore the shortleaf pine population that was heavily depleted during the timber boom period in the 1880's to early 1920's ("U.S. Forest Service"). Prescribed fire was deemed an effective tool to reduce understory fuel loads. The majority of Big Barren Creek watershed is comprised of deciduous forest with evergreen forested areas throughout. Small areas of private cultivated land make up the valley floor (Fig. 12). In Big Barren Creek watershed, approximately 40% of the private forest land is owned by both full-time or part time farmers (Raeker et al., 2011).

Stream Channelization. Stream modification in the form of channelization has been a method implemented by engineers and private land owners alike to reduce flood magnitude and frequency and control destructive bank erosion (Simon and Rinaldi, 2006). Analysis of repeat aerial photography in the Ozarks has indicated channelization of the stream occurring as early as the 1960's on private land (Bradely, 2017) (Fig. 4). This practice often involves the straightening of the channel and the removal of material from the stream bed by dredging (Fig. 2). This regularly results in direct increases in both channel capacity and stream gradient, and indirect increases in bed load capacity and discharge (Simon and Rinaldi, 2006). Disturbance within channelized reaches in the form of bank destabilization will often times be accompanied by waves of disturbance felt upstream and downstream. Upstream areas may experience zones of accelerated degradation and aggressive head-cutting (Simon and Thomas, 2002), while downstream reaches may experience zones of accelerated aggradation (Simon and Rinaldi, 2006). Natural stream systems are characterized by in-stream vegetation and flow obstructions and have low banks with a high level of connectivity between the stream and its adjacent floodplains allowing for the effective dissipation of flow velocity (Theis, 2017). Channelized stream reaches have characteristically deep, smooth channel beds, with steep banks that prevent connectivity between the stream and adjacent floodplains effectively concentrating flow (Wohl, 2014).

Table 4. Large-scale soil associations in Big Barren Creek Watershed.

Soil Association	Acres	Percent of Alluvial Soils
Captina-Clarksville-Macedonia	26,011	55.2
Clarskville-Poynor-Doniphan	11,907	25.3
Clarksville-Coulstone	7,882	16.7
Poynor-Macedonia-Captina	1,314	2.8
Total	47,114	100.0

Table 5. Soil orders in Big Barren Creek Watershed.

Soil Order	Acres	Percent of Alluvial Soils
Ultisol	40,491	85.9
Alfisol	4,875	10.3
Entisol	1,564	3.3
Mollisol	57	0.1
Total	47,114	100.0

Table 6. Physical soil description and classification chart of alluvial soils along Big Barren Creek.

Series name	Soil Order	Taxonomic classification	Landform position	Horizon Order/ Suborder	Flood Frequency	Solum Thickness (in)
Bearthicket	Alfisol	Fine-silty, mixed, active, mesic, Ultic Hapludalfs	floodplain, low terrace	Ap/Bt1/Bt2/Bt3/Bt4/Bt5	rarely flooded	40-80+
Secesh	Alfisol	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs	floodplain, terrace	Ap/Be/Btl/Bt2/2Bt3/2Bt4/2Bt5	rarely flooded	21-80
Higdon silt loam	Alfisol	Fine-silty, mixed, active, mesic Aquic Hapludalfs	terraces, foot slopes	A/E/Bt1/Bt2/2Bt3/2Bt4/2Bt5/2Bt6/2Bt7	occasionally flooded	0-91
Tilk-Secesh complex	Alfisol	Loamy-skeletal, siliceous, active, mesic Ultic Hapludalfs	Floodplain, Alluvial fan, low terrace	A1/A2/E/Bt1/Bt2/2BC/2C	occasionally flooded	36-70
Midco	Entisol	Loamy-skeletal, siliceous, super active, nonacid, mesic, Typic Udifluvents	floodplain	A/C1/C2/C3	occasionally flooded	1-10
Sandbur-Wideman-Relfe Complex	Entisol	Coarse loamy, siliceous, superactive, nonacid, mesic Mollic Udifluvents	floodplain	Ap/C1/C2/C3/C4/C5/C6	frequently flooded	10
Relfe sandbur complex	Entisol	Sandy, skeletal, siliceous, mesic Mollic Udifluvents	floodplain	Ap/C1/C2/C3/C4/C5	frequently flooded	0-6

Table 7. Alluvial Soil Series in Big Barren Creek Watershed.

Alluvial Soil Series	Acres	Percent of Alluvial Soils
Secesh	663	24.4
Bearthicket	477	17.5
Sandbur-Wideman-Relfe	20	0.7
Tilk-Secesh	812	29.8
Relfe-Sandbur	356	13.1
Midco	379	13.9
Higdon	15	0.6
Total	2,722	100.0

Table 8. Land use History of Big Barren Creek Watershed

Event	Time Period
European Settlement	1850
The Railroad begins building rail lines into Grandin	1887
Missouri Lumber and Mining Company opens in Grandin, Carter CO	1879
Height of Timber Boom Period in Carter CO	1899
MLMC Grandin Mill closes and moves to Shannon CO	1909
U.S. Forest Service purchases 3.3 million acres designated as Mark Twain National Forest	1935
U.S. Forest Service implements "Cyclic Timber Harvesting" management practices in Big Barren Creek	1950
Land owners begin channelizing the stream on private property	1960's
U.S. Forest Service Begins Implementing prescribed fire management techniques	2000

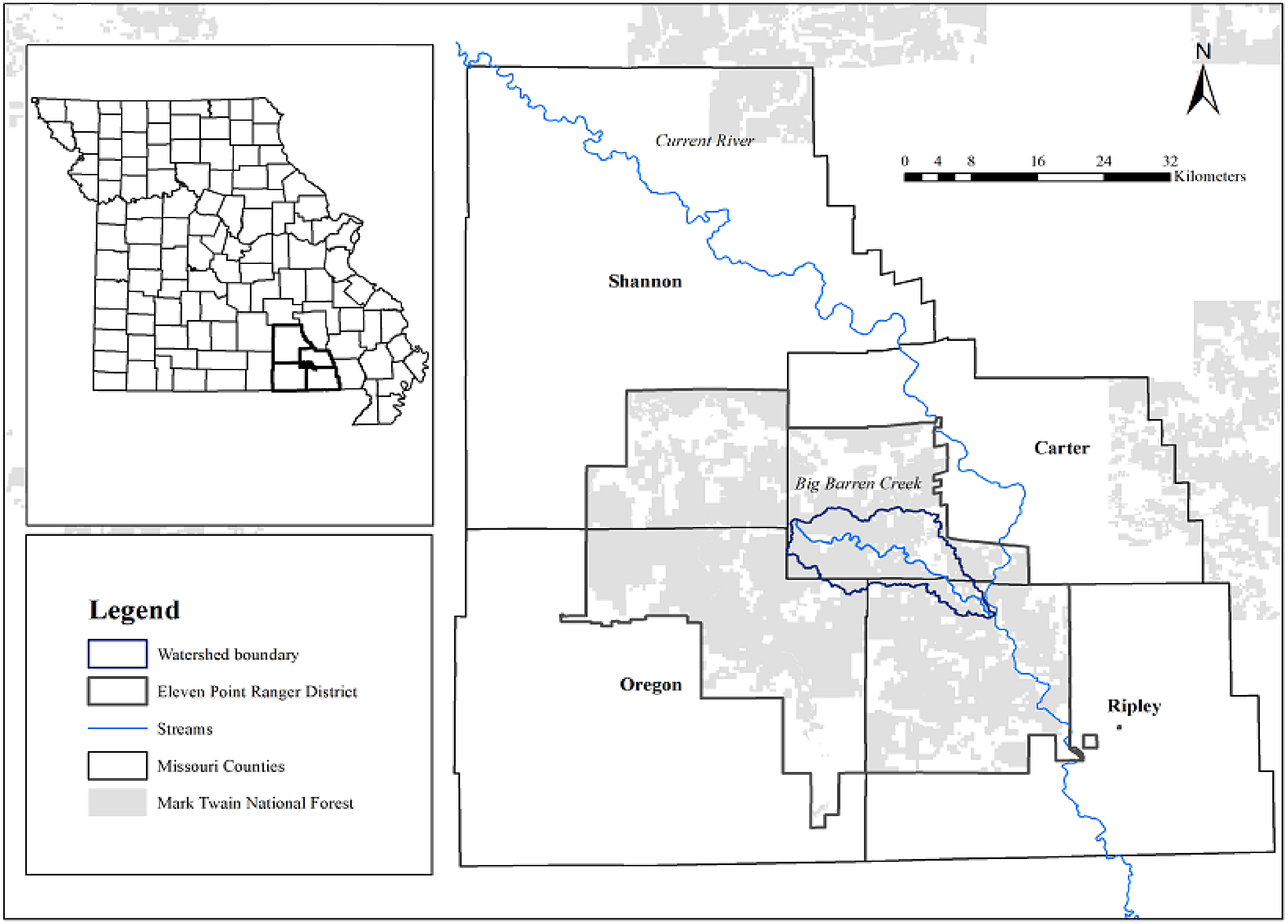


Figure 4. General study area map showing the location of Big Barren Creek watershed within Carter, Oregon, and Ripley Counties.

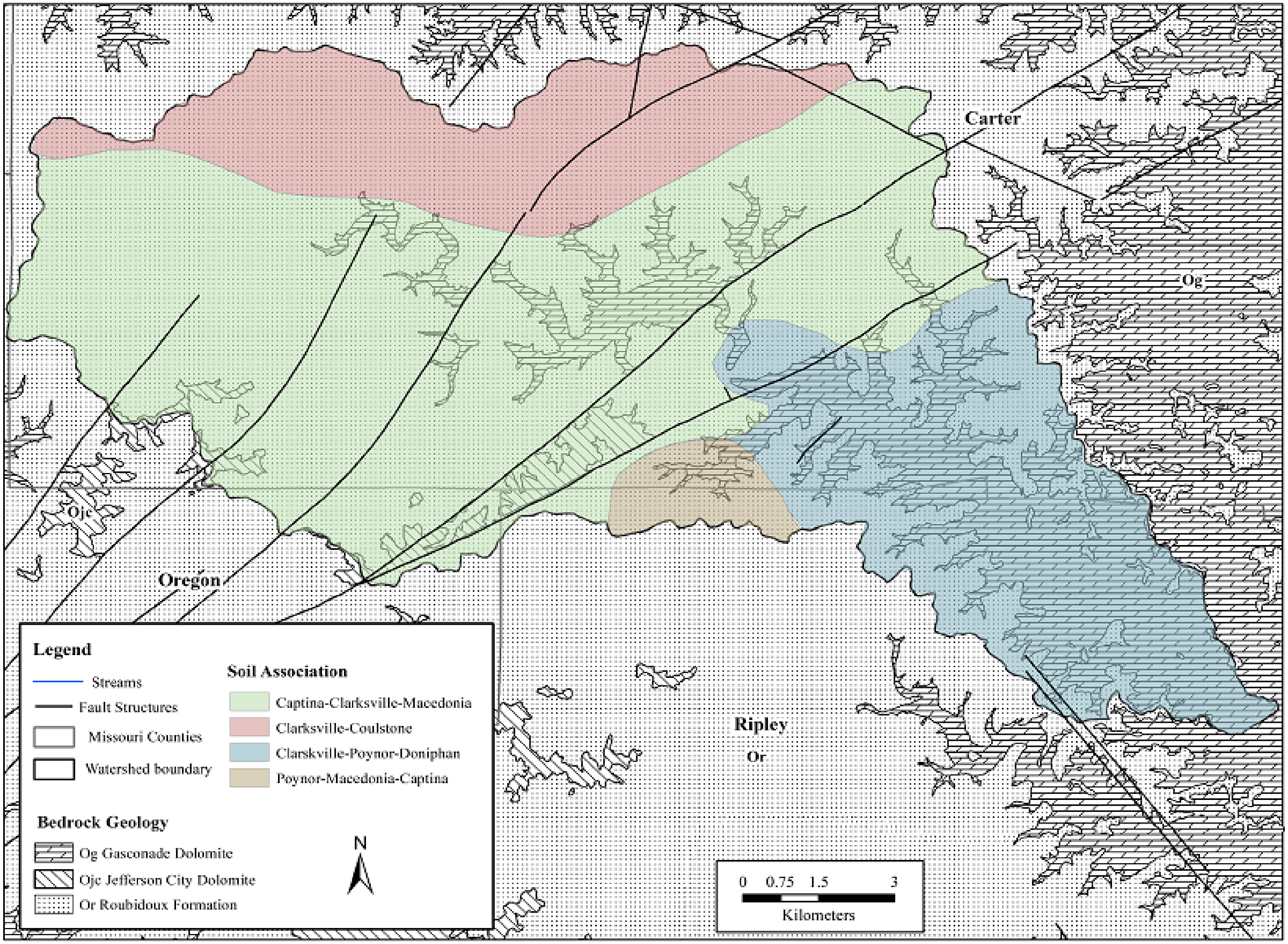


Figure 5. Large-scale soil association and geology map of Big Barren Creek Watershed.

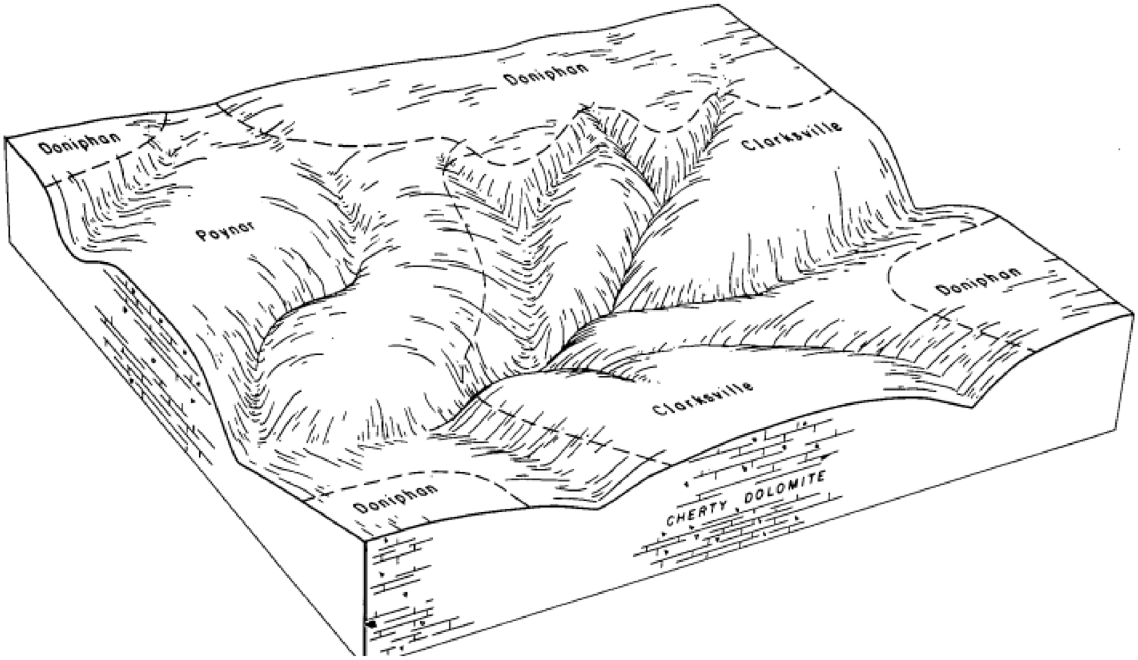


Figure 6. Soils patterns and landforms and subsurface material in the Clarksville-Poynor-Doniphan association (Gott, 1975).

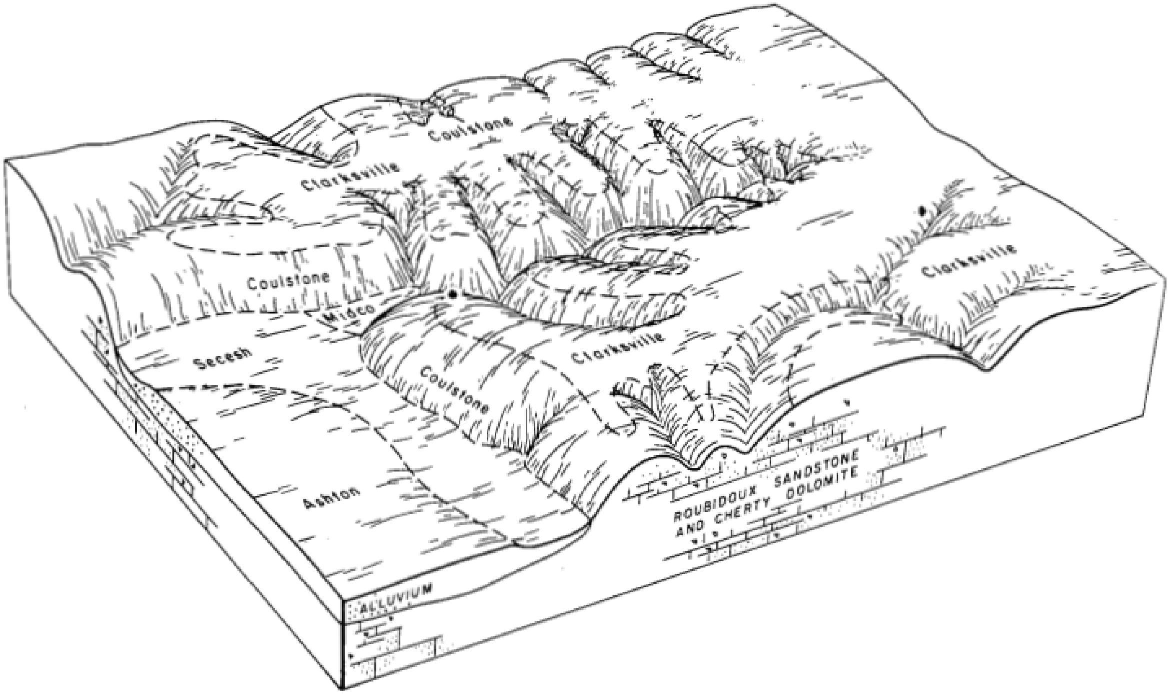


Figure 7. Soils patterns and landforms and subsurface material in the Clarksville-Coulstone association (Gott, 1975).

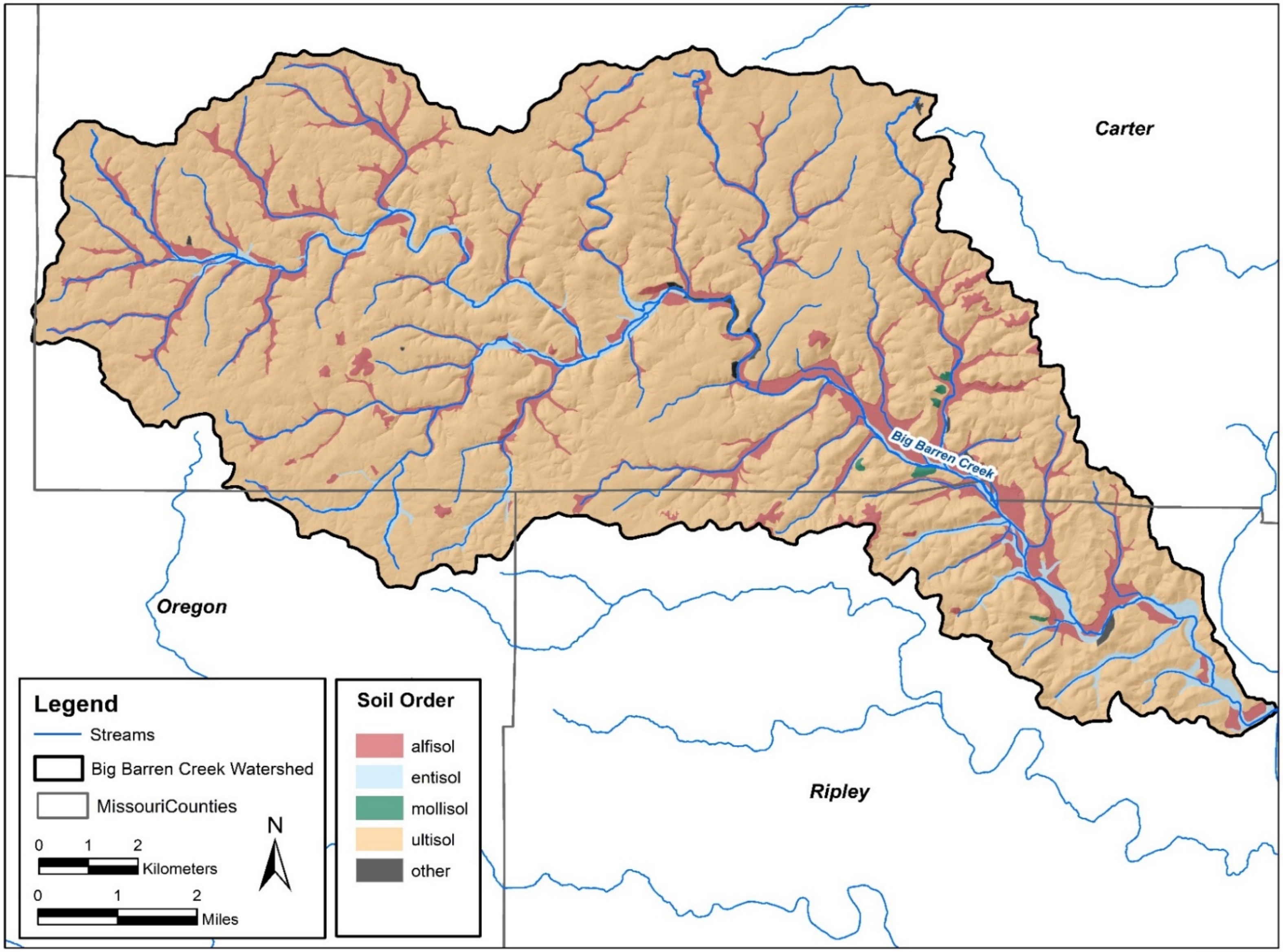


Figure 8. Big Barren Creek soil order map.

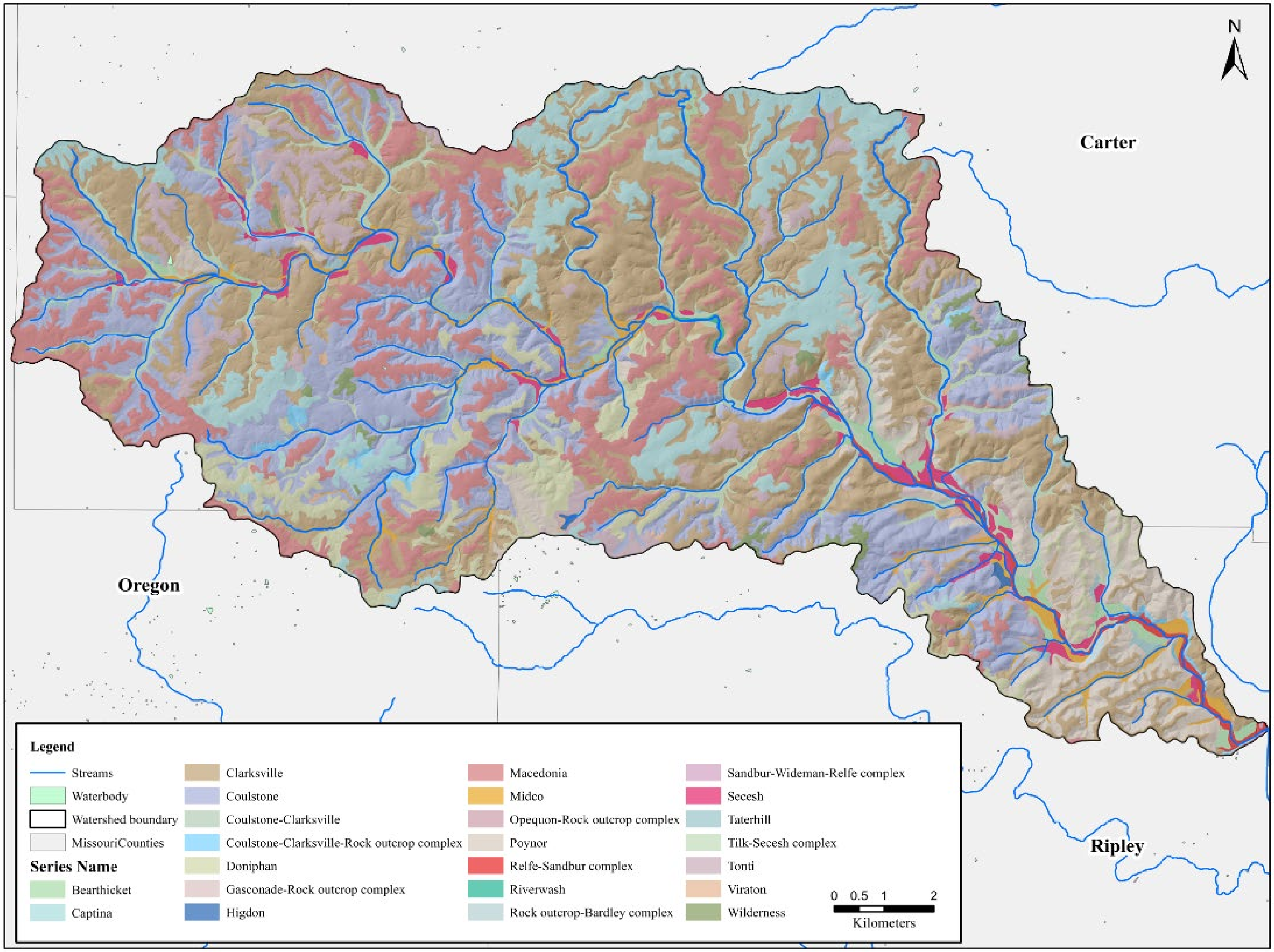


Figure 9. Big Barren Creek soil series map.

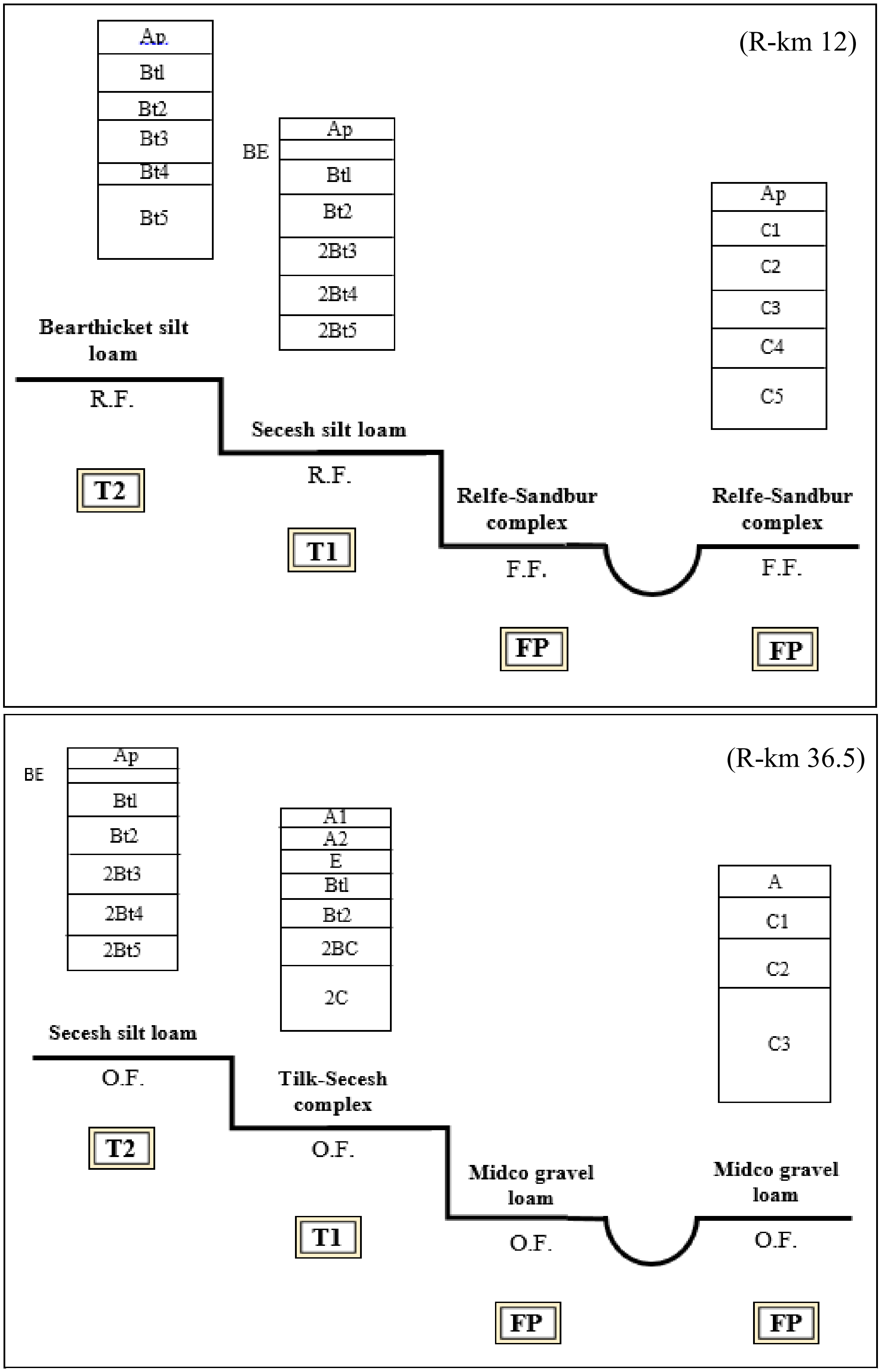


Figure 10. Soil-landform relationships of alluvial soils in Big Barren Creek Main stem (R-km 12 and 36.5). Boxes abbreviations indicate landform position, and T2 is high terrace. The abbreviations F.F, R.F., and O.F., stand for frequently flooded, rarely flooded, and occasionally flooded respectively.

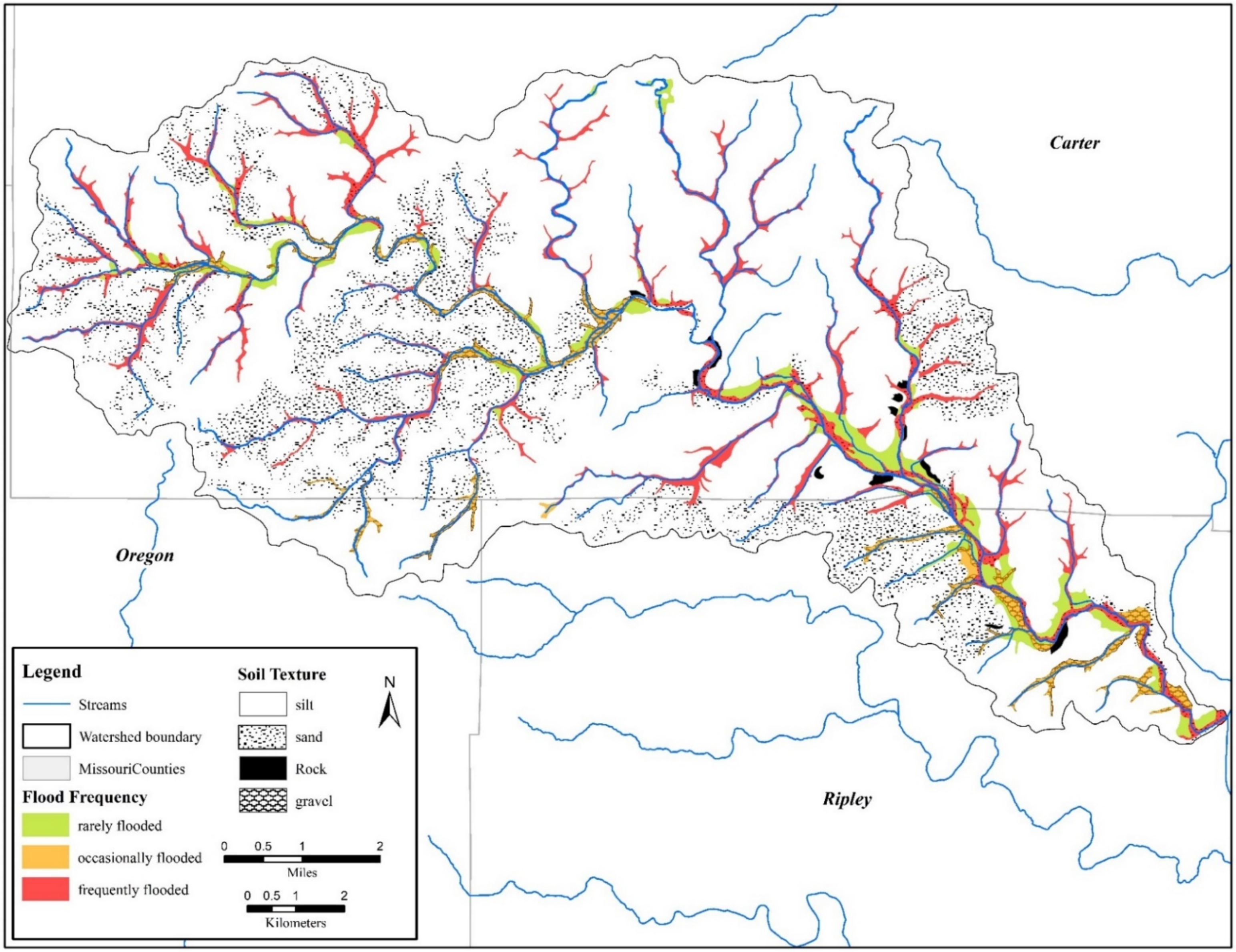


Figure 11. Alluvial flood frequency and soil texture map of Big Barren Creek.

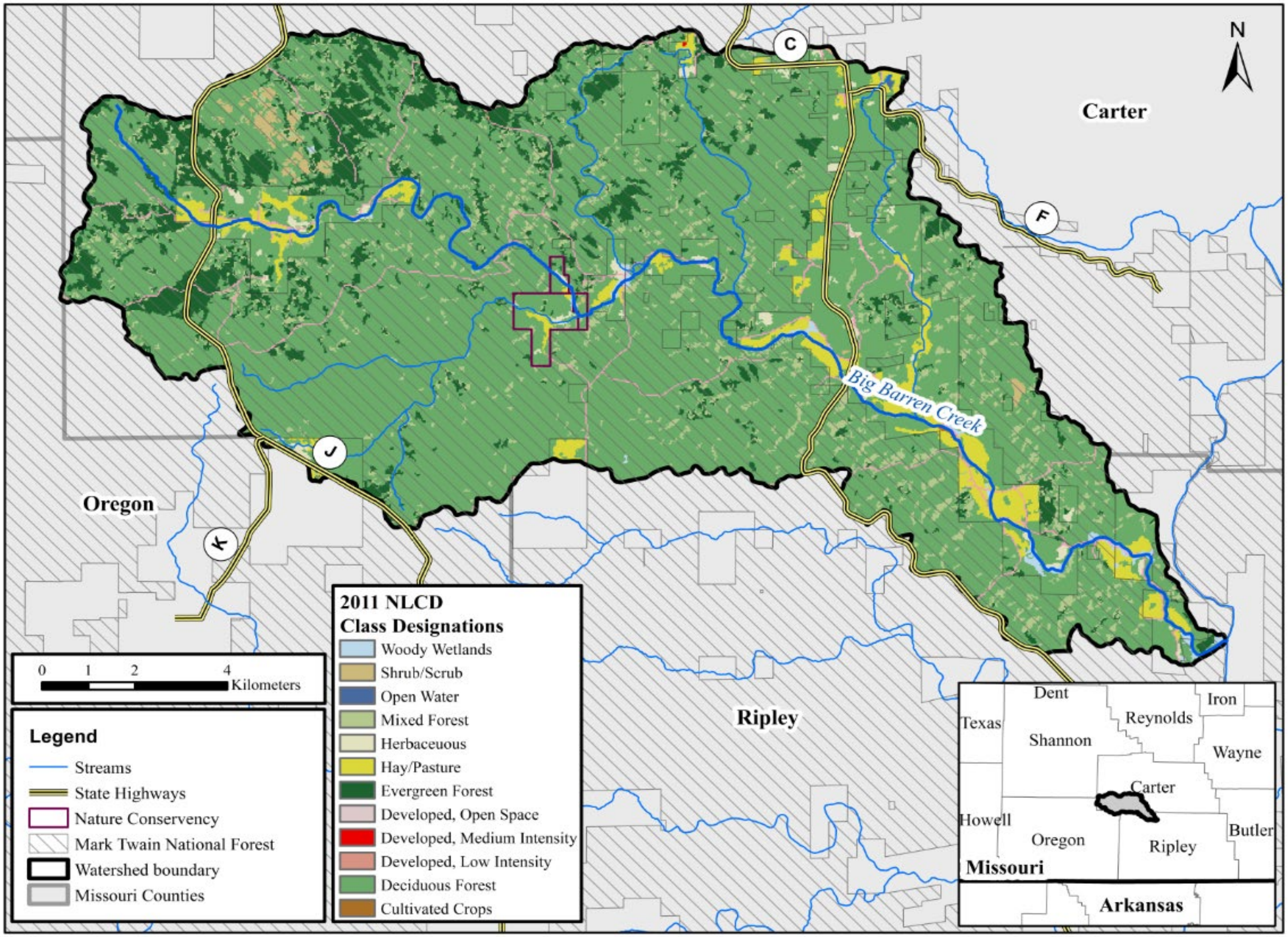


Figure 12. Big Barren Creek land use map.

METHODS

A combination of field, laboratory, and geographical information system (GIS) techniques were used to complete this study. The goal of this chapter is to describe the methods used to accomplish the following research tasks: (1) determine the distribution of fine-grained channel and floodplain forest deposits, (2) determine the spatial distribution of alluvial soils, (3) complete subsurface analysis through soil coring and mapping, (3) use stratigraphic boundaries such as buried soils (Ab horizon), buried trees, and C3137 to date deposits. These tasks are used to assess the extent of disturbance in Big Barren Creek watershed in response to historical disturbance.

Site Selection

The goal of sampling was to assess channel and floodplain form and deposits in the headwaters, upper, middle, and lower segments of BBC to evaluate their cross-valley distribution, downstream variation, and ages, to identify post-settlement logging legacy deposits. These deposits were identified as reworked sand and silt sediments on top of floodplains, benches, and terrace surfaces, often medium to dark brown in color and without structure or texture. Sample sites were located along the 40 km stretch of Big Barren Creek and were selected based the range of landform types, presence of fine-grained soils series derived from WSDA web soil survey data, flood frequency maps, and ease of access to the stream. Most sites were located along public land areas including The Nature Conservancy property, designated natural areas, and U.S. Forest Service owned extents of Mark Twain National Forest. Where sites were located along privately-owned segments were granted permission for access and consent for soil collection was obtained from local land owners.

Field Surveys and Soil Sample Collection

Cross-valley transects were surveyed at 23 sites along the main stem and tributary branches of Big Barren Creek (Figs. 13-14). Twenty-seven total floodplain cores were collected using either a truck mounted Giddings Rig soil corer, shovel-dug pit sampling, or open-face cut bank sampling (Fig. 15). Sampling depths ranged from 35 – 80 cm for seven dug pits, 70- 80 cm for five cut-banks, and 22-120 cm for 15 truck-mounted auger cores. Samples for all methods were collected at intervals of 3-10 cm based on stratigraphic units encountered, and the maximum length of the core obtained. Field data collection and surveys were completed during four extended field visits taking place beginning December of 2017, June 2018, October 2018, and December of 2018 (Appendix A-1).

Fine-grained sediment storage within valley alluvial landforms was estimated by using a simple storage calculation combining channel cross-sectional information obtained by total station, auto level, and LIDAR, with depth of fine-grained sediment refusal determined using a tile probe. Volumes were approximated using an equation relating length of landform, depth of fine-grained sediment, both multiplied by 1 meter, to calculate the storage volume in m^3 using the following equation:

$$W \times D \times L = V \qquad \text{(Eq. 1)}$$

Where:

W = landform width (m)
D = mean probe depth to refusal (m)
L = unit length (1 m)
V = Fine-grained storage volume (m3/ (m of stream length))

Landform Identification

To properly estimate fine-grained storage in alluvial landforms, both in-field and hydraulic classification of landform features was performed. In the field, cross-section surveys with auto-level and stadia rod were used to gauge approximate heights and widths of landform features delineated by breaks in slope (Fig. 16). By utilizing observations of the soil and vegetation we were able to accurately distinguish landform features. Higher landform features containing Bt soil horizons were generally classified as terrace features, and major breaks in vegetation and the identification of riparian areas helped to delineate channel and floodplain boundaries. Identification of bar and bench features with changes in sediment texture also helped to identify channel boundaries. Cross-sectional information was then analyzed in excel to double check in-field landform distinctions using flood recurrence interval information. The tops of floodplain surfaces in stable channels should approximately equal the stage height of a 1.5 to 2-year flood event.

Predicting Fine-grained Storage

Previous work done by Theis (2017), utilized a USGS developed rural discharge equation to identify the stage heights of the 2-year flood event using Hydra Flow Express hydraulic modeling software at each of his sites. By doing this, he effectively estimated the approximate bankfull stage height in natural, channelized, and aggraded stream types in Big Barren Creek for the upper half of the watershed. By modeling his reported data on maximum depth (m) for the bankfull discharge against drainage area (km^2) we were able to obtain a power function capable of predicting max depth at any site along the channel where drainage area was known. The following equations were used to model predicted maximum depths for both channelized and natural reaches:

Channelized reach equation:

$$y = 0.5028x^{0.4145} \qquad \text{(Eq. 2)}$$

$$R^2 = 0.5756$$

Natural reach equation:

$$y = 0.6824x^{0.185} \qquad \text{(Eq. 3)}$$

$$R^2 = 0.558$$

where:

y = max depth

x = cross-sectional area

These predicted depth values where then compared to our in-field identified floodplain heights and fell within a reasonable range of the predicted values. Some variability did exist between predicted and observed max depths but can be explained by the natural variability of the stream and the difficulty of modeling multi-threaded stream sites alongside of single-threaded stream sites. In general, the bankfull stage was typically found to be the top elevation of the first bank confining the active channel belt.

Dating Methods

Three methods used for determining sedimentation rates including the use of Cesium-137 (^{137}Cs) to determine the 1950's radionuclide depositional surface (Magilligan, 1985; Walling and He, 1993; Walling and He, 1998; Owens et al., 1999; Knox, 2006; Owen et al., 2011), buried root crown dendrochronology (Phipps et al., 1995), and the identification of buried A-horizons (Magilligan, 1985; Owens et al., 1999; Owen et al, 2011).

Cesium-137. ^{137}Cs is a radionuclide that quickly and strongly absorbs to fine-grained sediments and is associated with two primary processes of adsorption (Walling and He, 1993). The two methods capable of capturing adsorbed ^{137}Cs include the direct interaction of the floodplain with atmospheric fallout or the remobilization and deposition of fine-grained floodplain deposits previously containing ^{137}Cs (Walling and He, 1993). Floodplain sediment cores can be analyzed, and the resulting levels of ^{137}Cs within the profile will vary with depth.

The depth-integrated relationship between ^{137}Cs can be directly related to the temporal distribution of ^{137}Cs in the atmosphere (Walling and He, 1993). Therefore, by pinpointing the maximum concentration of ^{137}Cs within the stratigraphic profile, one can isolate the surface associated with the height of nuclear bomb testing which occurred in the early 1960's (Magilligan, 1985; Walling and He, 1993.) This surface serves as a stratigraphic boundary separating deposition occurring after or before 1963 as well as serving as a point of reference used to constrain rates of deposition occurring within a given interval (Walling and He, 1998). The first occurrence of ^{137}Cs in the atmosphere occurred in 1954 at the start of nuclear testing. It is suggested that Cs-137 can mix downward by approximately 10 cm within the floodplain creating a small potential error in the date. Research done by Walling and He, 1998 use this as the principle method for determining sedimentation rates occurring within the floodplains of the River Culm in the Ukraine**.**

Buried Root-crown Dendrochronology. Root crown dendrochronology is a technique that combines data on the ages of trees, and the burial depths of tree roots to estimate rates of sedimentation. By measuring the depth of sediment from the buried root crown to the present ground surface, one may derive a sediment yield constrained by tree age and current depositional surface age (Phipps et al., 1995; Sigafoos, 2014).

Tree core samples were collected when a set of three criteria were met at a site. First, there had to be an appreciable thickness of fine-sediment deposited on the landforms of trees being analyzed. Coring trees in areas of erosion yield little information on the change in rates of sedimentation, but are rather more indicative of the long-term rate of erosion for that area (Sigafoos, 2014). Second, the site had to contain a reliable species of trees in which tree age and the depth to root crown could be determined (Sigafoos, 2014). The tree cores collected included species of short leaf pine, sycamore, hackberry, and green ash. The most reliable tree data collected came from the shortleaf pine as the wood was softer and less likely to break during the coring process and due to the distinct visibility of the tree rings. Additionally, at each tree, a pit was dug directly adjacent to the tree center to be certain of the depth to buried root crown where the original lateral roots began to develop (Fig. 17).

Third, mature trees of a variety of different sizes were sampled to ensure that sample ages were representative. If only large trees were sampled, this may effectively under or over-estimate rates of sedimentation occurring if at any time during that tree's life sedimentation rates spiked or declined for a period of time. This occurs because the burial depth of the tree reflects the net deposition of sediment during the entire life of the tree, any fluctuations occurring within that time will not be identified (Sigafoos, 2014). Rather, they will be represented as an average sedimentation rate occurring over the entire life of the tree. For this reason, trees of varying diameter were selected to ensure this bias could be avoided. All cores were extracted from trees at standard breast height of approximately 1.5 m and information on the diameter and fine-grained burial depth to root crown was recorded (Fig. 18). Burial depth was determined as the distance from the present-day ground surface down to the furthest extent of the buried root crown of the tree where the lateral tree roots first begin to emerge (Sigafoos, 2014).

In the historically logged headwaters of BBC, historically cut pine stumps were used to establish pre-settlement soil boundaries. These historical pine stumps varied in burial depth from 6 cm to 22 cm in depth. And while the stump itself could not be cored to determine tree ring counts and subsequent tree ages, we could reasonably assume that these large mature pines germinated in pre-settlement soils with lateral root crown's that still exist to mark that boundary today. In total, four pine stumps were used to identify pre-settlement boundaries from two sites in the headwaters of BBC, three at the Upper Big Barren Gauge, and one at the Upper Big Barren Farm Site.

Buried A-horizons. Floodplain soil cores can also be studied to identify buried A-horizons. A buried A-horizon is a stratigraphic marker indicative of the organic-rich pre-settlement depositional surface. The dark, mollic A-horizon separates the post-settlement boundary from the more mature, stable pre-settlement soils (Knox, 1972, 1977; Beach, 1994; Owen et al., 2011). In the Upper Midwest, these darkened, A-horizons can be identified in the field with the naked eye when found buried under more recent sediment (Magilligan, 1984; Owen et al., 2011) (Fig. 19). Extensive historical records date the European settlement surface in the Ozarks to occur in the early 1800's (Jacobson and Pugh, 1992; Jacobson and Primm, 1997). The location of a buried A-horizon acts as a benchmark for constraining rates of sedimentation occurring after the onset of European settlement (Owen et al., 2011). Research done by Knox (1987) utilized this method to identify the overlying legacy floodplains in the Galena River in southwest WI and northwest IL. Knox (1972, 1977) was one of the first to show the usefulness of the testable relationship between depth below the ground surface and the temporal distribution of organic matter found in floodplain soils. He illustrated that identifying peaks in organic matter content within the soil profile could establish the boundary between the presettlement and post settlment soil surfaces of that region. In the Ozarks, buried A-horizons are not as readily identified in the field but analysis of organic carbon peaks within the floodplain samples can still accurately identify these surfaces where these boundaries are not visually apparent (Owen et al., 2011).

Laboratory Analysis

All soil samples were dried immediately after sampling for 48 hours in an oven at 60 degrees Celsius, disaggregated with mortar and pestle. After samples were properly disaggregated, they were then sieved to less than 2 mm to separate out the fine soil fraction for ^{137}Cs gamma spectroscopy analysis, and to less than 250 microns for loss on ignition organic carbon analysis.

^{137}Cs Analysis. After sieving, approximately 100g of fine-grained soil from samples KRB1-KRB40 and EB9 -EB29 (seven cores) were put into Marinelli beakers and analyzed for 20 hours using a GC4020 GE Co-Axial Detector and DSA 1000 Digital Spectrum Analyzer with 747 Series Lead Shield. This 20 hour analysis detects and quantifies gamma-ray emitting radionuclides. All samples run using this method were measured under an activity uncertainty of <1 Bq/Kg. The standard operating procedure for the method can be found at http://oewri.missouristate.edu/58411.htm. Note: Samples KRB89-KRB111 (four cores) were prepped in OEWRI's sediment analysis lab and were sent to Dartmouth University Laboratories for Cs-137 processing following a period where the GC4020 GE Co-Axial Detector and DSA 1000 Digital Spectrum Analyzer was unavailable for use.

Organic Matter Analysis. After samples (KRB1 to KRB162; KRB187 to KRB215) were sieved to less than 250 microns they were analyzed for peak organic matter content. Organic content was determined using the Loss on Ignition (LOI) method following procedures defined in the Soil Science Society of America Methods of Soil Analysis (Sparks, 1996) and the OEWRI Standard operating procedure (OEWRI, 2007). Each sample was weighed to approximately 5 g and placed in a pre-weighed crucible. Then using a 105-degree C convection oven, all samples were heated for 2 hours to remove all residual moisture content and then placed in a desiccator to cool. The samples were then measured for their pre-burn weights and placed in a 600-degree C muffle furnace for eight hours to remove any organic matter present. After the final burn, samples were placed in the desiccator and measured for their post-burn weights. The percent organic matter loss was calculated by taking the difference between the pre-burn sample weight and post-burn sample weight, divided by the pre-burn weight and times 100 as shown in the following equation:

$$\% \text{ OM LOI} = [(A-B)/ (A)] * 100 \qquad \text{(Eq. 4)}$$

Where:

A= Pre-burn dry sample weight (g)

B= Post-burn dry sample weight (g)

This procedure was completed on all 191 samples with an duplicate analyses at <10% relative percent difference (OEWRI, 2007). Samples KRB163- KRB186 were not analyzed for organic carbon content due to extremely shallow depth to refusal while coring and due to soil loss during the initial coring process.

Dendrochronology Analysis. All tree cores were brought back to the lab, dried in an oven to remove any residual moisture, and examined visually to corroborate tree ages calculated in the field (Fig. 20). Ages were determined according to the number of counted rings starting from the center of the core (determined visually) and counting out toward the bark of the tree. This initial age was then granted five additional years to account for the initial vertical growth period of the tree as shown in the following equation:

$$R + 5 \text{ years} = A \qquad \text{(Eq. 5)}$$

Where:

R = number of tree rings counted (count)

A= approximate age of the tree (years)

Channel Change Analysis

A series of five 1: 15,748 scale USGS Government Land Office Township and Range maps were obtained for regions of Carter and Ripley County, MO. These maps contained survey information spanning from 1850-1861 from the General Land Survey Office of the United States on location of streams and timber resources starting at the confluence of the Arkansas and Mississippi rivers moving west across the United States. The five maps that were chosen for analysis include township and range maps identifying the locations of streams and tributaries west of the confluence of Big Barren Creek and the Current River. These maps were rectified using 2015 aerial imagery of Big Barren Creek obtained from the MSDIS. The newly rectified maps were then used to create an 1850's stream network showing the areas of Big Barren Creek watershed with visible channels. All areas where the surveyors were unable to identify a channel were recorded and digitized for comparison to the present-day channel.

To make comparisons to the current channel in Big Barren creek, 1 m resolution LIDAR provided by the U.S. Forest Service was used in combination with 2 ft resolution, leaf off, 2015 MSDIS aerial imagery to classify segments of Big Barren Creek into distinct channel forms. Any depressions in the LIDAR were filled using the "Fill" spatial analyst tool and then used to create a flow direction raster. The flow direction raster was used to create a flow accumulation raster that could be used to create a precise stream network. This stream network was used in combination with aerial imagery and the LIDAR to classify areas of the stream as single-threaded, 1.5 threaded (single channel with a chute channel), multi-threaded (multiple channels), or channelized. Single-threaded streams were classified as areas of the stream with one distinct well-defined channel, while areas of the stream with wide valleys and three or more channels was considered multi-threaded (Fig. 21). Channelized areas while also technically single-threaded, are also accompanied by artificial levees lining the banks that are readily observed on the LIDAR (Fig. 22). Additionally, all channelized areas were previously mapped in the field and were used to double check all areas of the stream that had been classified as channelized in the LIDAR analysis.

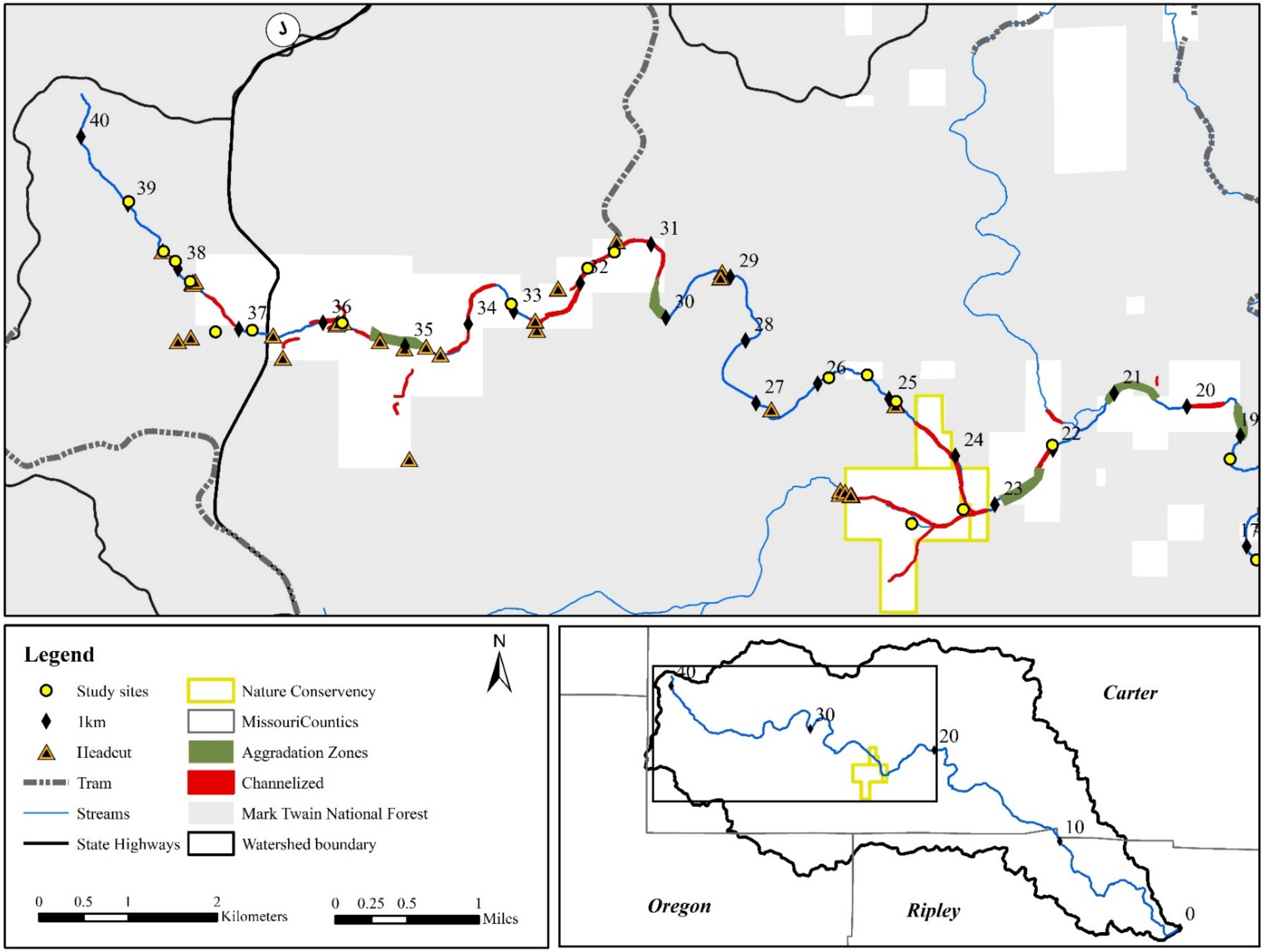


Figure 13. Site map of Big Barren Creek showing R-km 20-40. Zones of channelization and aggradation delineated by Bradely, 2017 are also indicated.

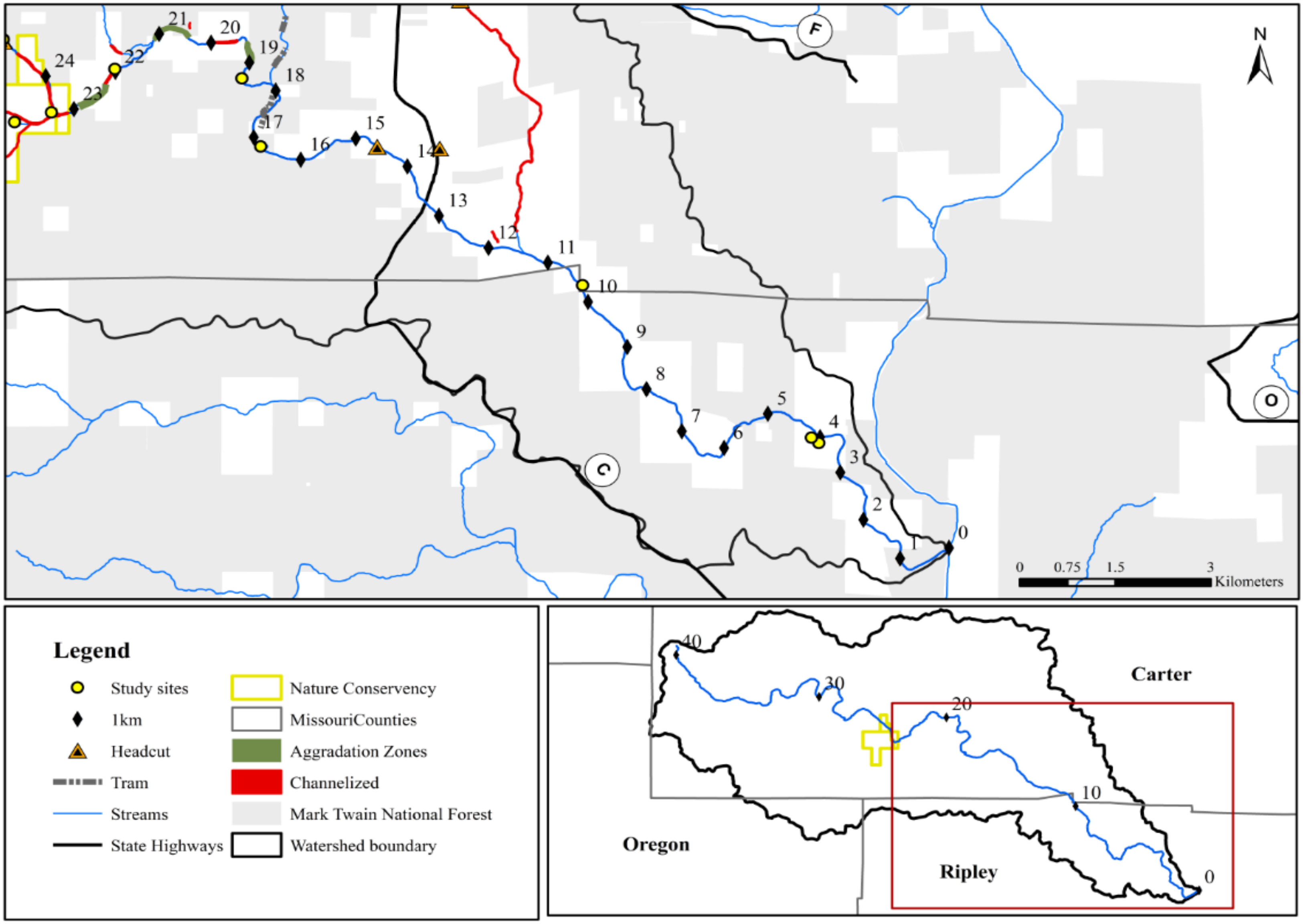


Figure 14. Site map of Big Barren Creek showing R-km 0-20. Zones of channelization and aggradation delineated by Bradley, 2017 are also indicated.

Figure 15**.** Examples of soil sample collection. Figure 17-a shows the collection of soil via pit sampling at the Lower Big Barren 101718 site. Figure 17-b is an example of soil core analysis in the field using soils cores from the Giddings soil corer at the Nature Conservancy site 1.

Figure 16. Example of site cross-sectional surveys at UBB headcut site where auto-level and stadia rod were used to gauge approximate heights and widths of landform features delineated by breaks in slope.

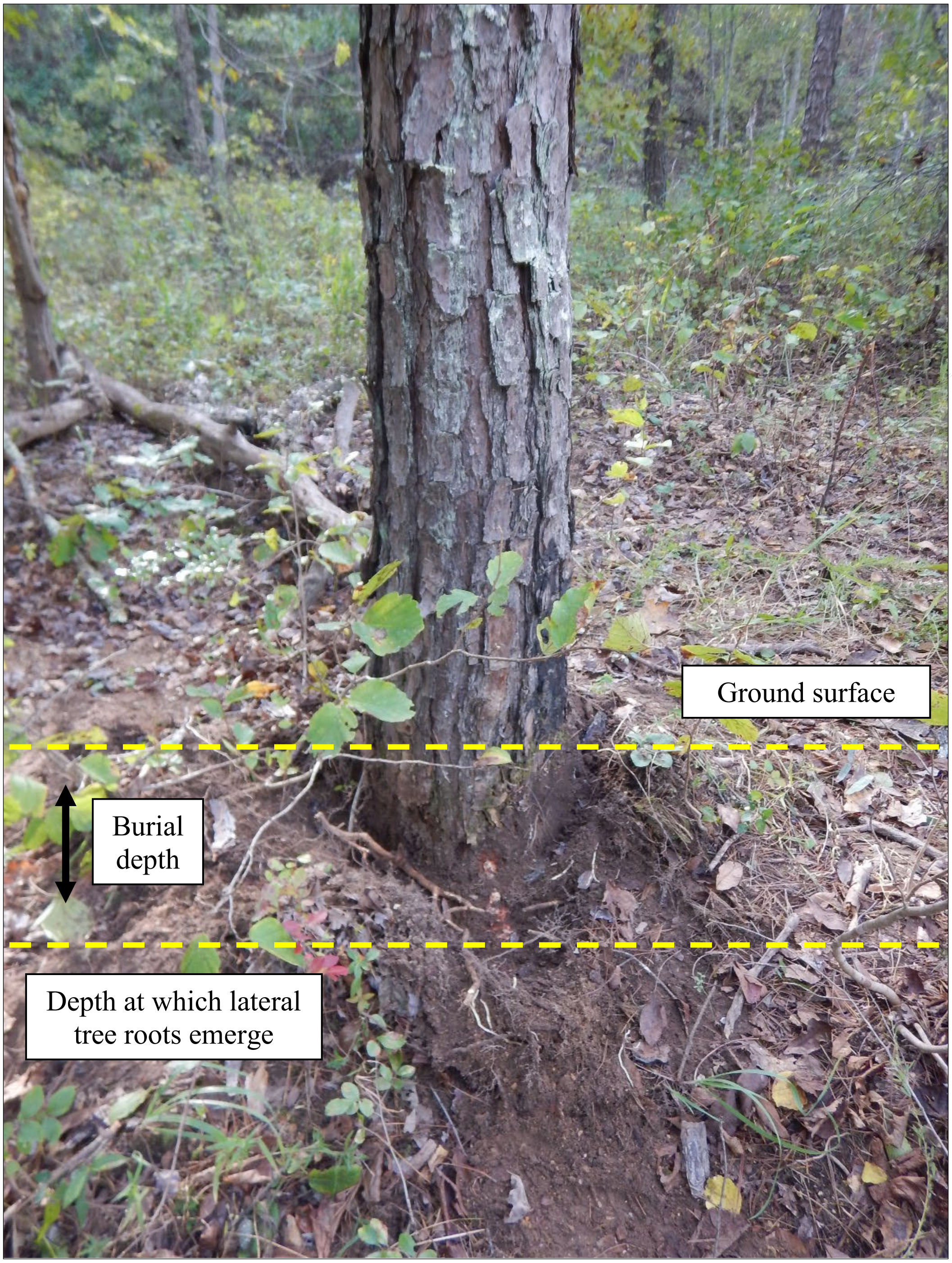


Figure 17. Example of pit dug at the UBB Farm site showing points where lateral roots where used to mark depth to tree burial.

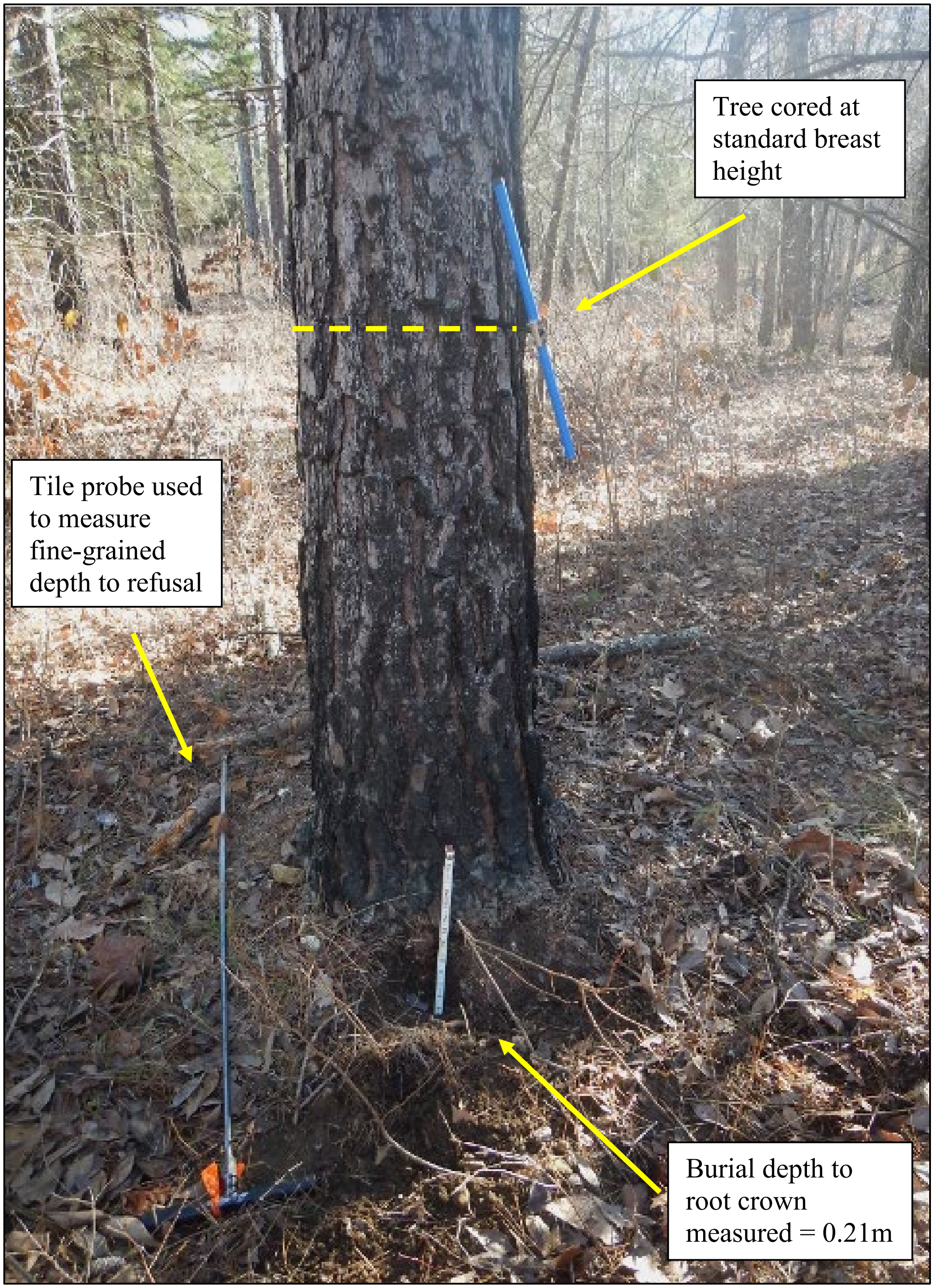


Figure 18. All cores were extracted from trees at standard breast height of approximately 1.5 m and information on the diameter and fine-grained burial depth to root crown was recorded. The above picture is an example of a tree cored at the upstream of UBB Farm site.

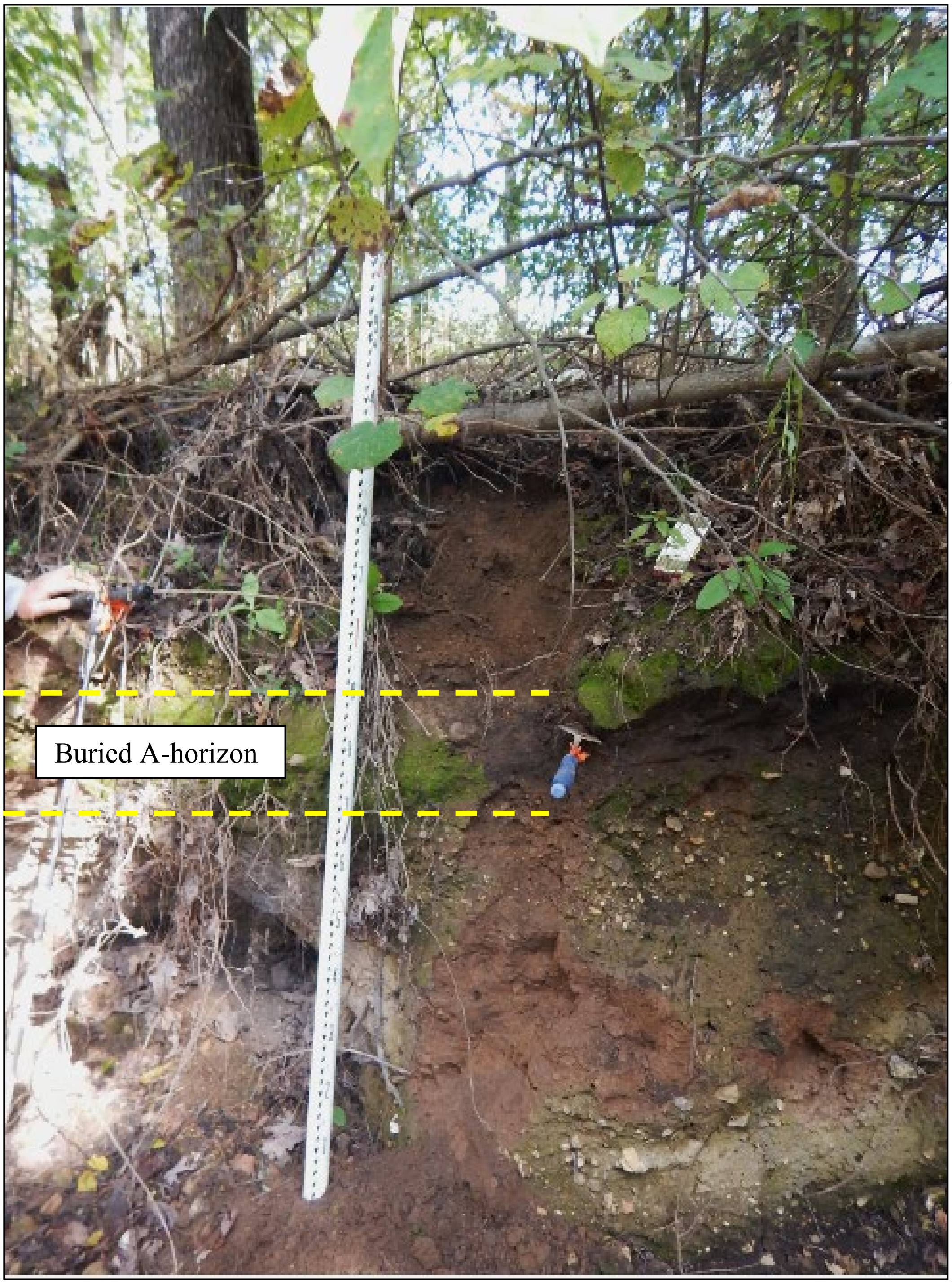


Figure 19. Buried A-horizon identified at the UBB Head-cut site. Dark mollic A-horizon separates young sediment from mature pre-settlement soils.

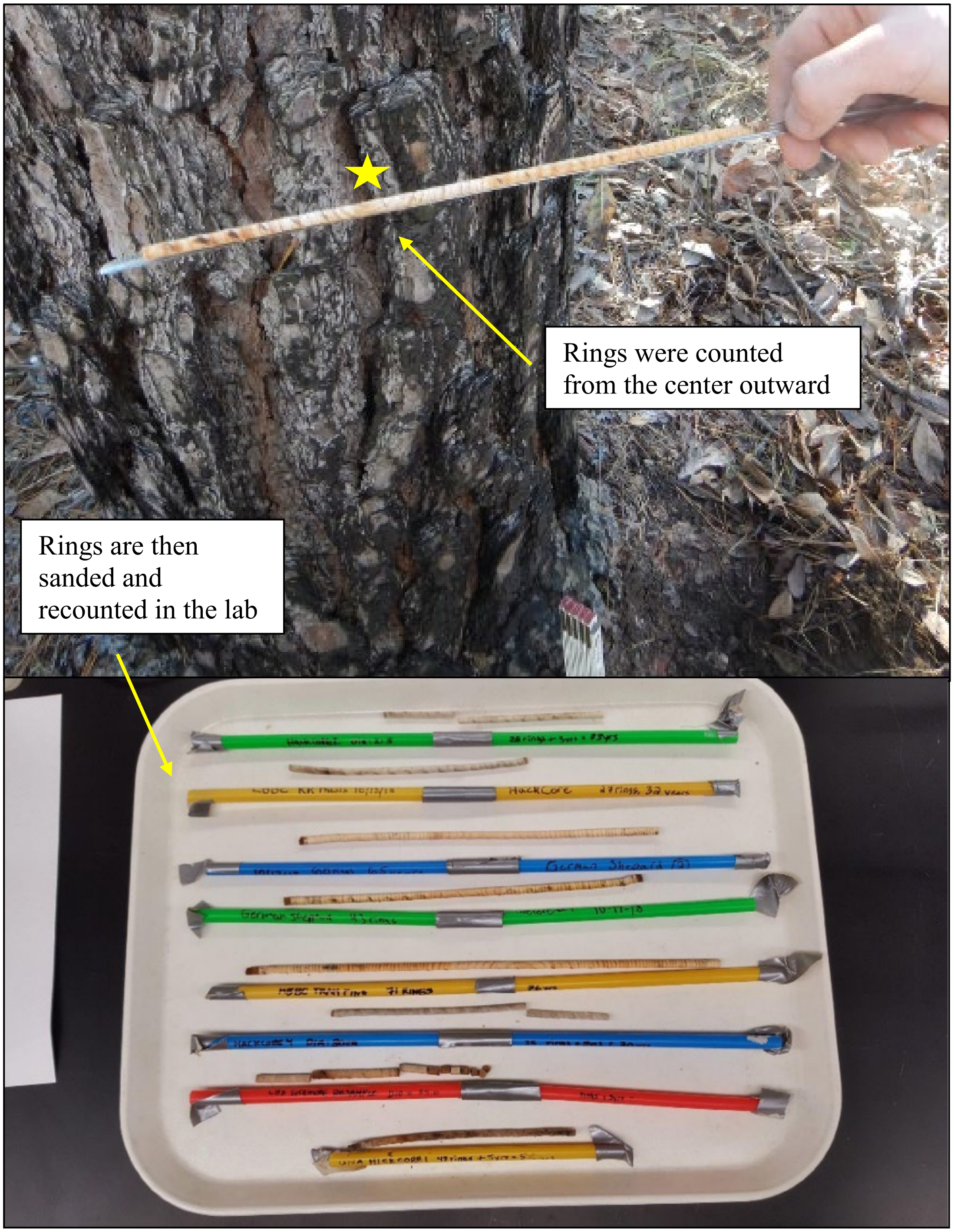


Figure 20. Example showing trees rings counted in the field from the center ring outward. Tree cores are brought back to the lab where they are treated and sanded for re-counting.

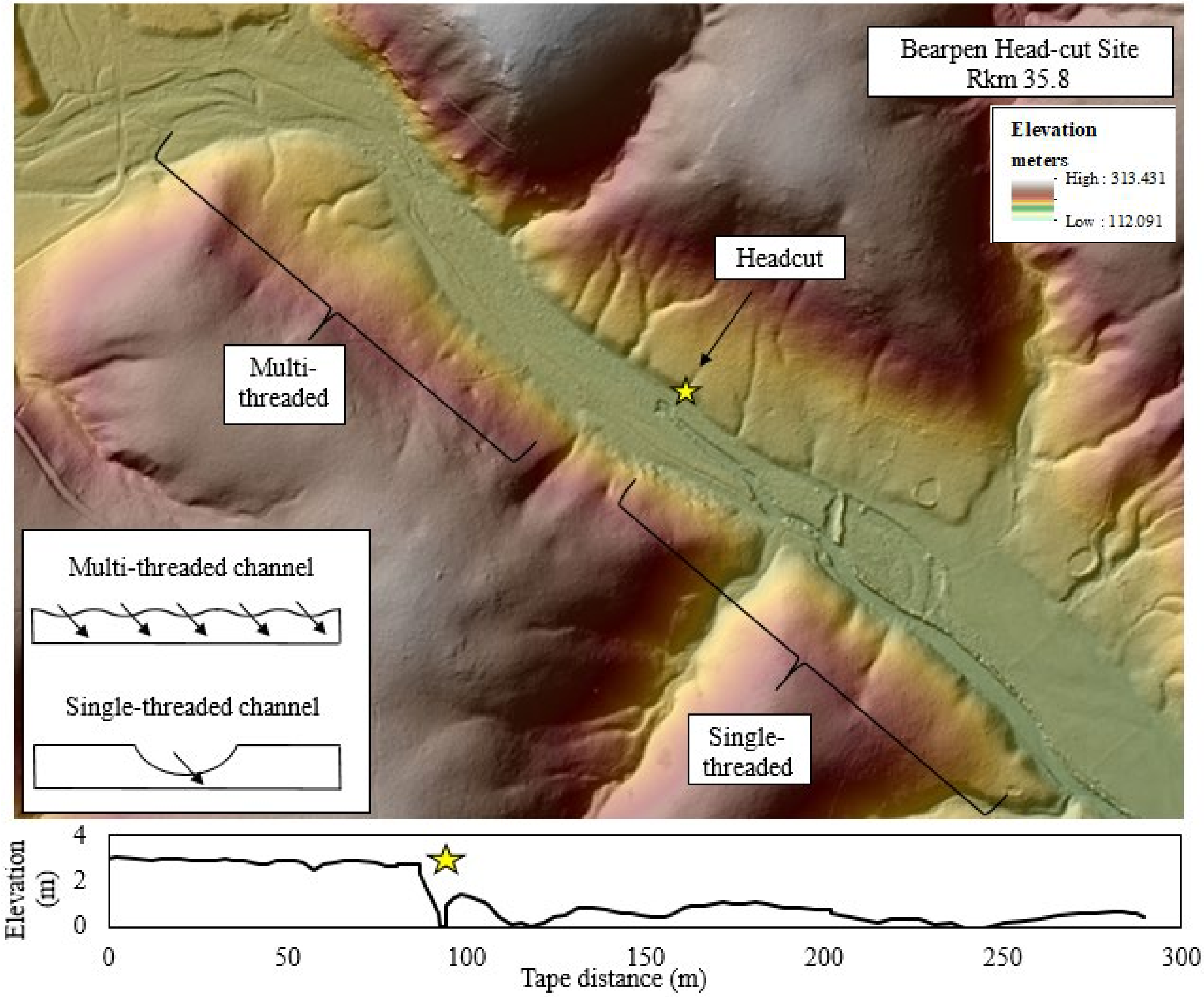


Figure 21**.** Example of multi-threaded and single threaded channel classifications using LiDAR.

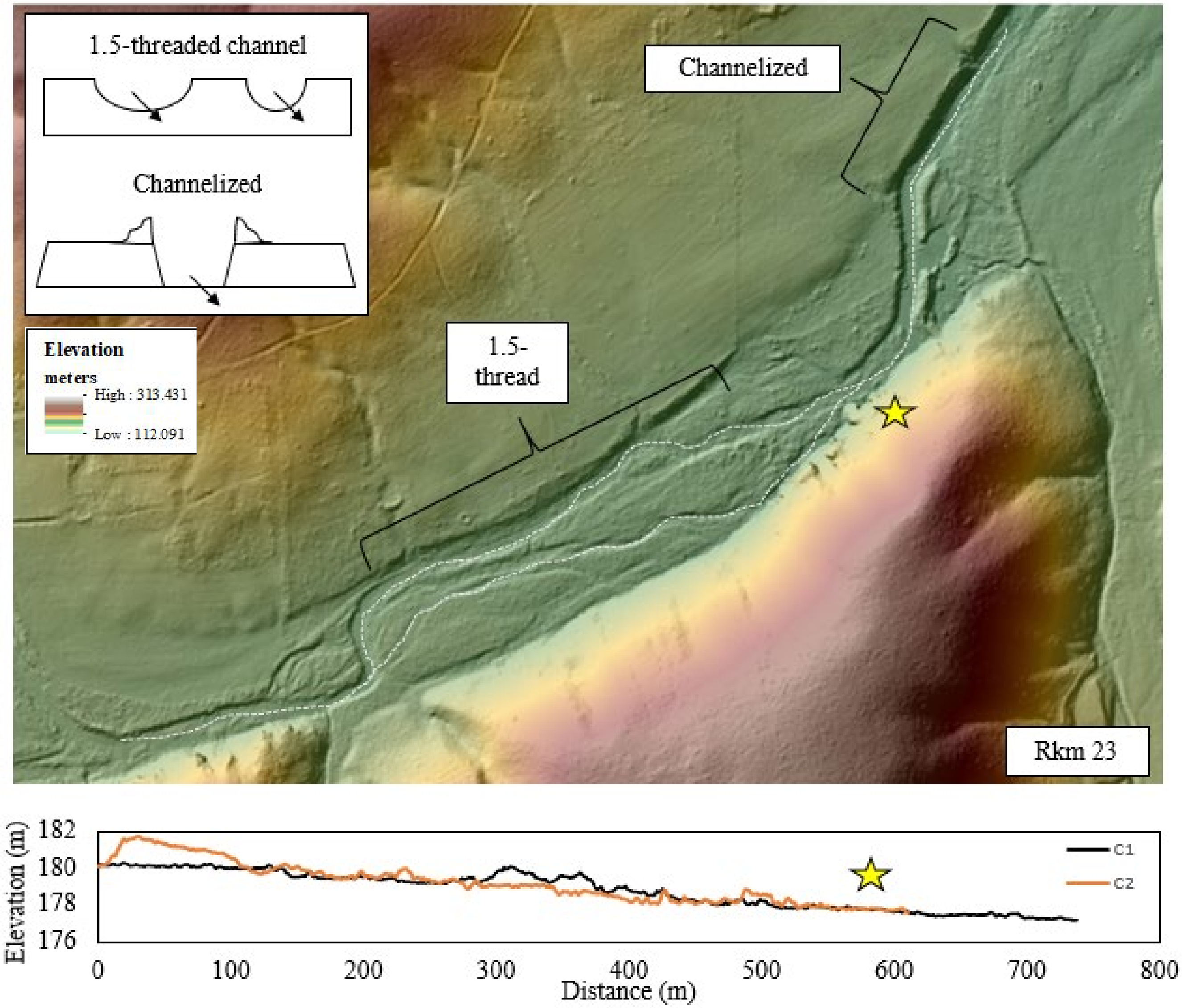


Figure 22. Example of channelized stream section with adjacent levies and 1.5 threaded channel classifications using LIDAR.

RESULTS AND DISCUSSION

Hydro-geomorphic Zones

Big Barren Creek can be described using four distinct hydro-geomorphic zones based on in-field observations, aerial imagery, and a 1-meter resolution LiDAR analysis of the watershed (Table 9, Fig. 23). These zones are characterized by stream hydrology, geomorphology, and dominate drivers of channel disturbance. The locations of these channel zones are important to understanding the non-uniform channel response of Big Barren Creek to historical and current watershed disturbances. The upper portion of the watershed (R-km 38-40) is characterized by a multi-threaded channel system that is a relatively undisturbed (EM channel class). This segment is characterized as ephemeral with a relatively wide planform and forested channel beds including tall short-leaf pine and hardwoods. The main processes occurring here include periodic scour of the soil formed on the channel bed and periodic transport of sediment up to fine-gravel size at relatively low rates. The soil formed on the channel bed has a dark A-horizon about 10 cm thick, forming a bio- mantle composed of a silt loam to loamy matrix containing fine-gravel and a dense root system. Fine-sediment deposits occur on the channel bed in places at < 0.5 m thick.

The next hydro-geomorphic zone (R-km 30-38) has an ephemeral, deeply incised, single-channel morphology resulting from past and on-going stream channelization practiced by local farmers to reduce flooding in riparian fields (ES channel class) (Table 9). Bradley (2017) indicated channelization practices occurred sporadically from 1966 to 2018 on over 5.6 km or (70 %) of this segment of BBC. Channelized segments are characterized by a channel bottom that is typically 1 m deeper than the surrounding natural channel beds and accompanied by levees approximately 1 m high on one or both sides of the channel. Additionally, headcuts originate at the upstream end of the channelized stream and have migrated upstream 200-400 meters since the initial channelization of the stream. Aggraded deposits typically occur within 1 km downstream of the channelized reaches. These deposits are composed mainly of sand < 0.5 m thick, distributed over the channel bed (Theis, 2017).

Below the first channelized segment, the stream is again characterized as an EM channel type (R-km 25.6-30). Below this segment is another ES segment of channelized channel in middle BBC (Table 9). This downstream-most channelized area (R-km 21-25.6) is more recently disturbed having underwent channelization sporadically from 2007- 2013 and encompasses over 41 % of the segment length. Channelization in these areas is disconnected, localized within < 1.5 km reaches along privately-owned sections of the stream, and separated by natural stream types on public land. In response, head-cuts commonly migrate headward upstream of deeply channelized zones into National Forest lands.

Starting at R-km 21 down to R-km 16.5, the channel exhibits permanent base flow hydrology with a natural, single-threaded channel morphology (PS channel class) (Table 9). This area of the stream is a Missouri designated Natural Area with narrow valleys and includes protected mussel habitats (https://nature.mdc.mo.gov/discover-nature/places/big-barren-creek). Below the Natural Area, from (R-km 6.5-16.5) the stream is characterized by intermittent hydrology and alternating areas of natural stream and disturbance reaches (ISD channel class) (Table 9). Disturbance reaches are large areas of the stream where aggressive lateral bank erosion is accompanied by widespread bar formation across an over-widened channel (Jacobson,1995; Martin and Pavlowsky, 2011). These disturbance zones show dramatic changes in active channel width where gravel bar area increases dramatically with variable planform. Non-disturbed channel widths range from 15-20 m while disturbed channels may reach up to 100 m in active width where unstable channels continue to cut into banks and coarse gravel bars form along opposite banks of the stream (Fig. 24). The widening and extension of channel bends in disturbance zones probably indicates an inability of the channel to accommodate the increased sediment transport caused by upstream disturbance. The last segment of BBC (R-km 1-6.5) is characterized by permanent base flow hydrology, wide valleys, and a relatively undisturbed channel morphology (PS channel class) (Table 9). However, bed material becomes more fine-grained and muddier in this segment.

Fine-grained Sediment Storage

A total of 23 sites (10 tributary sites, 13 main stem sites) were assessed to estimate cross-sectional fine-grained sediment depths (Table 10, Fig. 25) and storage volumes within valley landforms (Table 11). For discussion purposes, storage analysis is separated by drainage area into three groups with sites having drainage areas less 10 km^2 (upper BBC), 10-50 km^2 (middle BBC), and 50-103 km^2 (lower BBC).

Fine-grained Depth. In Big Barren Creek, the distribution of fine-grained sediment was calculated for each study site by multiplying the width of the landform by the average probe depth of fine-grained sediment along cross-valley transects for channel, floodplain, and terrace features (Fig. 26). In places with drainage areas less than 10 km^2, fine-grained sediment depths in the channel ranged from 0 m to 0.60 m with an average depth of 0.26 m (Table 10). Sediment depths on floodplain features increased slightly to 0.18 m to 0.70 m with an average depth of 0.48 m. Terrace features contained the thickest fine-grained sediment deposits with highest depths ranging from 0.34 m to 0.89 m, and an average depth of 0.58 m. In places with drainage areas between 10-50 km^2, fine-grained sediment depths in the channel ranged from 0 m to 0.43

m with an average depth of 0.19 m. Resistant channel beds yielding probe depths of zero, occurred in heavily scoured or incised areas of the channel at four sites ranging from 1.60 to 48 km^2 in drainage area. Floodplain features stored slightly more sediment with fine-grained sediment depths ranging from 0.58 m to 0.98 m with an average depth of 0.75 m. Terrace features contained the highest fine-grained sediment with depths ranging from 0.83 m to 1.44 m, with an average depth of 1.09 m.

In the lower portion of the watershed with drainage areas between 50-103 km^2, fine-grained sediment depths in the channel ranged from 0 m to 0.54 m with an average depth of 0.23 m (Fig. 26). Floodplain features had fine-grained sediment depths ranging from 0.38 m to 0.83 m with an average depth of 0.63 m. Terrace features again stored the most fine-grained sediment with depths ranging from 0 m to 1 m, with an average depth of 0.62 m (Table 10). Depth values of zero in the terrace features of this section relate to areas of the stream within the Natural Area where extremely narrow valleys are controlled by steep valley walls and coarse colluvial toe slopes.

In general, floodplain and terrace depths increase downstream at approximately the same rate (with terrace values being slightly higher). Our measured depths indicate almost no change in floodplain depth in lower BBC compared to upper BBC along the main stem (Table 10). However, fine-grained sediment depths within terrace landforms increase by 50% in downstream. Conversely, channel depths decrease downstream by 65% in lower BBC compared to upper BBC (Table 10).

Fine-grained Volume. The volume of fine-grained sediment in each of these landforms was determined by multiplying average depths by landform width, then multiplied by a one-meter distance downstream to determine storage volume in m^3/m (i.e., cubic meters of sediment storage per meter valley length) (Table. 11; Fig. 27). For drainage areas less than 10 km^2 (upper BBC), channel features stored the least amount of fine-grained sediment with cross-sectional volumes ranging from 0 m^3/m in places where gravel armored streams beds were affected by frequent channel scour to over 29 m^3/m in areas where large, wide channels stored sand and fines in bench and bar features. Also, relatively large storages of fine-grained sediment occurred in upstream channels (<2 km) draining forested upland areas (Fig. 27). The average fine-grained cross-sectional storage in channel features is approximately 9.3 m^3/m. The amount of storage in floodplain features is considerably higher with storages ranging from 2.4 m^3/m to 33.6 m^3/m of sediment. The average fine-grained sediment storage in floodplains is 10.9 m^3/m and generally increases downstream. Terrace features store the most fine-grained sediment reflecting changes in valley width. Fine-grained sediment storage in terrace features ranges from 2.5 m^3/m, where valley widths are small and channel widths are relatively large, up to 179 m^3/m of sediment where very wide valleys are coupled with narrow single-threaded or channelized streams. The average fine-grained storage in these features is approximately 39 m^3/m.

In the middle portion of the watershed with drainage areas between 10-50 km^2, fine-grained sediment volumes in the channel ranged from 0 m^3/m to 16.6 m^3/m with an average volume of 8.8 m^3/m (Table. 11; Fig. 27). Channel storage values of zero in this portion of the watershed occur in channelized areas of the stream with eroded channel bottoms and no depositional bars or benches. Floodplains contained fine-grained sediment volumes ranging from 9.8 m^3/m to 43.8 m^3/m with an average volume of 26.4 m^3/m. Terrace features again stored the most fine-grained sediment with depths ranging from 13.3 m^3/m to 152.5 m^3/m, with an average volume of 71.4 m^3/m.

In the lower portion of the watershed with drainage areas between 50-103 km^2, fine-grained sediment volumes in the channel ranged from 0 m to 25 m^3/m with an average volume of 7.4 m^3/m (Table. 11; Fig. 27). Channel storage values of zero in this portion of the watershed are due to both localized channelization and incised single-channel streams with little deposition of fine sediment. Floodplain features had fine-grained sediment volumes ranging from 5.7 m^3/m to 50.6 m^3/m with an average volume of 22.6 m^3/m. Terrace features stored the most fine-grained sediment with volumes ranging from 0 m^3/m to 262 m^3/m, with an average volume of 108 m^3/m. In total, fine-grained sediment stored in terrace features accounts for approximately 72% of the total fine-grained storage in Big Barren Creek.

Average volumes of fine-grained sediment in valley-landforms generally increase moving downstream, with floodplain and terrace volumes increase downstream at approximately the same rate. Our measured volumes indicate a 2-fold increase in floodplain volume in the downstream portions of the watershed compared to upper BBC. Fine-grained sediment volumes within terrace landforms show a similar increase in downstream areas compared to upper BBC. Conversely, measured channel volumes indicate a 26 % decrease in depth downstream compared to upper BBC (Fig. 28).

We then analyzed the correlation among our measured geomorphic variables to assess how strongly these variables were correlated and in what direction they were associated (positively or negatively). Geomorphic variables including landform width, average probe depth, and total volume of fine-grained sediment were assessed using power functions in relation to increasing drainage area and valley width (Fig. 29-30). Average fine-grained probe depth was assessed in relation to drainage area and returned a negative relationship with a modest r^2 value for the channel of 0.44. This indicates decreasing in-channel deposition and sediment storage downstream due to multi to single threaded channel change. However, the relationship is weak (80% or p= 0.2). In addition, the floodplain and terrace series returned much weaker r^2 values of 0.12 and 0.19 respectively. Fine-grained sediment depth decreases in the channel due to bed erosion and sorting under single-threaded channel conditions that become more common downstream (Fig. 25). Overall, drainage area proves to be a poor predictor of channel depth but correlates better with depth of floodplain and terrace deposits.

As a function of valley width, average probe depth returned slightly weaker correlations, with the exception of channel depth which returned the same strength of correlation to both valley width and drainage area. Like with drainage area, channel probe depths decreased downstream with valley width (r^2= 0.44). Floodplain and terrace depth gradually increase downstream, but not simultaneously (r^2 values of 0.07 and 0.16 respectively). In contrast to width, where valley width better explains trends, fine-grained sediment depth explains both drainage area and valley width (Figs. 29-30).

Total storage volume of fine-grained sediment was weakly related to drainage area (r^2 = 0.38) (Fig. 29), but more strongly related to valley width (r^2 = 0.63) (Fig. 30). In BBC, valley width is a much better indicator of the total volume of fine-grained sediment stored within alluvial landforms, mostly due to terrace deposits being distributed across the valley floor to fill accommodation space for alluvial deposition. This supports the findings of Donovan et al (2015) and Magilligan (1985) who found that variations in the magnitude of sediment stored in valley-landforms is subject to the control of valley width and to a lesser degree, subject to changes in drainage area.

Sediment Storage Correlation Analysis. Using arithmetic correlation matrices, total site storage (m^3/m) was evaluated among sites in relation to six total variables including reach slope, drainage area, valley width, location downstream, active channel width, and distance upstream from disturbance to understand downstream trends (Table 12). Total cross-sectional valley storage showed the strongest correlations with changes in valley width ($r = 0.95$, $p = 0.01$). To a lesser extent, total fine-grained storage volumes were correlated with reach slope ($r = 0.59$) and drainage area ($r = 0.57$), both significant at the 0.01 level (Table 12). These trends suggest that as reach slope increases, transport increases, and the amount of fine-grained sediment deposited decreases. Places where the stream encounters a break in slope or an overall lowering of stream gradient will see larger accumulations of fine-grained sediment in alluvial landforms. This corroborates findings by Rieke-Zapp and Nearing (2005) who found increased sediment deposition along stream reaches with more gradual slopes, and more erosion in steeply graded areas. These trends also suggest that increasing drainage area generally results in increases in more fine sediment stored downstream. This may indicate the greater influence of increased water and fine sediment loads available downstream, as well as, wider valleys as drainage area increases.

Site storage was also evaluated in relation to storage within individual landform features including channels, floodplains, and terraces (Table 13**.** Fine-grained sediment storage in channel features display poor correlations to all variables evaluated. The highest correlation was with active channel width ($r = 0.37$) suggesting that as channel width increases so does the amount of sediment stored in the channel. The lack of systematic relationships with geomorphic variables suggests that channel deposition is controlled more by land us or other local factors.

Fine-grained sediment storage within floodplain landforms showed slightly stronger correlations to individual site variables with reach slope as the main correlated variable ($r = -0.515$; $p = 0.05$). This indicates that as stream gradient decreases the average amount of sediment stored will increase in floodplain landforms within that reach. Floodplain storage in particular is more closely related to changes in reach slope rather than valley width which more strongly controls total cross-valley storages.

Fine-grained sediment storage in terrace features showed the second strongest correlations to physical site variables such as drainage area and valley width behind total storage. The amount of sediment stored in terrace features was predominately correlated with valley width ($r = 0.46$; $p = 0.05$). This suggests that with increased valley width, the amount of fine-grained sediment in terrace features will increase. Average depths (m) were also evaluated in relation to site variables but returned very low values of correlation, with only total average depth and channel width returning a significant value ($r = 0.91$, $p = 0.01$) (Table 13). This result is interesting since channel depth and storage tends to decrease downstream. However, valley width may affect depth increases locally within sampled sites to drive the relationship. More sampling sites may have produced a different result.

Linear Regression Modeling to Predict Sediment Storage Volume. Step-wise and two parameter linear regression techniques were used to model the strongest predictors of total fine-grained sediment storage in valley landforms. The strongest indicator of total fine-grained sediment storage in Big Barren Creek is a function of valley width with an approximate r^2 value of 0.90, a slope coefficient of 0.973, and a standard error of 85 m^3/m significant at the 0.01 level. This suggests that as valley width increases, so does the amount of fine-grained sediment stored in alluvial landforms. Additionally, this suggests that for every one-meter increase in valley width, the volume of sediment stored will increase by about 1 m^3/m. Other equations used to model storage volume in channel and floodplain features were less effective and a two-parameter model combining multiple geomorphic variables did not improve results.

Stratigraphy and Dating of Historical Sediment Deposits

A total of 31 historical sedimentation rates were determined for historical sediments at 12 of the 23 total sites along Big Barren Creek using ^{137}Cs, buried root crown dendrochronology, and identification of buried A-horizons in cutbanks (Tables 14-16). Nine sediment cores were analyzed and dated for ^{137}Cs to determine the 1963 depositional boundary at each site (Fig. 31). Eleven living trees were analyzed using buried root dendrochronology to determine recent surfaces (Table 14), while four historically cut pine-stumps assumed to be remaining from early logging activities before 1880-1920 by U.S. Forest Service scientists were used to indicate the elevation of pre-settlement surfaces (Table 15). A total of eleven buried A-horizons were identified through in-field observation and LOI techniques in the lab (Table 16). Buried A-horizons identified in Big Barren Creek were often found in pre-historical channel bed and low bench deposits within a densely rooted bio-mantle overtopping the pre-settlement channel bed. Buried (Ab) horizons also occurred in either alluvial or colluvial deposits on low terraces, floodplains and channel benches.

Analysis of ^{137}Cs trends in three collected floodplain cores in upper BBC indicate rates of post-1963 sedimentation ranging from 0.28 cm/yr to 0.45 cm/yr (Fig. 31). Four floodplain cores in middle BBC returned sedimentation rates ranging from of 0.40 cm/yr to 0.66 cm/yr and revealed higher contemporary rates of sedimentation in the upper reaches of middle BBC that quickly attenuate downstream (Fig. 31). Two floodplain cores from lower BBC yielded post-1963 sedimentation rates of 0.54 cm/yr and 0.40 cm/yr (Fig. 31). In general, upstream pit locations had shallower accumulations of post-1963 legacy deposits at depths ranging from 10-25 cm. Middle BBC had larger accumulations of contemporary legacy deposits at depths ranging from 13-35 cm. Legacy depths in lower BBC ranged from 22.5- 30 cm. Post 1954 sediment depths are about 50 cm deep in upper, 40-50 cm in middle, and 60 cm deep in lower BBC sites. According to these results, middle BBC has been subject to higher rates of contemporary sedimentation than the upper reaches of the watershed. This may be due to recent channelization disturbance occurring in middle BBC which increase transport capacity of the channel and introduce more bank and bed sediment to the stream. Also, rates of sedimentation could be higher here as a result of increased historical and recent pastoral and farming practices in middle BBC compared to upper BBC. Due to a lack of ^{137}Cs analyses from multiple locations in the lower portions of BBC, recent sedimentation rates from other methods are needed to put upstream depositional rates into a larger, drainage basin-scale context.

In upper Big Barren, there were six locations in which the pre-settlement surface was located. These boundaries helped to constrain rates of post-settlement sedimentation occurring on low terrace and floodplain surfaces ranging from 0.24 cm/yr to 0.64 cm/yr. The depth to buried soil boundary ranged from approximately 30 cm to 80 cm. In middle BBC, three pre-settlement surfaces were identified and constrained rates of post-settlement sedimentation ranging from 0.24 to 0.35 cm/yr. Depths to buried soil boundaries ranged from 30 cm to 45 cm. Two pre-settlement boundaries were identified in lower BBC and helped to constrain rates of post-settlement sedimentation prior to 1963 ranging from 0.20 cm/yr to 0.24 cm/yr. These results indicate that rates of contemporary alluvial landform deposition in the upper and middle portions of BBC decreased during the time following the 1960’s. This corroborates findings of earlier literature that found peaks in legacy sedimentation associated with the height of original soil and runoff disturbances such as agricultural land clearing periods in the U.S. (Knox, 1987; Lecce and Pavlowsky, 2014; Owen et al., 2011).

In upper BBC, a total of six trees ranging in age from 28 to 51 years were cored to estimate contemporary sedimentation rates (Table 14). Tree analyses returned recent sedimentation rates ranging from 0.0-0.41 cm/yr with an average rate of 0.24 cm/yr. Additionally the stumps of historically cut pines during the early logging period were used to determine rates of sedimentation to present ranging between 0.31-0.36 cm/yr occurring after the logging period in upper BBC. A total of four trees in middle BBC aged 48-76 were cored and returned rates ranging from 0.0-0.21 cm/yr with an average rate of 0.14 cm/yr. In lower BBC, a total of four tree ages 30-45 and returned rates ranging from 0.26 cm/yr to 1.36 cm/yr with an average rate of 0.96 cm/yr. These trends are consistent with the results obtained from the ^{137}Cs analysis (Table 31).

Legacy Sediment Contribution to Fine-grained Alluvial Storage. At sites where stratigraphic boundaries within legacy deposits were determined, the average storage of legacy sediment within landform features was calculated (Table 17). In general, most of the legacy sediment identified in the upper portions of the watershed was stored on paleo-channel features which presently (in 2018) form channel bench or floodplain features. These features are areas of the stream that once exhibited a wide, multi-threaded channel geometry, were infilled with legacy sediment, and then incised down past the depth of the paleo-channel bed, and now function as bench or floodplain surfaces for the current stream. Average legacy storage within these floodplain paleo-channel features ranges from 0.8 m^3/m -12.8 m^3/m in the headwaters of BBC. In middle BBC, channels, floodplains, terraces, and floodplain paleo-channels store legacy sediment ranging from 3 m^3/m to 50.4 m^3/m with terraces storing most of the legacy sediment. In lower BBC, most of the legacy sediment is stored in floodplain and terrace features with 15.2 m^3/m stored in floodplains and over 89.3 m^3/m stored in terrace features (Table. 17). Overall, legacy storage seems to be spatially discontinuous with most sediment being stored on paleo-channel banks and benches in the headwaters, terrace features in the lower, and mixed among landforms in middle BBC.

Legacy sediment was calculated as a percent of total fine-grained landform storage at 12 different sites within BBC (Table 17). Legacy storage was calculated for the floodplain, floodplain paleo-channel, and terrace by taking the average total fine-grained sediment volume within a landform, divided by the average volume of legacy sediment within that landform to determine the percent legacy storage by landform for each site. In upper BBC, legacy storage volumes within floodplain paleo-channels accounted for between 5 and 16 % of the total fine-grained floodplain storage, while legacy sediment storage in terrace features accounted for nearly 38 % of the total fine-grained terrace storage. In middle BBC, between 9 to 15.5 % of all floodplain paleo-channel storage is accounted for by legacy sediment, while legacy sediment stored in terrace features accounts for nearly 26 % of total fine-grained terrace storage. To a lesser extent, only 8 % of the total fine-grained channel storage is made up by legacy deposits in middle BBC. However, places with larger in-channel bench deposits returned higher percent legacy channel storages of approximately 11 %. In lower BBC, legacy sediment within historically stable floodplain features was determined to make up around 5 % of the total fine-grained storage. Conversely, legacy storage within terrace features accounted for a substantial 30 % of total fine-grained terrace storage within sites in lower BBC (Table 17). Overall, legacy deposits in BBC tend to contribute to about ≥ 10% of total fine-grained sediment storage in paleo-channel and flood plains and approximately 30% in terraces (table 17).

Stratigraphic Analysis at Selected Sites. The buried-A horizons marking the pre-settlement boundary were difficult to find and identify in the field. Barnes Hollow head-cut site at R-km 35.8, is one example of a visible buried-A that was identified in the field (Fig. 32). This boundary occurred within a high floodplain feature cut off from the stream due to aggressive head-cutting and stream incision. The exposed cut bank contained approximately 20 cm of yellowish-brown sandy loam with 40% gravel at the top of its profile. Underlying this, a small layer of yellow-brown sandy loam with minor gravel overlies a distinctly darker Ab horizon buried at a depth of 50 cm. The Ab is characterized by a dark brown silt loam deposit overtopping a light brown, sandy loam mixed with 30% gravel. At a depth of 90 cm the old channel bed is visible and is characterized by a sandy deposit with 60% coarse gravel. Assuming the top of the A-horizon indicates the pre-settlement contact, sediment has been accumulating on this floodplain at an average rate of 0.39 cm/ year since the onset of European settlement (Fig. 33). A-horizons typically have LOI%'s from 0.8 to 6.2, while subsoil samples tend to have lower LOI % values from 0.3 to 1.8, depending on the location.

Upper Segment. At the upper BBC site at river kilometer 37.9, a combination of older cut pines and living trees were used to piece together a sedimentation history for the headwater region of BBC (Fig. 34). A pine-stump from the historical logging period (1880-1905) was determined to be buried at a depth of 0.22 m within the floodplain adjacent to the current channel. Using a tile probe we were able to identify the depth of the old channel bed at a depth of 0.45 m. Just upstream of our site along the same floodplain landform, a mature pine was cored and determined to be 29 years of age. The lateral roots of the tree were determined to be at the current ground surface. This indicates that during/ following the historical logging period there was approximately 0.22 m of fine-grained sediment accretion occurring on top of the paleo channel bed. More recently, since 1990 there has been effectively no accumulation of fine-grained historical infill overtop of the legacy sediment acquired after the logging period.

However, following infill of a portion of the paleo-channel bed, the current channel has continued to incise down below the depth of the old channel bed causing historical paleo-channel sediment to appear as sediment accumulated on higher floodplain features.

Middle Segment. Several stratigraphic boundaries were identified at Nature Conservancy site two where the truck mounted soil corer was able to extract seven cores along the floodplain and terrace units (Fig. 35). Core 5 was extracted from the Midco very gravelly loam alluvial soil series, and cores six through eleven were extracted from the Secesh silt loam series. Peaks in organic matter, ranging from 1.0 to 6.17 % were detected in most all the cores excluding core seven where a buried A-horizon was not visible. As a result, average post-settlement sedimentation rates for both the floodplain and terrace features were determined at 0.26 cm/yr and 0.30 cm/yr, respectively. Buried-A horizons in floodplain cores at this site were characterized by dark brown, organic-rich layers overlying a thick B horizon characterized by a blocky silt loam (B-horizons do not form in < 100-year-old sediment). A Bt horizon was indicated in core seven along the terrace/floodplain boundary at approximately 90 cm deep. This is an indicator that this surface is more representative of older Holocene sediments and less indicative of recent legacy sedimentation. Floodplain core five was tested for ^{137}Cs with the peak located at 7.5 cm below the surface, returning a rate of post 1963 sedimentation of 0.14 cm/ year. The buried-A identified in the same core was buried at a depth of 0.6 m. This area is known to be subject to recent channelization disturbance. The over-deepening of the stream and lack of connectivity between the channel and floodplain at this site may explain the decreased rate of sedimentation in recent years due to the fact that sediment is less likely to overtop channel banks and more likely to be transported downstream during the more frequent 1-2 year flow events.

Lower Segment. At the Lower Big Barren site a farm field surrounds a forested riparian belt. In this area there was an ample supply of mature trees growing on the floodplain suitable for dendrochronology analysis (Fig. 36). One soil pit was also dug here to provide information on the depth of the 1963 depositional boundary at the site. In general, the site was characterized by a large depth of fine-grained sediment within the floodplain features containing an average fine-grained sediment depth of 0.71 m. Additionally, trees ranging from 30-45 years of age were buried at depths of up to 0.43 m. This indicates a high level of recent sedimentation occurring in this area since at least 1973. The 1963 depositional boundary identified at this site returned a depth of approximately 0.23 m. This suggests a difference of 0.2 m in boundary depth which is within reasonable error. However, this disagreement in stratigraphy poses a potential problem and suggests that uneven topography of the floodplain and chute areas may preclude assumptions of horizontal stratigraphic relationships. It is known that during times of higher flood stages water spreads across the floodplain and into the adjacent roadcut which acts as a secondary channel during high water. It appears that the edges of the floodplain nearest to the road have a lower density of trees and riparian vegetation and may be subject to faster rates of erosion during these larger flow events when the road is activated as a second channel. The roots of vegetation and trees work to anchor and reinforce the soil matrix making it less prone to bank failure (Krzeminska et al., 2019). Places along the floodplain along the road with less vegetation may have eroded at an accelerated rate in comparison to the rest of the floodplain causing stratigraphic boundaries to vary in depth across the floodplain.

Watershed Disturbance Effects on Historical Sedimentation. Sedimentation rates for all landform features were combined to determine sedimentation histories occurring during different periods of time for the upper, middle, and lower portions of BBC highlighting the spatial distribution of legacy deposits, at what rate they were deposited and why (which period of disturbance did they follow) (Table 18; Fig. 37). In the upper portions of the watershed, sedimentation rates were much higher during the post-settlement (>1890) period with an average rate of 0.46 cm/yr. Recent rates of sedimentation occurring post-land management (>1963) are much lower in this zone with average rates of approximately 0.29 cm/ year (Table 18; Fig. 37). This suggests that this portion of the watershed was more strongly influenced by the effects of historical logging disturbance (construction of trams, logging roads, and soil cover disturbance) occurring before 1963 and has been stabilizing ever since. This trend is consistent with watersheds subject to early disturbance associated with agricultural activities in the upper Mississippi valley accompanied by high rates of sedimentation that tend to decrease following periods of better land management (Knox, 1987).

While direct logging activities had some effect, it was most likely subtle compared to the indirect effects of forest cover change from coniferous to hardwood forest. The selective removal of conifer species from watersheds decreases rainfall interception and increases stream discharge (Dunne and Leopold, 1978). Conifers possess greater amounts of foliage and branches more consistently throughout the year. Furthermore, the needles of conifer species provide more precipitation interception potential and storage than broad leaf hardwoods (Dunne and Leopold, 1978). Median values of canopy interception as a percentage of annual gross precipitation indicate that coniferous forests intercept approximately 15% more gross annual precipitation than deciduous forests (Dunne and Leopold, 1978). Additionally, research by Shuhan Du (2013) compared interception rates of two different forest cover types (coniferous and mixed broadleaf/ coniferous) in the Sichuan Province of China near the Yangtze River, and found that coniferous forests in Tibet intercepted 30% more rainfall than their oak-dominated mixed forest counterpart.

Hardwood deciduous forest stands tend to lose their leaves in the winter leading to a decrease in rainfall interception and an overall increase in runoff and stream discharge during the leaf off season. This trend is further worsened in Big Barren Creek watershed as most flood events occur in the late fall and early spring months (Pavlowsky et al., 2016). Consequently, the increased runoff resulting from a decrease in precipitation interception in the headwaters of BBC may have contributed to the increase in hillslope soil and channel erosion occurring in this area during the post-settlement period sometime after the 1890s. The extensive depletion of short leaf pine in this area during the logging exploitation period has allowed for the dominant regrowth of oak and other deciduous hardwoods. This change in vegetation may have caused longer-term changes in precipitation, interception, and runoff contribution to stream discharge allowing for increases in rates of upland soil and tributary erosion and deposition. Furthermore, continuing to the present day, it is estimated that mixed pine-oak woodland cover is only 15% of the prehistorical stand ranges once existing in the Ozarks (Cunningham and Hauser, 1989; Guyette et al., 2007).

However, since 2000 the U.S. Forest Service has implemented prescribed fire management as a part of the Missouri Pine Oak Woodland Restoration Project. This management technique involves the selective burning of certain watershed units to restore openings in tree canopies allowing for conifer species to compete and thrive in more open woodland environments. This slow conversion of the watershed back to pine stand dominated areas may be reversing the initial effects of logging disturbance and re-introducing higher precipitation interception potential. This process will diminish the effects of rain drop impact on the forest floor reducing soil erosion and potentially reduce rainfall runoff contributions to the stream leading to a reduction in legacy sediment deposition occurring in more recent years (>2000).

However, in contrast to better forest management practices in recent years, studies show that more frequent intense precipitation events (>3 in) within the last 30 years have been occurring in the Ozarks compared to historical records from 30 years prior (Pavlowsky et al., 2016). Additionally, a study by Wuebbles and Hayhoe (2004) analyzing precipitation totals in the Midwest, has projected a 30% increase in winter precipitation by the year 2090. In the same study, it was also determined that the frequency of heavy precipitation events in the Midwest has increased over the past century and is projected to nearly double by the end of the next century. This increase in frequent intense storm events may contribute to higher runoff and erosion rates occurring in BBC.

In middle BBC (R-km 16-36) sedimentation rates during post-settlement (1890-1950) and post-land management (>1950) periods moderate at 0.28 cm/yr and 0.26 cm/yr, respectively. The lower rate of post-land management sedimentation suggests that recent channelization that is cutting the channel off from its adjacent floodplains, may be limiting the amount of recent deposition in this area. Theis (2017) indicated that in some channelized locations with constructed levees along Big Barren Creek the channel can contain up to the 100-year flood stage. This prevents a majority of smaller, more frequent flows from overtopping channel banks and depositing suspended sediment on floodplains by increasing transport capacity and flushing sediment downstream. This effect, though quickly attenuating downstream of channelized zones, drastically influences the spatial distribution and quantity of sediment deposited in landform features in channelized areas following the post-channelization period (> 1960). Historical post-settlement sedimentation rates in the channelization zone average at approximately 0.30 cm/year. It is likely that sediment is transported through areas of channelized stream where transport capacities are great and carried further downstream.

In the lower portions of the watershed (R-km 36-40), we see an opposite trend in sedimentation rates compared to the headwaters of BBC. The post-settlement sedimentation rates occurring post 1890 in this area were among the lowest in the watershed at an average of 0.22 cm/year. The decrease in sedimentation rates suggest that the effects of timber harvest were not as prevalent in this area of the watershed during the initial logging period and effects likely attenuated very quickly moving downstream out of the upland areas into tributaries. Following logging practices, downstream soil and vegetation were left largely intact in many places, while upstream runoff and sediment loading increased slightly. This sediment was trapped in the tributaries because the hydraulically rough, multi-threaded, channels worked to resist channel flow velocity and resulted in the deposition of sediment close to the source. The highest rates of legacy sedimentation occurred in the lower portion of the watershed (R-km 0-16) downstream of several large disturbance zones following the land management period (post 1950) with sedimentation rates ranging from 0.40 cm/year to 1.36 cm/year with an average recent rate of 0.80 cm/year. These rates remain historically the highest rates of sedimentation in BBC despite the widespread introduction of land conservation practices that were implemented in this time starting in the 1950's (Knox, 1977, 1987, 2002, 2006; Magilligan, 1985).

The drastic increase in sedimentation rates following the 1950's period leads us to believe that direct modification of the stream through channelization increased sediment input in the channel and increased transport capacity. This allowed for increased rates of recent sedimentation into channels and on the floodplains of lower BBC. Furthermore, increases in the amount of intense rain events occurring in the Ozarks as a result of climate change have increased the frequency of flood events capable of eroding and transporting sediment in streams

(Wuebbles and Hayhoe, 2004; Pavlowsky et al., 2016). The increase in flood events may account for increased rates of sedimentation in recent years. Additionally, erosion occurring in large disturbance zones may be releasing sand downstream as a result of channelization upstream occurring after the 1950s.

Channel Response

Legacy sediment deposition patterns in BBC are also indicative of larger-scale changes in channel morphology. Channels in BBC prior to European settlement would have consisted of predominantly multi-threaded channel systems hydraulically controlled by the location of trees and dense vegetation. Channels during this time would have had no legacy deposition on floodplains and channel features. More runoff caused by the transition to hardwood forests would have increased flood peaks causing higher stream power and channel enlargement. However, channels in BBC during this time were robust and resistant due to high density of trees in the channel, coarse substrate and bedrock in places, and bio-mantled beds with significant armoring from roots and riparian vegetation. This would have limited and buffered the rates of channel response causing a geomorphic lag. Geomorphic lags are introduced into watershed networks when a gradual or persistent geomorphic change occurs due to disturbance outside normal boundary conditions, in this case a change in channel hydrology related to increased runoff following pine logging (Chappell, 1983). In other words, channels are responding slowly to past disturbance and may still be responding to historical disturbances today. These responses may be further exacerbated by more intense storms due to recent climate change (Pavlowsky et al., 2016).

Following historical disturbances, multi-threaded channels in BBC have filled with fine-grained sediment in some places. Sediment fills are limited to bank margins and channel beds and benches and have facilitated the narrowing of active channel flows, thus concentrating water into incised main threads creating a 1.5-thread (single channel with a chute) or single-threaded channel geometry in places (Fig. 38). The process is contrary to the classic model of overbank legacy deposition experienced by most single-threaded streams since deposition occurs in and over the channel and not on adjacent overbank floodplains. However, Walter and Merritts (2008) and Jacobson and Coleman (1986) during their studies on north American rivers, found similar legacy sedimentation patterns characterized by post-settlement alluvium that has infilled and covered most pre-settlement wetland channels and their poorly drained floodplains. It may be suggested that forested watersheds, are more likely to exhibit this multi-channel infill of legacy deposition as a result of smaller more frequent flooding events as opposed to the vertical accretion of legacy deposits occurring on larger main stems resulting from large flooding events exceeding bankfull discharge. Qualitative evaluation of present main channel suggests that only about 3 km of the stream exhibits a multi-threaded morphology in BBC accounting for approximately 8 % of the present channel length. However, GLO-VIS maps from 1850-1860 suggest about 23 km of multi-threaded channel planform accounting for approximately 58 % of the historical channel length. This evaluation suggests a reduction in multi-threaded main channel of about 88% since 1850. This supports research done on the Platte River in Wisconsin and other Wisconsin and midwestern channels that have tended toward more narrow, deep, single-threaded main channel in the lower reaches of the watershed in response to human disturbance compared to their pre-settlement counterparts (Knox, 1977). This tendency toward a more single-threaded channel geometry has facilitated in the decrease of in channel sediment accumulation in the downstream reaches of BBC due to the increase in transport capacity and bed scour occurring in these single-threaded stream reaches. This transition also facilitates in the movement of fine-grained sediment downstream through these single-threaded areas and toward the confluence with the Current River.

Overall, comparisons of legacy deposition rates indicate that legacy deposition in Big Barren Creek is on par with disturbance related legacy deposition experienced in other main stem streams and rivers throughout Missouri and the Midwest (Table 1). Owen et al., 2011 found average rates of sedimentation along the James River in southwest Missouri between 1800 and 1950 of 0.55 cm/yr and 0.32 cm/yr occurring after the 1930's. In addition, Pavlowsky et al., 2017 found rates of sedimentation along the Big River in southeastern Missouri of (1.3- 3.0) cm/yr occurring between 1800 and 1950 and (1.3- 3.0) cm/yr in the land management phase occurring after the 1930's. Both papers reveal increased sedimentation resulting from historical agricultural disturbances in the area. This is a strong indication that the amount of legacy deposition observed within Big Barren Creek may bare some significance as to the level of forest disturbance experienced in this area. In addition, similarities in BBC's legacy deposition rates compared to studies done in larger, less forested, valley systems are further made significant due to the normally low natural rates of overbank sedimentation assumed to occur in mature forested watersheds. This indicates that in order for a small, heavily forested watershed to experience rates more common to open valley main stem systems, there needs to be large-scale forest stand or direct channel disturbance. In BBC, disturbances may have been further exacerbated by the effects of climate change and its effect on increasing recent flood frequency (Pavlowsky et al.,2016). These changes in watershed factors may be effectively working in combination to influence the channel morphology in forested watersheds and increase the amount of sediment deposited in the alluvial landforms in BBC.

Table 9. Downstream Variation in Main stem Hydro-Geomorphic Zones

R-km	Stream Hydrology	Class	Geomorphic Classification	Recent Disturbance
38-40	Ephemeral	EM	Multi-threaded	Logging, Tram construction (minor)
30-38	Ephemeral	ESC	Single-channel, Channelized	Channelization: deep channel, head-cuts, and levees
25.6- 30	Ephemeral	EM	Multi-threaded	Minor
21- 25.6	Ephemeral	ESC	Single-channel, Channelized	Channelization
16.5-21	Permanent Base Flow	PS	Natural, single-threaded with chutes	Minor
6.5-16.5	Intermittent	ISD	Disturbance zone channels, single-threaded (wide and filled with gravel bars) with chutes	Bank erosion, aggradation (bed and bench)
1-6.5	Permanent Base Flow	PS	Natural, single-threaded with chutes	Minor

Table 10. Fine-grained sediment depths (m) on valley landforms.

Site Name	Distance from mouth (km) (*= mainstem)	Ad km^2	Probe Depth (m)						
			Channel		Floodplain		Terrace		Total
			n	Avg.	n	Avg.	n	Avg.	Width weighted Avg.
1) Tram Hollow	38.6	1.6	1	0.00	6	0.42	3	0.50	0.25
2) R-KM3/M9	39.0*	1.8	8	0.49	4	0.68	1	0.64	0.60
3) Upstream UBB farm	38.2*	1.9	4	0.44	8	0.59	2	0.54	0.51
4) UBB farm site	38.0*	2.0	13	0.37	2	0.70	2	0.36	0.38
5) Cowards Hollow	18.7	2.2	6	0.21	15	0.26	6	0.73	0.27
6) Upper Big Barren	37.9*	2.5	0	N/A	3	0.38	9	0.40	0.30
7) UBB Head-cut	37.7*	2.5	4	0.24	1	0.61	4	0.89	0.26
8) Wolf Pond	33.2	5.1	3	0.25	12	0.43	3	0.39	0.65
9) Pole Cat Hollow	32.5	6.2	0	N/A	27	0.68	3	0.50	0.35
10) South Prong Cedar	27.5	7.3	1	0.33	9	0.35	9	0.34	0.19
11) Fools Catch Creek	23.7	7.8	1	0.10	6	0.18	12	0.83	0.62
12) Above J-HWY/C road	36.6*	8.0	2	0.60	4	0.56	4	0.73	0.69
13) Barnes Head-cut	35.8	9.1	4	0.37	0	0.40	1	0.75	0.63
14) NatCon2	23.3	21	1	0.00	2	0.58	4	1.44	0.98
15) German Shepard House	32.8*	23.5	4	0.43	5	0.85	0	N/A	0.48
16) Middle Big Barren	26.0*	47.5	2	0.08	14	0.58	5	1.01	0.71
17) MBBC Head-cut	26.8*	48	6	0.27	8	0.98	1	0.83	0.25
18) U.S. Bearpen Head-cut	25.0	52	5	0.22	2	0.83	7	0.99	0.76
19) NatCon1	23.9	53	1	0.00	5	0.64	1	0.38	0.43
20) Bristol Road Upstream	22.0*	87	7	0.11	3	0.48	2	1.00	0.86
21) Upper NA	18.5*	103	6	0.54	5	0.76	0	0.00	0.61
22) Ford Site	10.3*	160.5	5	0.42	6	0.38	0	N/A	0.05
23) Lower BBC	4.0*	183	2	0.08	9	0.71	2	0.74	0.70

Table 11. Measured cross-sectional landform storage (m^3/m).

	Measured Widths (m)					Calculated Volume (m^3/m)			
Site Name	Channel	Floodplain	Terrace	Total width (m)	Confinement ratio	Channel	Floodplain	Terrace	Total Volume (m^3/m)
1) Tram Hollow	10	16	16	58	0.16	0.0	6.7	8.0	15
2) R-KM39	41	26	59	126	0.32	20.0	17.6	37.8	75
3) Upstream UBB farm	29	19	12	60	0.49	12.7	11.3	6.5	30
4) UBB farm	27	4	34	65	0.42	10.0	2.4	12.2	25
5) Cowards Hollow	10	15	10	49	0.20	2.1	3.8	7.3	13
6) Upper Big Barren	6	6	14	27	0.23	N/A	2.4	5.7	8
7) UBB Head-cut	12	10	9	66	0.18	2.9	6.1	8.0	17
8) Wolf Pond	10	50	60	72	0.14	2.6	21.4	23.2	47
9) Pole Cat Hollow	12	23	10	60	0.20	N/A	15.7	5.0	21
10) South Prong Cedar	15	25	7	87	0.17	5.0	8.8	2.5	16
11) Fools Catch Creek	4	18	70	100	0.04	0.4	3.3	58.0	62
12) Above J-HWY/C	29	60	247	336	0.09	17.5	33.6	179.2	230
13) Barnes Head-cut	78	21	200	300	0.26	29.1	8.4	150.1	188
14) NatCon2	19	76	106	200	0.09	0.0	43.8	152.5	196
15) German Shepard House	31	30	19	80	0.39	13.2	25.6	N/A	39
16) Middle Big Barren	74	45	48	167	0.66	5.6	26.4	48.3	80

Table 11. continued. Measured cross-sectional landform storage (m^3/m).

	Measured Widths (m)					Calculated Volume (m^3/m)			
Site Name	Channel	Floodplain	Terrace	Total width (m)	Confinement Ratio	Channel	Floodplain	Terrace	Total Volume (m^3/m)
17) MBBC Head-cut Site	62	10	16	158	0.39	16.6	9.8	13.3	40
18) 40m U.S. Bearpen Head-cut	25	18	54	97.2	0.26	5.4	14.9	53.7	74
19) NatCon1	28	79	93	200	0.14	0.0	50.6	35.4	86
20) Bristol Road Upstream	29	12	189	230	0.13	3.3	5.7	189.2	198
21) Upper NA	46	22	0	68	0.68	25.0	16.6	0.0	42
22) Ford Site	23	36	443	500	0.05	9.6	13.9	N/A	23
23) Lower BBC	19	48	357	423.8	0.04	1.4	33.9	262.4	298

Table 12. Pearson Correlation between Site Characteristics and Fine-grained Sediment Storage Volume (m^3/m)

Variable	R-km	Channel width	Drainage Area	Slope	Valley Width	Distance from Disturbance
Total Volume	-0.443*	0.214	0.569**	-0.568**	0.949**	0.589**
	0.044	*0.351*	*0.007*	*0.007*	*0.000*	*0.005*
Channel Volume	0.279	0.374	-0.035	-0.149	0.122	-0.128
	0.220	*0.095*	*0.879*	*0.520*	*0.597*	*0.581*
Floodplain Volume	-0.276	0.240	0.273	-.515*	0.379	0.278
	0.203	*0.270*	*0.207*	*0.012*	*0.075*	*0.199*
Terrace Volume	-0.451*	0.152	0.560**	-0.509*	0.921**	0.596**
	0.040	0.512	0.008	0.019	0.000	0.004

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Significance (2-tailed)

Table 13. Pearson Correlation between Site Characteristics and Fine-grained Sediment Storage Depth (m)

Variable	R-km	Channel width	Drainage Area	Slope	Valley Width	Distance from Disturbance
Total Average Depth	-0.199	0.458*	0.140	0.135	-0.036	0.156
	0.362	*0.028*	*0.523*	*0.538*	*0.871*	*0.478*
Average Channel Depth	0.061	0.305	-0.319	0.193	-0.184	0.129
	0.788	*0.167*	*0.149*	*0.388*	*0.412*	*0.568*
Average Floodplain Depth	-0.304	0.392	0.225	-0.046	-0.023	0.176
	0.159	*0.064*	*0.302*	*0.836*	*0.915*	*0.422*
Average Terrace Depth	-0.127	0.112	0.221	0.056	0.082	0.043
	0.563	0.609	0.311	0.798	0.711	0.847

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Significance (2-tailed)

Table 14. Dendrochronology Analysis.

Tree #	R-km	lat.	long.	Species	Diameter (dbh cm)	Burial Depth (m)	Tree Ring Age (Rings + 5 years)	Tree Sprout Year	Sed. Rate (cm/yr)
1	4	-90.9661	36.7980	Hackberry	29.5	0.4	32	1986	1.3
2	4	-90.9661	36.7979	Hackberry	21.5	0.45	33	1985	1.4
3	4	-90.9660	36.7980	Sycamore	35	0.43	45	1973	1.0
4	4	-90.9661	36.7977	Hackberry	30	0.08	30	1988	0.3
5	18.5	-91.0666	36.8532	Hickory	25	0	52	1966	0.0
6	26	-91.1169	36.8624	Green Ash	33	0.12	64	1954	0.2
7	32.8	-91.1567	36.8701	Pine	28.5	0.1	48	1970	0.2
8	32.8	-91.1566	36.8701	Pine	33.5	0.1	65	1953	0.2
9	37.8	-91.1978	36.8735	Pine	21	0	29	1989	0.0
14	38.2	-91.1994	36.8760	Pine	131	0.21	51	1967	0.4
15	39	-91.2045	36.8814	Pine	130	0.15	48	1970	0.3

Table 15. Old Growth Pine Stump Analysis.

Tree #	R-km	lat.	long.	Species	Burial Depth (m)	Landform	Tree Sprout Year	Sed. Rate (cm/yr)
1	37.8	-91.1979	36.8737	Pine stump	0.22	FP_{PC}	pre-settlement surface	0.2
2	37.8	-91.1986	36.8747	Pine stump	0.06	FP_{PC}	pre-settlement surface	0.05
3	37.8	-91.1986	36.8749	Pine stump	0.02	FP_{PC}	pre-settlement surface	0.02
4	38	-91.1987	36.8753	Pine stump	0.2	FP	pre-settlement surface	0.2

Table 16. Buried Soil and LOI and Analyses.

Site Name	R-km	Depth to buried-A (cm)	LOI %	Landform	Lat.	Long.	Sed. Rate (cm/yr)
7) UBB Head-cut	37.7	65	Identified in field	Terrace	-91.173906	36.86687	0.51
12) Cemetery Road	36.6	30	1.65	FP_{PC}	-91.189142	36.867859	0.24
12) Cemetery Road	36.6	50	0.88	Floodplain	-91.189275	36.867931	0.39
13) Barnes Head-cut	35.8	50	Identified in field	FP_{PC}	-91.177272	36.868046	0.24
13) Barnes Head-cut	35.8	50	Identified in field	Floodplain	-91.177272	36.868046	0.39
14) NatCon 2	23	45	1.58	FP_{PC}	-91.099944	36.848395	0.51
19) NatCon 1	24	30	0.94	Floodplain	-91.106623	36.847384	0.24
23) Lower BBC	4.2	30	Identified in field	Floodplain	-90.966056	36.797975	0.23
23) Lower BBC	4	25	0.96	Terrace	-90.965719	36.797561	0.2
24) U.S. of Cemetery Road	36.8	70	0.88	Floodplain	-91.189835	36.867974	0.56
25) R-km 35.6	35.6	80	Identified in field	Floodplain	-91.173906	36.86687	0.64

*Top of buried A-horizon is assumed to represent the pre-settlement and early logging period surface of the channel bed or floodplain in 1890. FP_{PC} represents an infilled paleo-channel that now functions as a current floodplain to an incised channel.

Table 17. Average legacy sediment volume stored cross-valley landforms by site.

Site Name	R-km	Method used for boundary	Landform	Legacy depth (m)	Average legacy volume (m^3)	Average volume by landform (m^3)	% of total fine-grained storage
R-km39	39	tree date	FP_{PC}	0.2	3.9	3.9**	5.2
U.S. UBB farm	38.2	tree date	FP_{PC}	0.2	0.8	0.8**	2.6
UBB farm	38	tree date	FP_{PC}	0.2	4.0	4.0**	16.2
UBB Head-cut	37.7	buried-a	Terrace	0.7	6.5	6.5***	38.4
Cemetery road	36.6	buried-a	FP_{PC}	0.3	18.0	12.8**	5.6
	35.8	Cs137	FP	0.1	7.5		
Barnes Head-cut	23.3	buried-a	FP_{PC}	0.5	10.5	10.5**	5.6
NatCon2	32.8	buried-a	FP_{PC}	0.5	34.2	18.2**	9.3
		buried-a	FP_{PC}	0.3	22.8		
		Cs137	FP_{PC}	0.1	5.7		
		Cs137	FP_{PC}	0.1	10.3		
		buried-a	Terrace	0.5	53.0	50.4***	25.7
		buried-a	Terrace	0.5	47.7		

FP_{PC} indicates a infilled paleo-channel that now functions as a current day floodplain to an incised channel

*Average legacy storage in the channel

** Average legacy storage in the floodplain

*** Average legacy storage in the terrace

Table 17. Continued…Average legacy sediment volume stored cross-valley landforms by site.

Site Name	R-km	Method used for boundary	Landform	Legacy depth (m)	Average legacy volume (m^3)	Average volume by landform (m^3)	% of total fine-grained storage
German Shepard	23.5	tree date	C1	0.1	3.1	3.1*	8.0
		tree date	FP_{PC}	0.1	3.0	3.0**	7.7
Middle Big Barren	26	buried-a	FP_{PC}	0.3	13.5	12.4**	15.5
		Cs137	FP_{PC}	0.3	11.3		
NatCon1	23.9	buried-a	FP	0.3	23.7	31.6**	36.8
		buried-a	FP (back swamp)	0.5	39.5		
Upper NA	18.5	tree date	Bench (channel)	0.1	4.6	4.6*	11.1
Lower BBC	4	buried-a	T1	0.3	89.3	89.3***	30.0
		tree date	FP	0.4	20.6	15.2**	5.1
		tree date	FP	0.5	21.6		
		tree date	FP	0.1	3.8		
		tree date	FP	0.4	19.2		
		Cs137	FP	0.2	10.8		

FP_{PC} indicates a infilled paleo-channel that now functions as a current day floodplain to an incised channel

*Average legacy storage in the channel

** Average legacy storage in the floodplain

*** Average legacy storage in the terrace

Table 18. Average Historical Sedimentation Rates by Channel Segment

Location	Period	# of sedimentation rates calculated	Average Rates (cm/yr)
Upper BBC R-km (35.6-40)	1890-1950	6	0.45
	1950-2018	6	0.29
	1890-2018	12	0.37
Middle BBC R-km (16-35.6)	1890-1950	3	0.28
	1950-2018	6	0.29
	1890-2018	11	0.26
Lower BBC R-km (0-16)	1890-1950	2	0.22
	1950-2018	6	0.8
	1890-2018	8	0.6

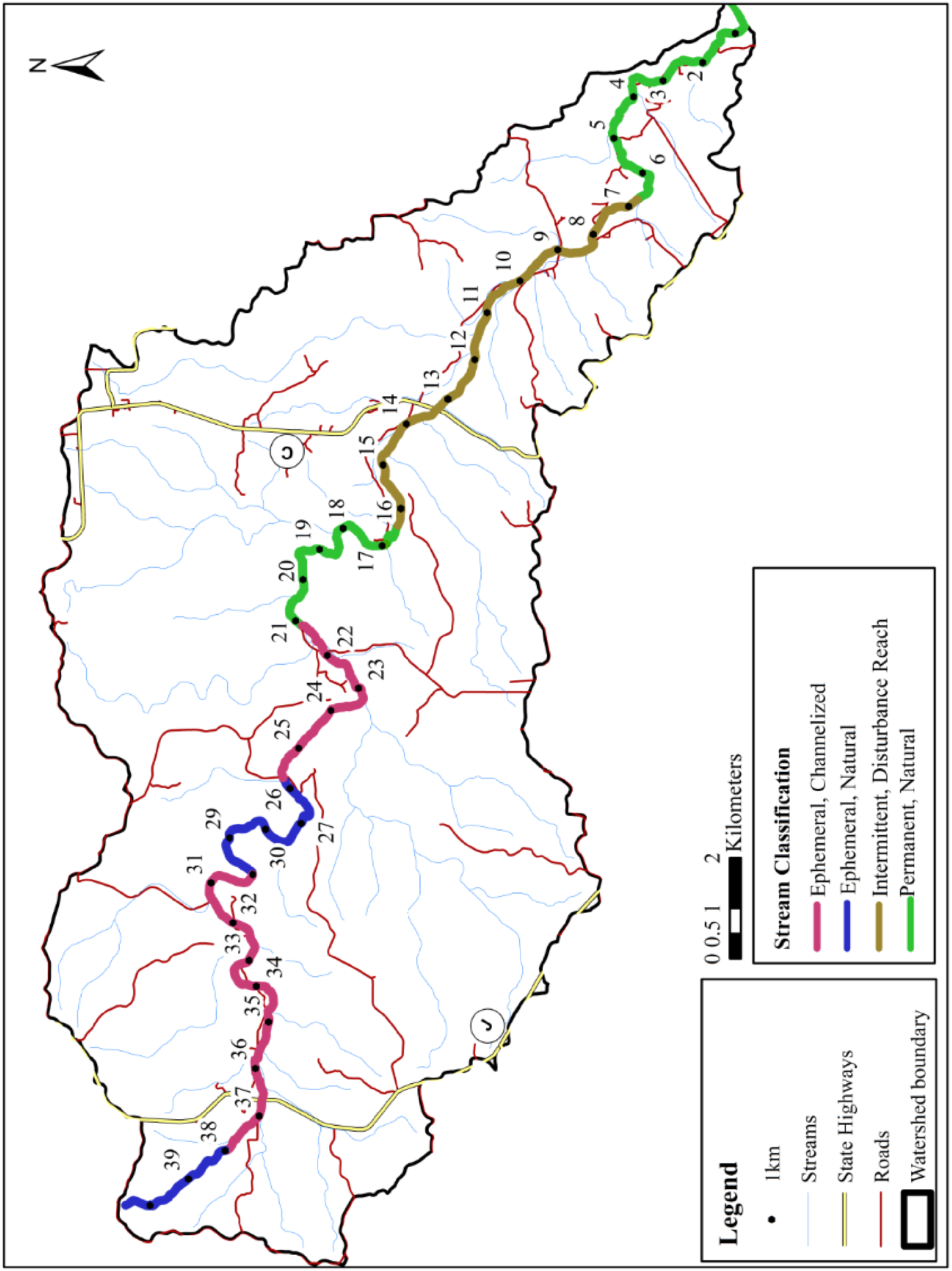


Figure 23. Hydro-geomorphic zones of Big Barren Creek.

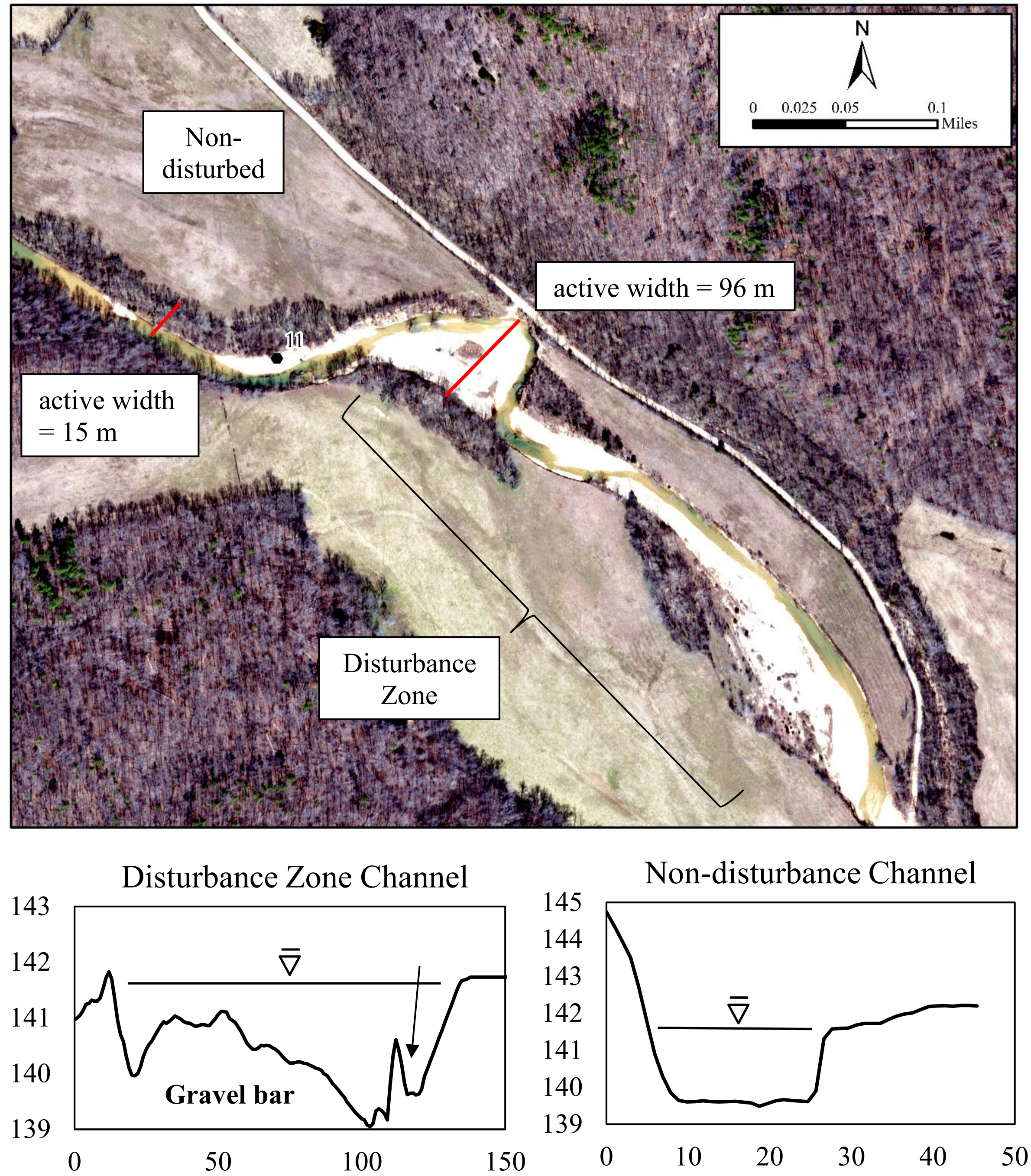


Figure 24. Aerial Imagery showing the dramatic changes in channel characteristics between disturbance and non-disturbance zones. Note: Lighter colored areas in the channel indicate active gravel beds and bars.

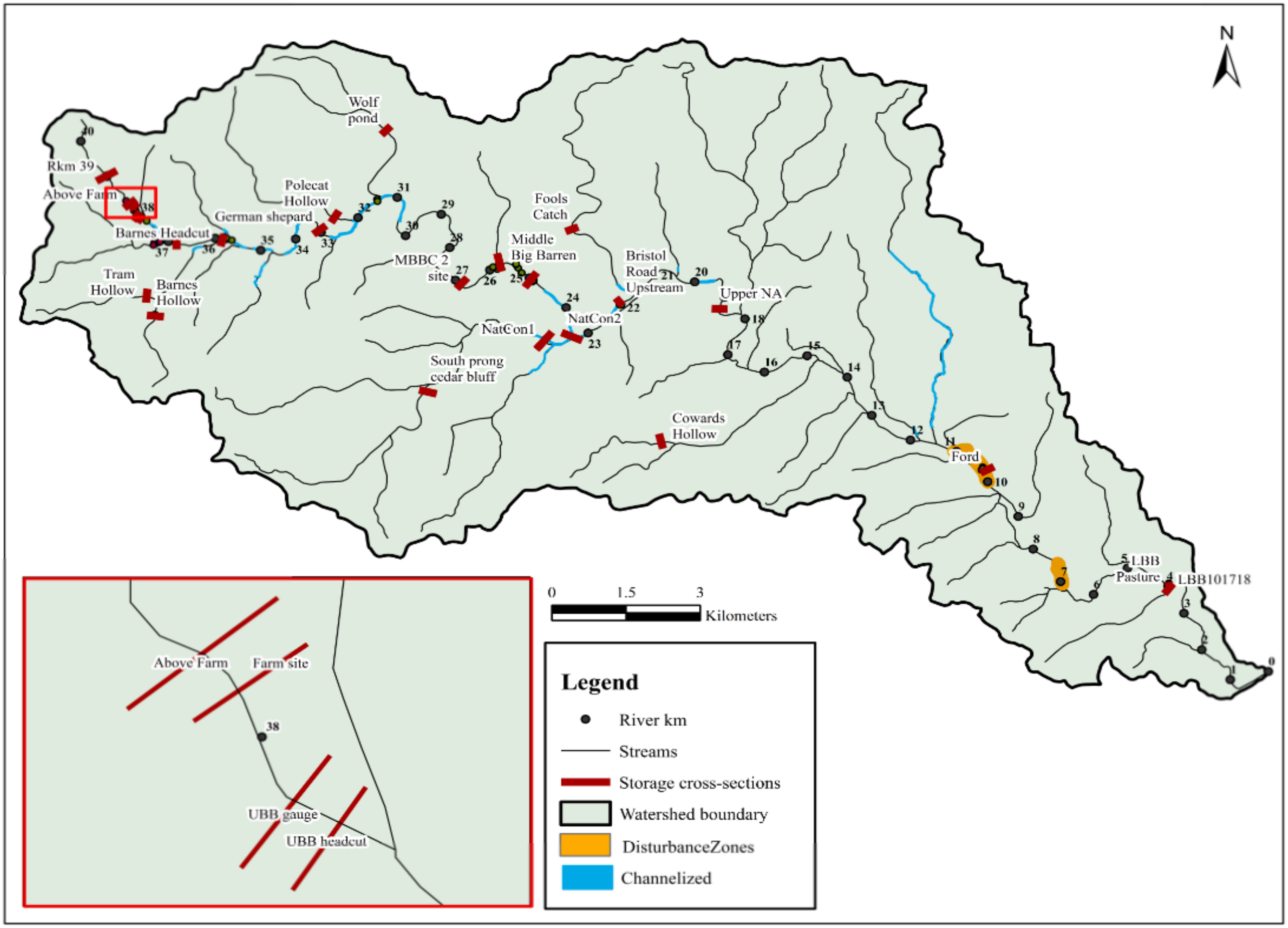


Figure 25. Valley cross-section sites used in storage analysis. An inset map indicated in red is included for a densely sampled area of the upper headwaters of BBC.

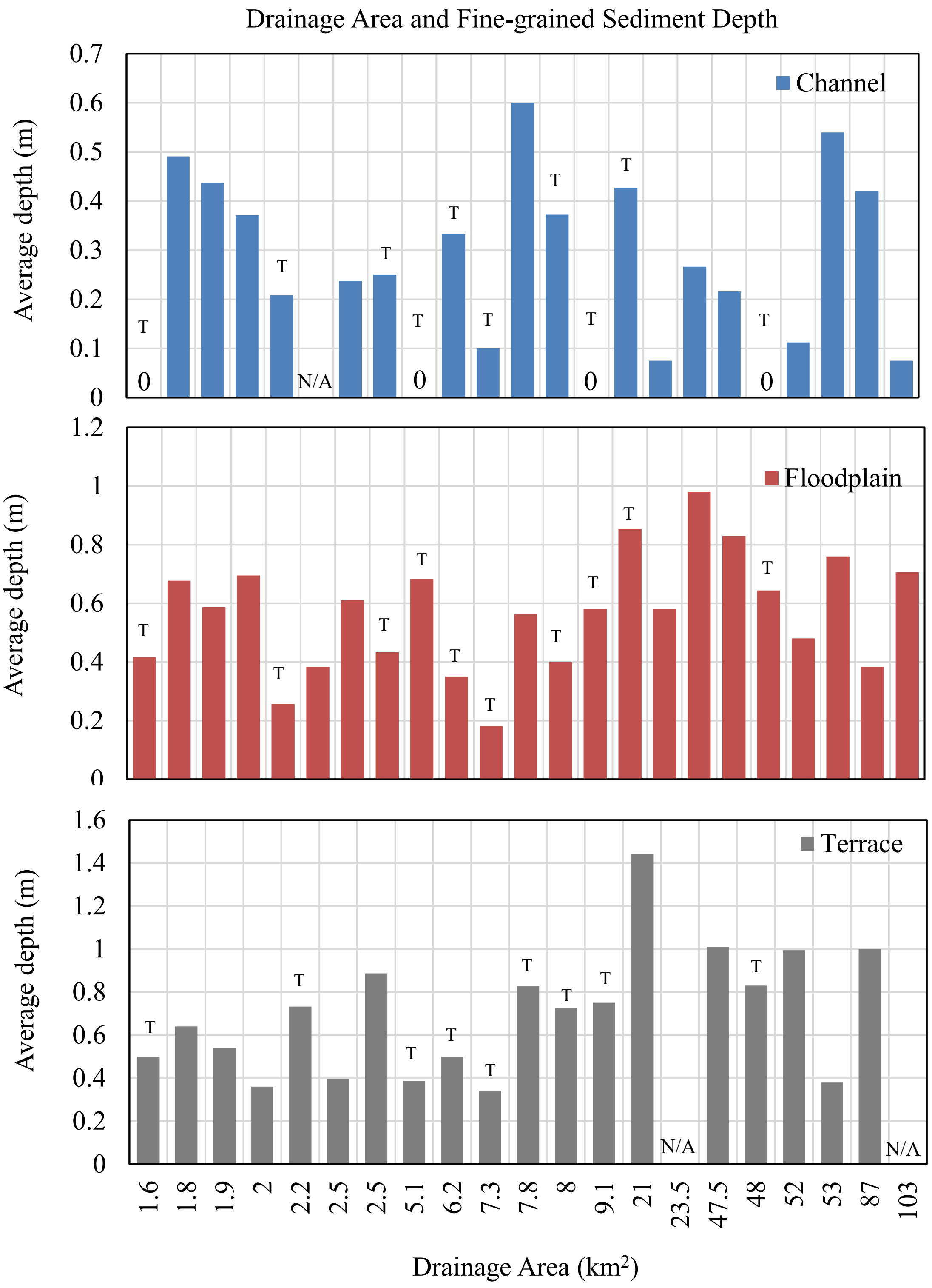


Figure 26. Fine-grained sediment depths by landform and drainage area. Locations labeled with a T indicate tributary sites while all others are mainstem sites. Values of zero indicated places were fine-grained sediment depth was 0 m deep. Values labeled N/A indicated places where measurement was unable to be obtained for a landform.

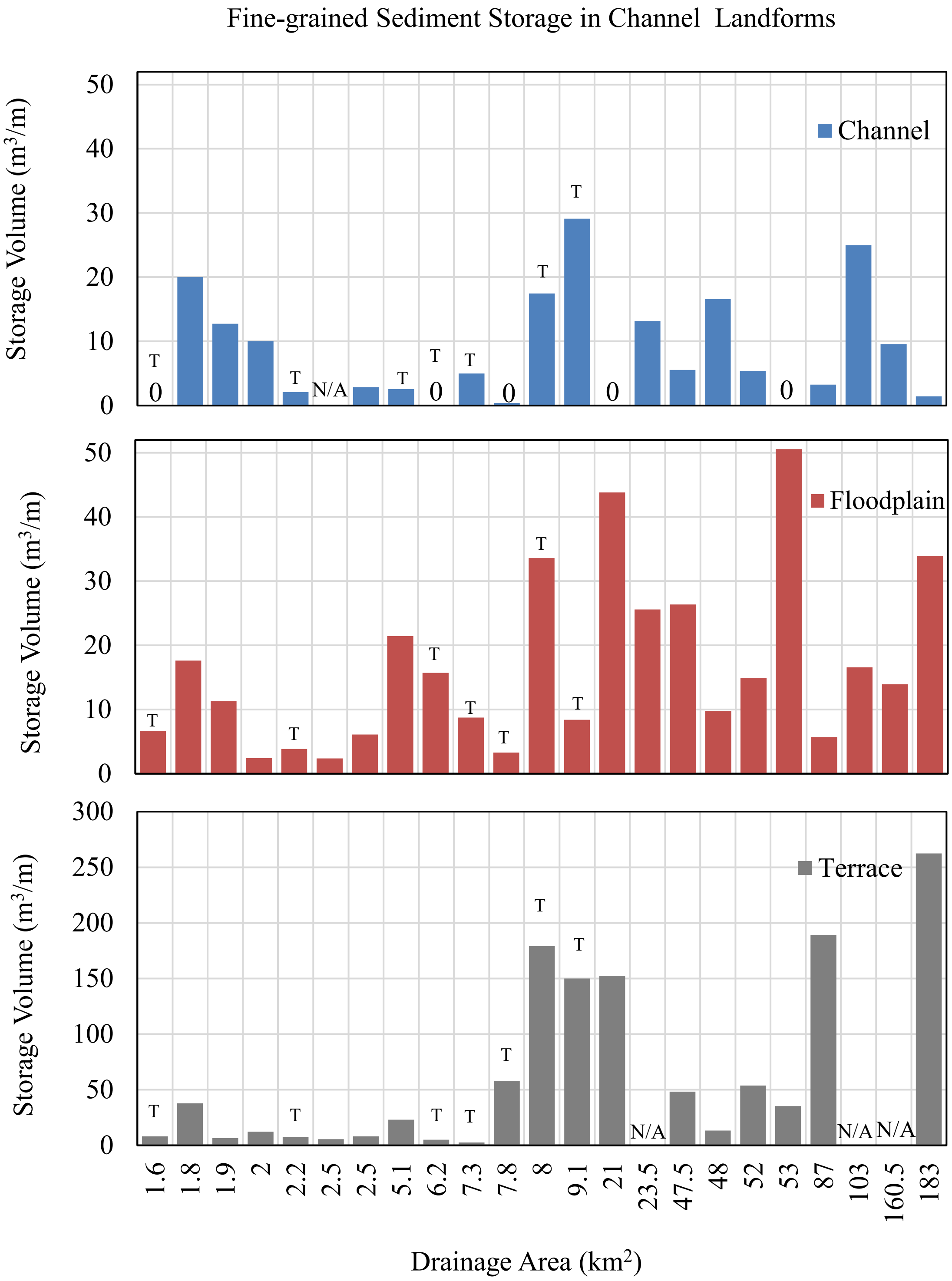
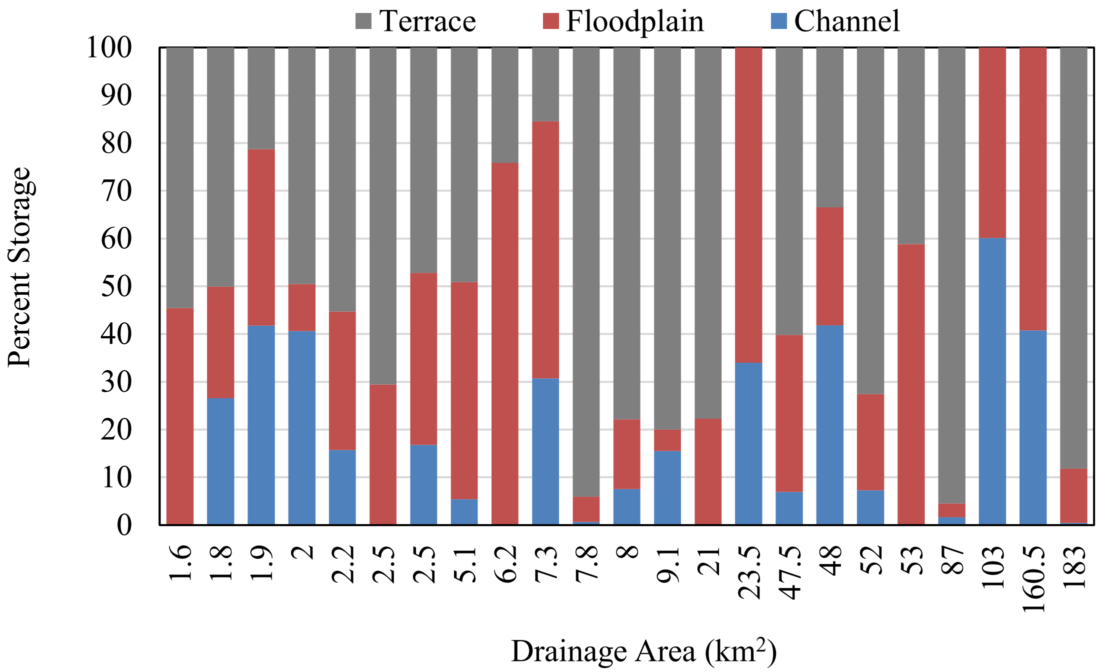


Figure 27. Fine-grained sediment volume by landform and drainage area. Locations labeled with a T indicate tributary sites while all others are mainstem sites. Vertical scale for terrace landforms is approximately six times greater than the scale for floodplain and channel landforms.



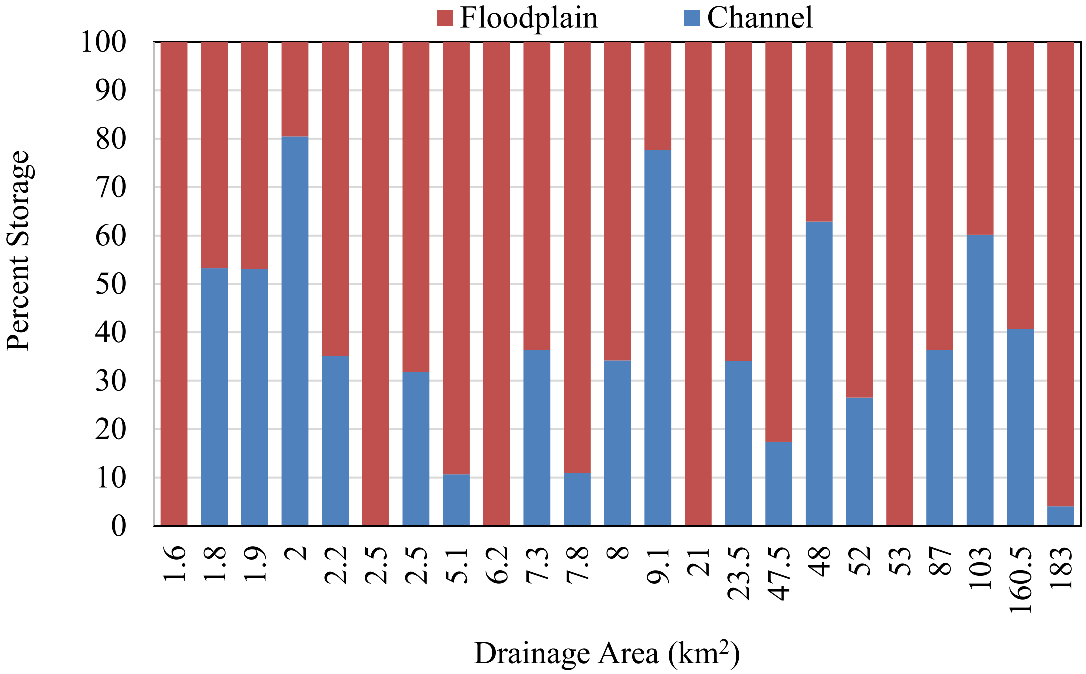


Figure 28. Percent volume of fine-grained sediment stored in landforms by drainage area. A) All landform features and B) Only floodplain and channel features.

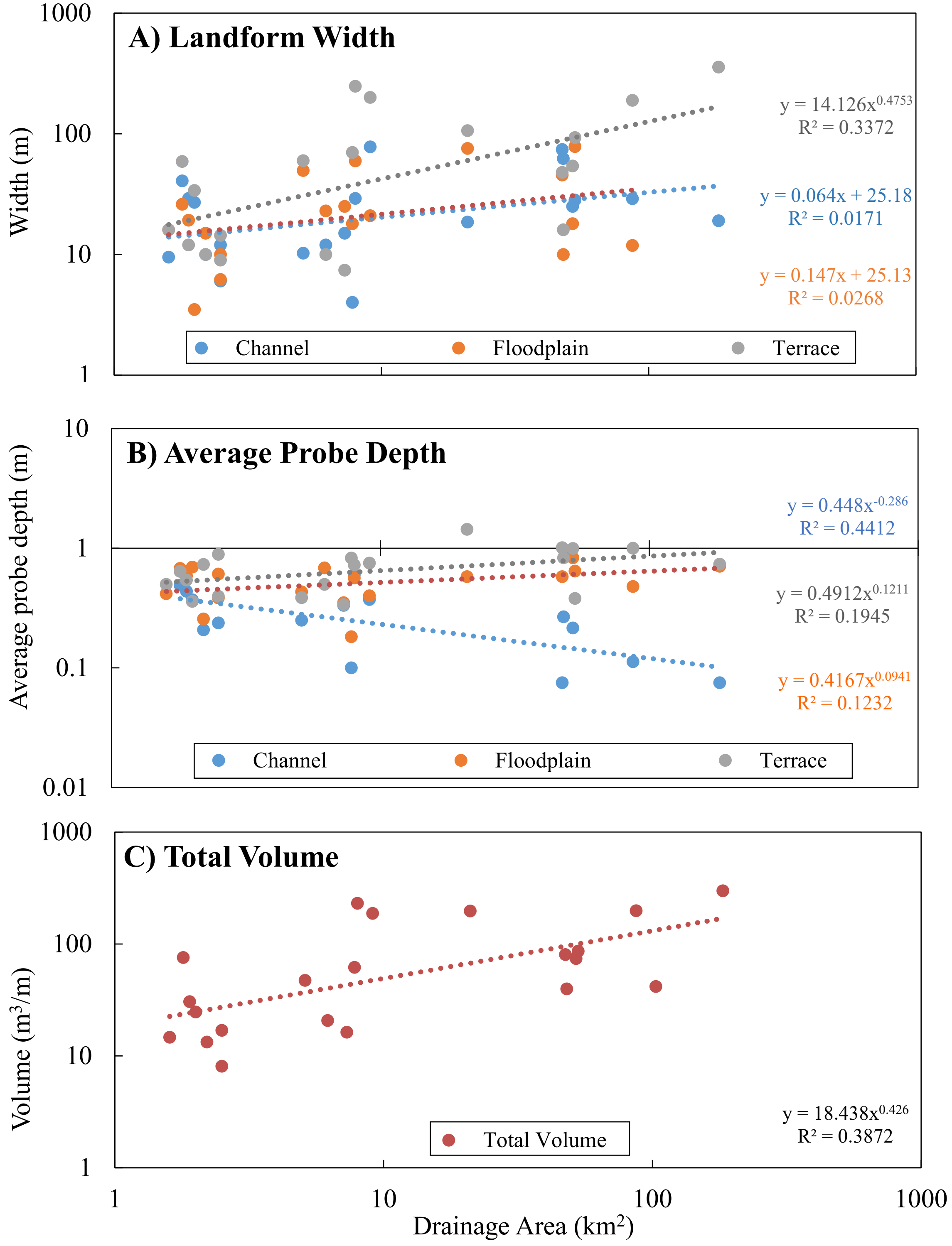


Figure 29. Drainage area influence on fine-sediment storage.

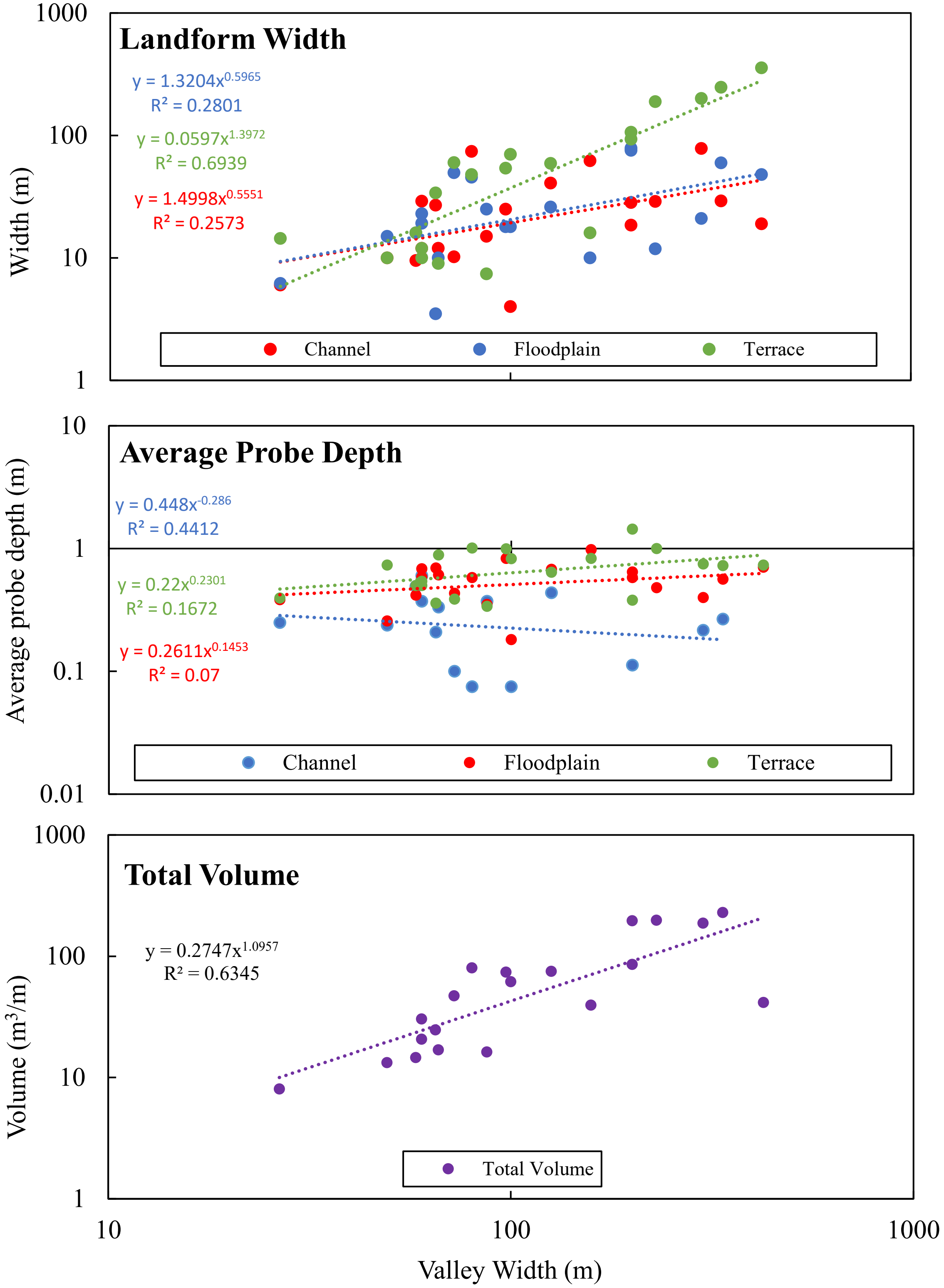


Figure 30. Valley width influence on fine-sediment storage.

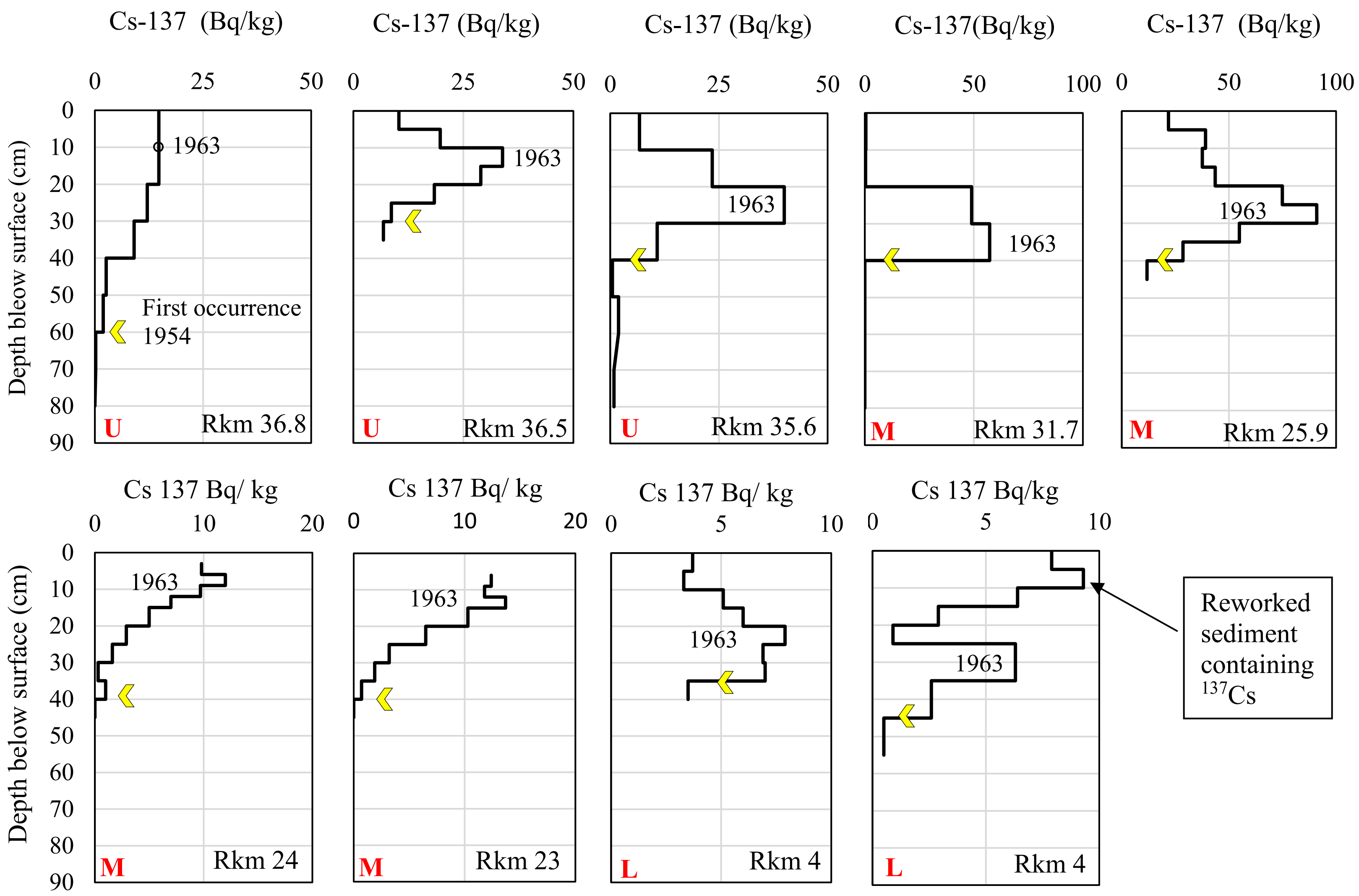


Figure 31. ^{137}Cs analysis results for nine soil cores sorted by distance downstream. Red letters indicate whether the core was pulled from upstream, middle, or lower BBC. Peaks in ^{137}Cs indicate the 1963 depositional boundary. Yellow arrows indicate first occurrence of ^{137}Cs detected in the soil.

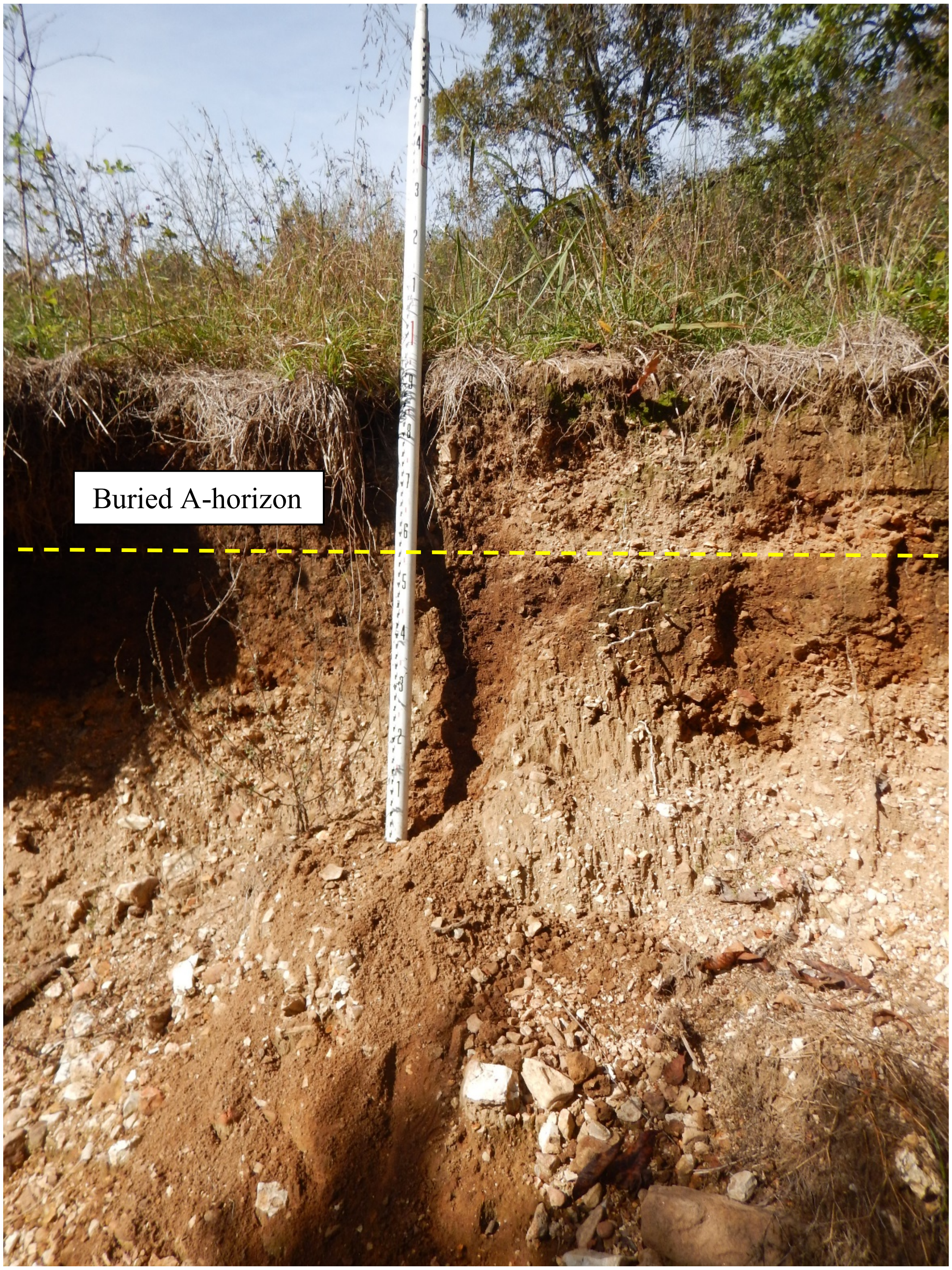


Figure 32. Buried A-horizon at the Barnes head-cut site at R-km 23.3. Fine grained depth to refusal at this site at 90 cm on old channel bed.

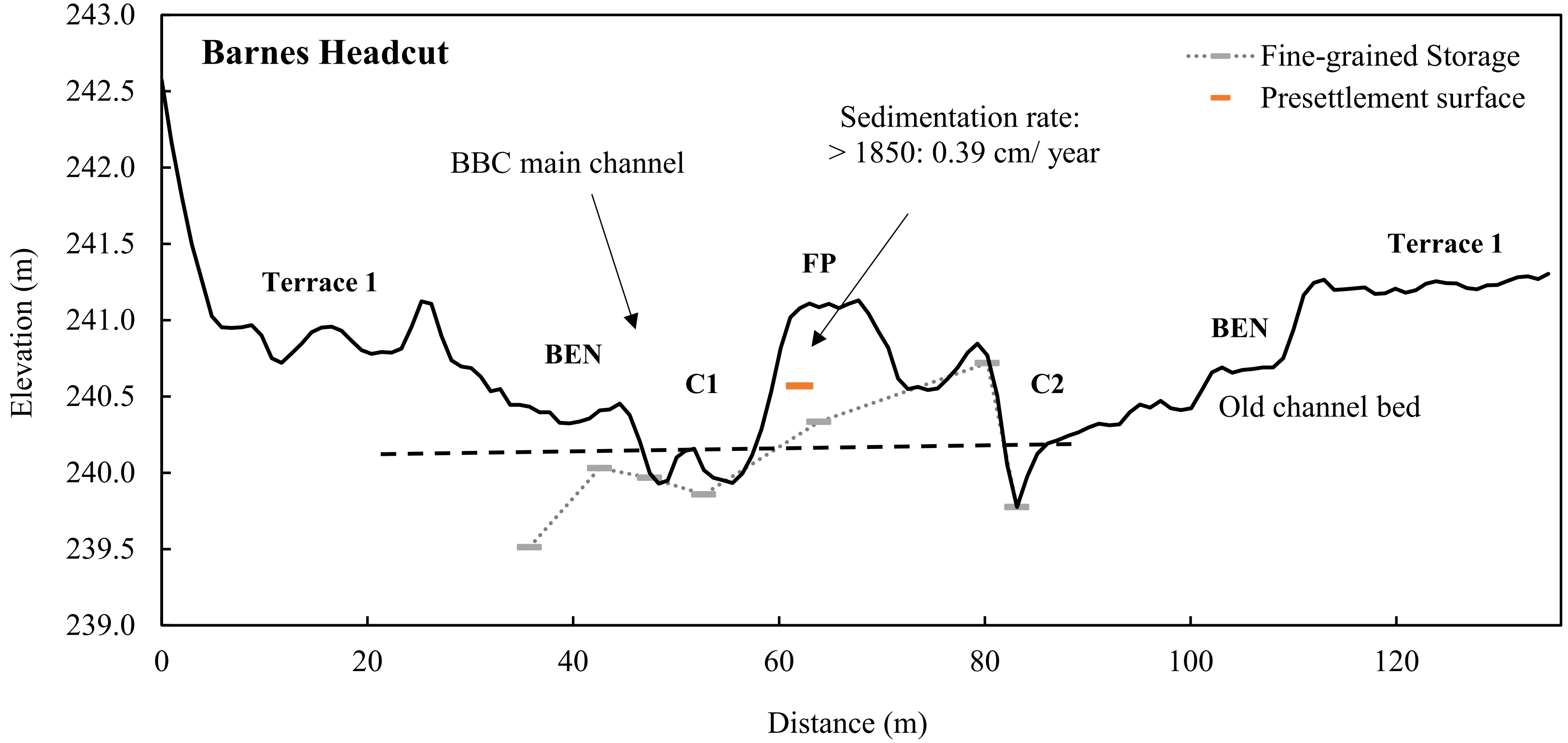


Figure 33. Cross section at Barnes Head-cut Site at R-km 35.8. Buried A-horizon was identified in floodplain cut bank. The post-settlement sedimentation rate occurring here is approximately 0.39 cm/yr.

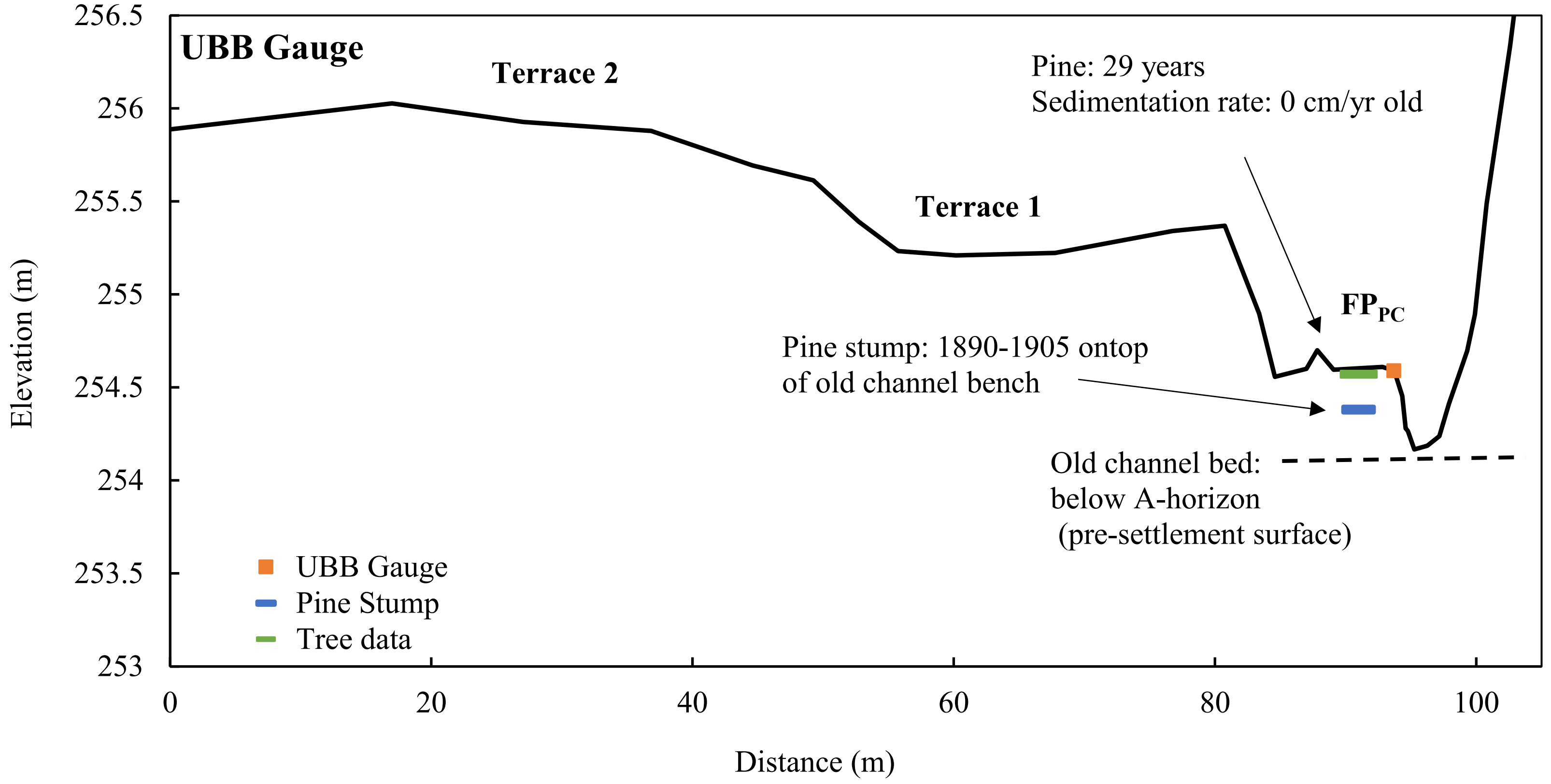


Figure 34. Cross section at upper BBC gage site at R-km 38.2. The stratigraphic position of the old channel bed is shown with historical infill of the channel over topping it. The floodplain we see today, is a reflection of infill of the old paleo-channel.

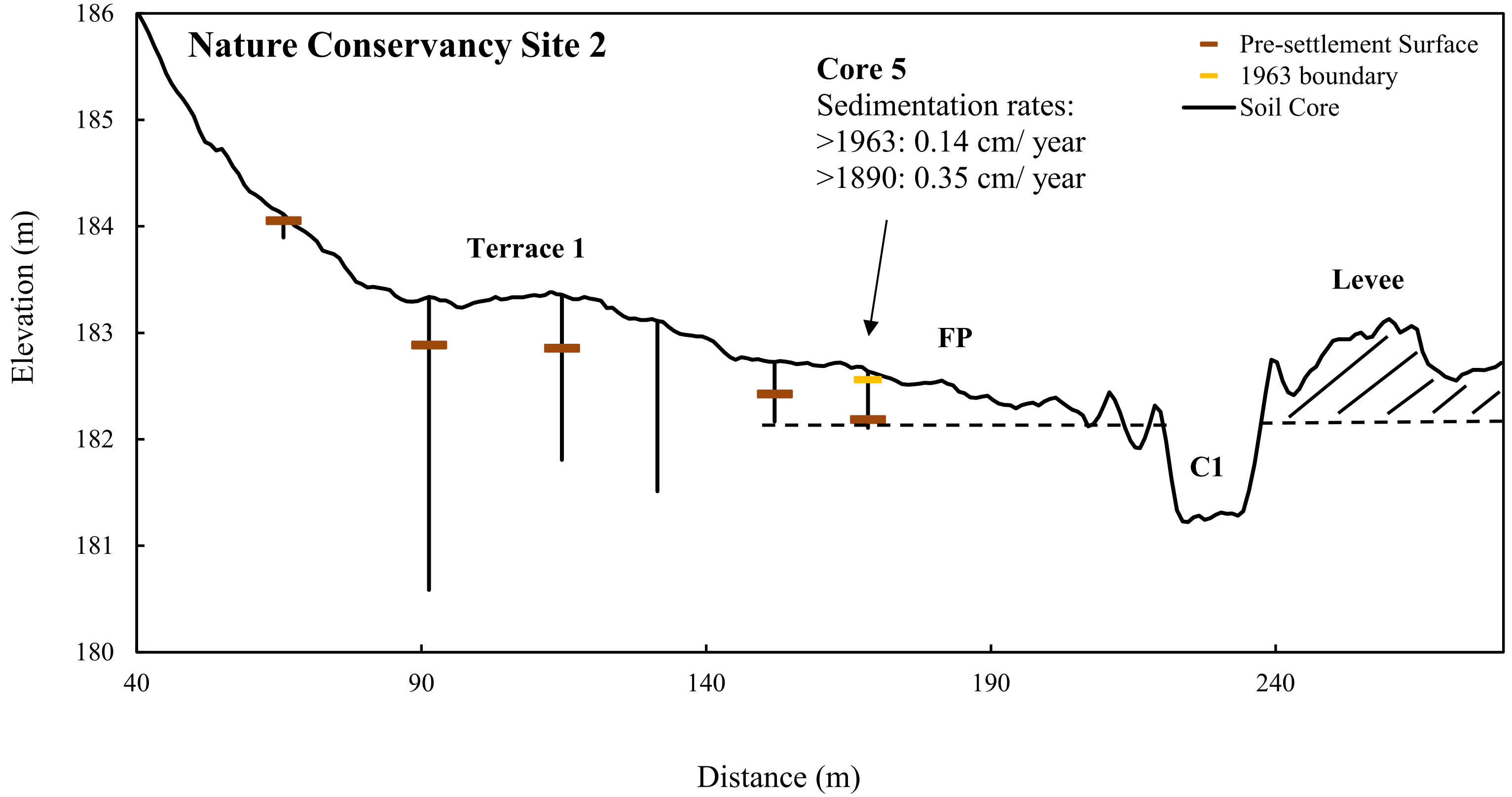


Figure 35. Cross section from Nature Conservancy site two at R-km 23.3. A truck mounted soil corer was able to extract seven cores along the floodplain and terrace units.

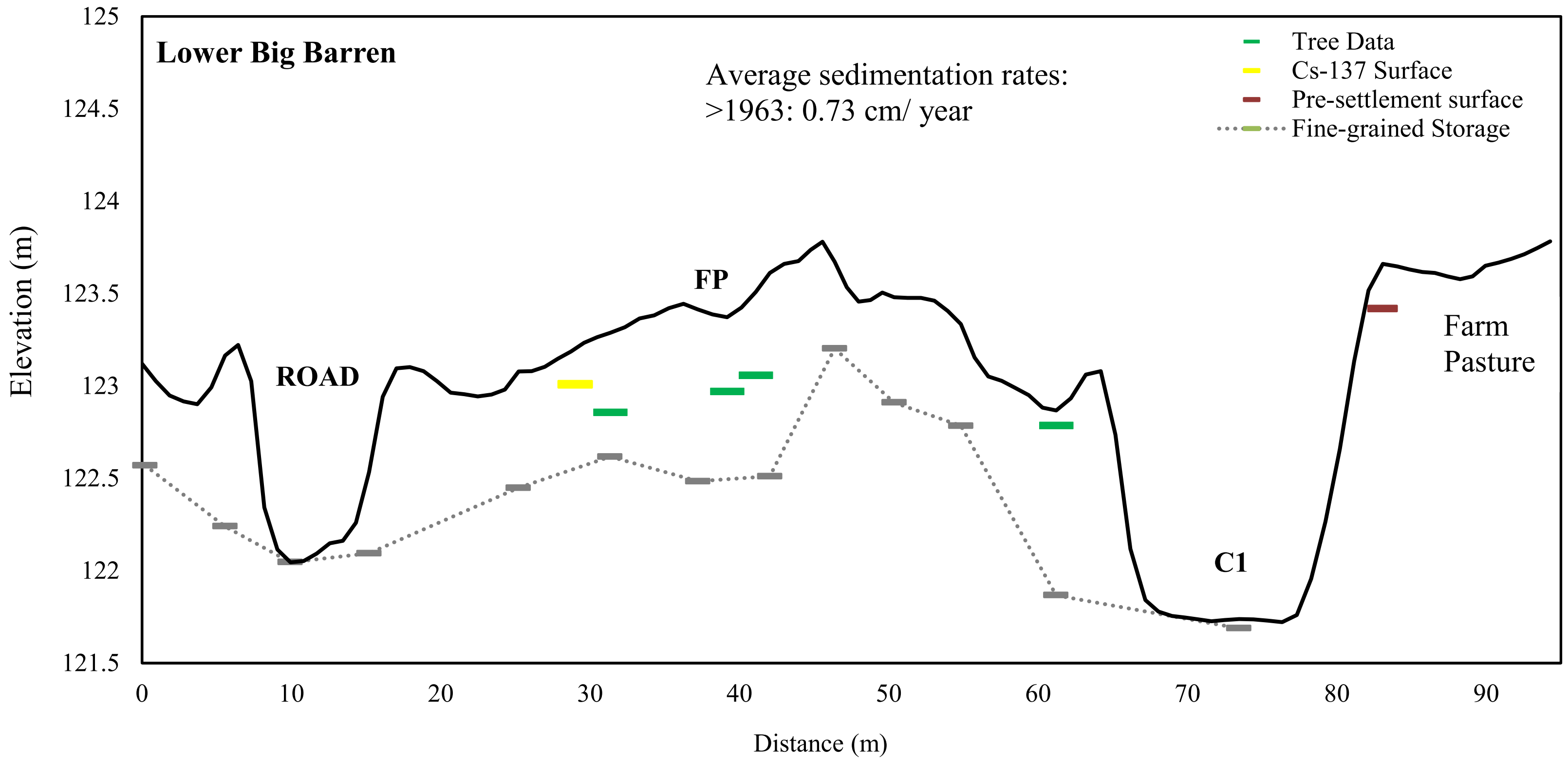


Figure 36. Cross-section of the Lower BBC site at R-km 4. Multiple trees were cored for dendrochronology analysis and one soil pit was analyzed for ^{137}Cs. The average sedimentation rate occurring after 1963 is 0.73 cm/yr.

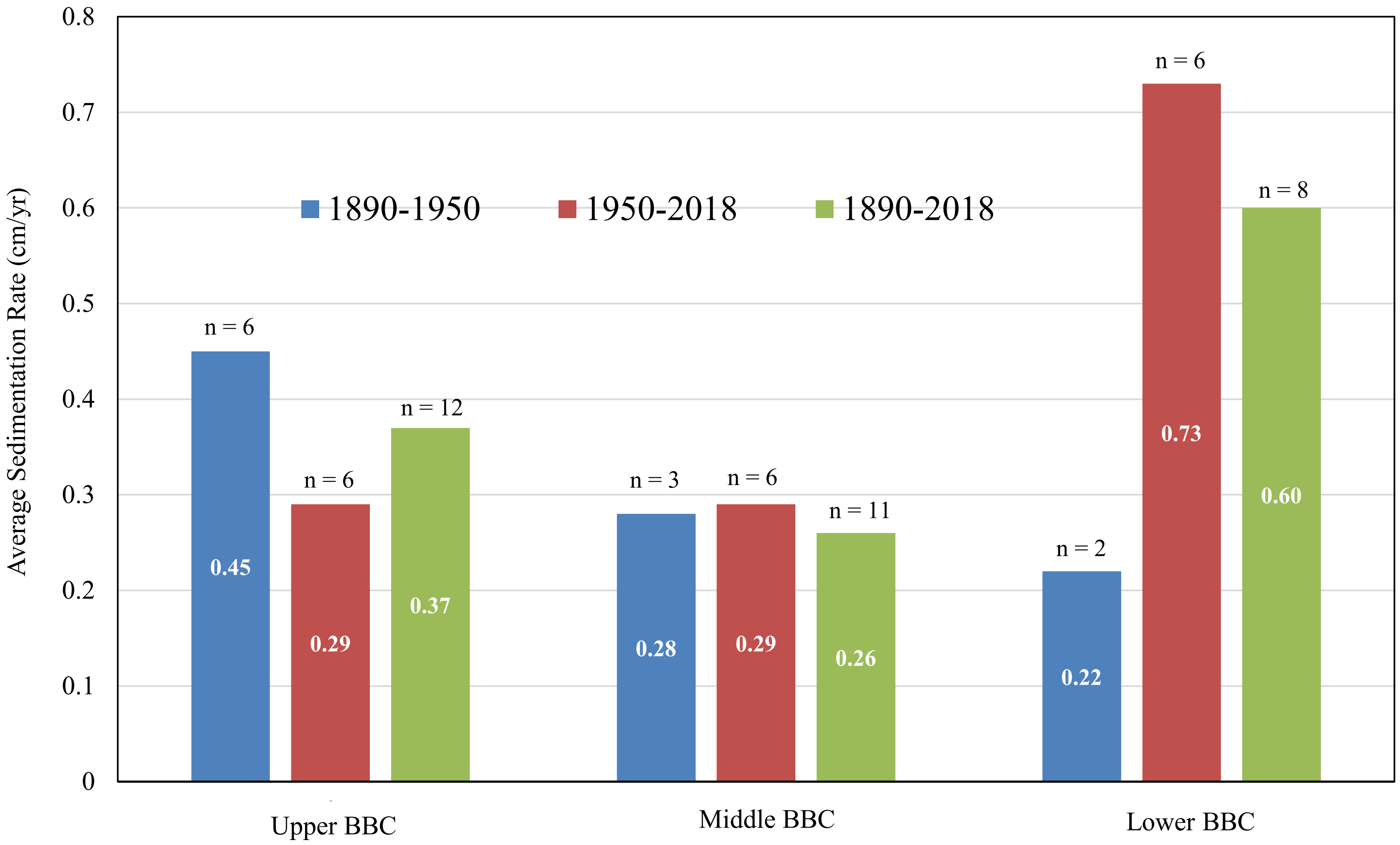


Figure 37. Average historical sedimentation rates along Big Barren Creek for all alluvial landforms.

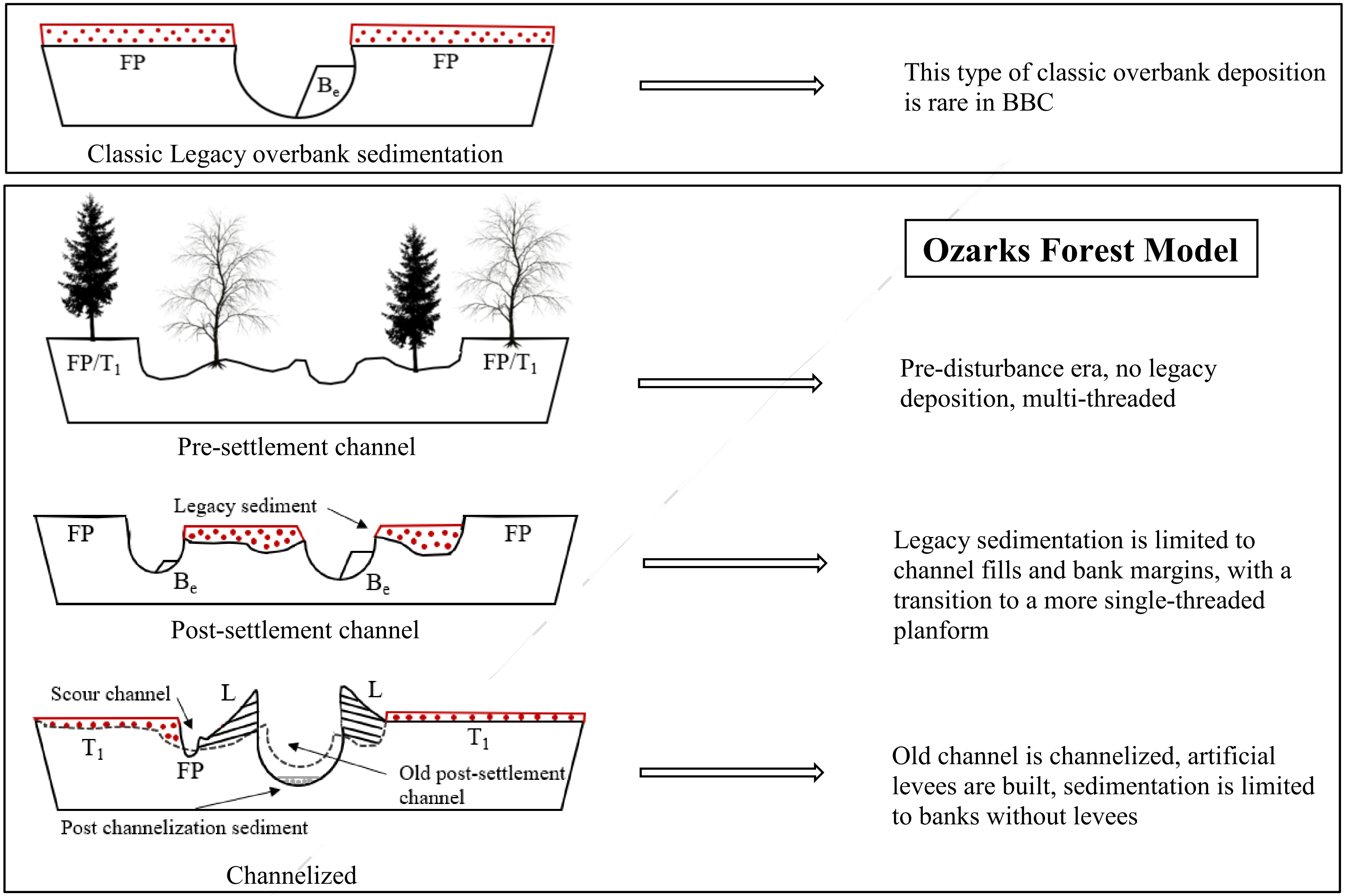


Figure 38. Conceptual diagram showing the channel evolution in Ozark Forests. The abbreviations FP, T_1, L, B_e represent floodplains, terraces, levees and bench deposits respectively. This model of legacy deposition is contrary to the classic model of over-bank vertical accretion of legacy deposits experienced on most main stem single-threaded streams.

CONCLUSIONS

The purpose of this study was to investigate the possibility of post-settlement or legacy sedimentation occurring as fine-grained deposits on alluvial landforms on the main stem and headwater tributaries of Big Barren Creek in the Ozark Highlands, and to evaluate the legacy sedimentation rates associated with historical logging and recent channelization practices. Specifically, form and distribution of fine-grained sediment deposits along Big Barren Creek were assessed by field and geospatial measurements of depth and width of valley landforms at tributaries and mainstem sites. Additionally, stratigraphic indicators including buried A-horizons, buried root crowns, and Cs-137 profiles were used to determine the age of sediment deposits. Lastly, human effects on headwater stream sedimentation and related channel responses and was described by presenting a model of century-scale channel evolution in Big Barren Creek in response to human disturbance from a multi-threaded to single channel form. There are seven findings of this study:

1. The majority of fine-grained sediment stored in Big Barren Creek remains in terrace features with lesser amounts of sediment stored in the floodplains and channels and generally increases with increasing valley width. Terrace storage accounts for approximately 72 % of the total fine-grained storage in BBC. Linear regression modeling has indicated that fine-grained sediment storage can be accurately predicted as a function of valley width. This supports previous research done by Magilligan in 1985 that suggests sediment volume and depth are a function of valley width;

2. Legacy sediment in terrace features accounts for 38 % of total fine-grained storage in upper, and 30% in lower BBC. Legacy sediment in floodplain paleo-channels accounts for between 5-16 % of total fine-grained storage in upper, and 5 % in lower BBC. Legacy sediment in channel features was only identified in middle BBC and accounts for between 8-11 % of the total fine-grained channel storage in middle BBC. Places were percent channel legacy storages were higher are indicative of areas with single-threaded channel types with large fine-grained benches.

3. Fine-grained legacy deposits (post-1890) occur in Big Barren creek and are distributed non-uniformly within channel, floodplains, and terrace landforms. Evidence for legacy deposits

include the identification of multiple stratigraphic horizons in floodplain and terrace soils indicative of the post-settlement period**;**

4. Rates of post-settlement deposition occurring from 1890-1963, are highest in upper BBC (~0.45 cm/yr) where the effects of historical timber harvest were most prevalent and quickly attenuate downstream to (~0.29 cm/yr) in middle BBC. Rates of sedimentation between 1890-1950 in this area of the watershed are two times higher on average than those occurring during the same time period in lower BBC. The selective removal of most all of the coniferous tree species in the upper portions of the watershed during the logging period probably contributed to increases in runoff and wide spread erosion of upland soils and local channel bed scour of streams in headwater reaches;

5. Rates of post-1963 sedimentation are highest in lower BBC (~0.73 cm/yr) due to sediment supply from upstream head-cutting, channelization, and lateral bank erosion in disturbance zones. Large volumes of fine-grained sediment, sand, and gravel are released from head-cuts, bank winnowing of channelized stream reaches, and floodplain turnover from laterally eroding channels in disturbance zones. The increased rates of post-1950 sedimentation in the lower portions of the watershed suggest that a combination of increased sediment supply and increase in stream power generated during stream channelization processes may have led to more frequent overbank flows downstream where fine-grained sediment was deposited. Rates of post 1963 sedimentation in this area of the watershed are 1.5 times higher on average than post-1963 rates of sedimentation in upper BBC;

6. Prior to European Settlement, Big Barren Creek exhibited a multi-threaded channel geometry in the upper and middle segments. In response to human-induced watershed disturbance, BBC has since undergone decadal to century-scale channel evolution tending towards a single channel geometry. Channels in BBC prior to European settlement would have consisted of heavily forested valley floors with multi-threaded channel systems hydraulically controlled by the location of trees and vegetation. Following historical timber disturbance, multi-threaded channels filled with fine-grained sediment and gravitated toward a 1.5 thread (single channel with a chute channel) or a single-threaded channel geometry. These effects have since been exacerbated by recent channelization practices which artificially straighten and deepen stream channels. These land use changes in combination with climate change induced increases in flood frequency may be working together to influence channel morphology and increase sediment deposition in Big Barren Creek; and

7. Long term effects of land disturbance in Big Barren Creek include fine-sediment deposited at accelerated rates into coarse gravel channels and fine-grained floodplains, damage to riparian corridors in channelized stream segments and disturbance zones, and a significant long-term source of post-settlement alluvium stored in channels and floodplains. This sediment is then made available for rapid remobilization during flood events through channel scour and lateral

bank incision. The destruction of riparian zones along channels lead to more frequent stream bank failures and lower the filtering capacity provided by vegetative barriers lining the channel banks. Additionally, increases in fine-grained sediment stored and readily remobilized in BBC introduce water quality and ecological concerns for the Current River Drainage basin as species that rely heavily on coarse gravel-bedded streams with suitable void space to provide habitats may suffer the effects of fine-sediment infill. These changes to the channel imply that contemporary river processes in BBC may be different from hydrologic and geomorphic processes occurring in the pre-settlement period and are largely due to the influence of human induced land disturbance.

More work is needed to better understand the sources of sediment under transport in the contemporary channel. Geochemical source analysis should be done to determine the sources of both past legacy sediment and present-day sediment loads. If the source of the sediment can be determined, than better management techniques can be developed to manage specific land areas to reduce the amount of human-derived sediment entering the watershed in response to land use disturbances. By better understanding human influences on sediment production and channel change in forested watershed systems, we can work to minimize the negative effects of these activities on water quality and channel stability in Ozark streams. This study is the first to recognize and explain the presence of legacy floodplain and channel deposits in the Mark Twain National Forest of the Ozark Highlands. These deposits represent a significant long-term source of stored fine-grained sediment and, along with human channelization practices since the 1950s, have led to historical channel change from multiple-thread to single-threaded channel planforms.

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APPENDICES

Appendix A. Physical Characteristics of Valley Cross-section Storage Sites

Location	R-km	Ad (km^2)	Elevation (m)	Chan width (m)	Max depth (m)	Reach slope	Vw (m)
Cemetery Road	36.6	8	245.7	29.1	1.0	0.16	336
MBB2	26.0	48	115.3	74.1	2.9	0.38	158
NatCon1	24.0	53	184.6	28.3	3.1	0.27	200
NatCon2	23.3	21	181.2	18.5	1.0	0.31	200
UNA	18.5	103	163.8	15.9	1.8	0.25	68
Barnes Head-cut	35.8	9	239.8	34.9	0.9	0.55	280
Upstream BH	25.0	52	187.5	33.6	0.9	0.61	97
Bristol RU	22.0	87	176.2	23.8	0.9	0.31	230
LBB101718	4.0	183	121.8	59.0	1.4	0.28	424
GSH site	32.8	24	226.3	30.8	0.6	0.61	80
UBB Farm	38.0	2	255.2	27.0	0.6	0.75	65
Ford	10.3	161	137.6	14.9	1.6	0.28	500
Rkm 39	39.0	2	263.2	40.8	0.7	0.85	126
LBB Pasture	4.0	183	121.4	25.8	1.3	0.28	424
UBB Gauge	37.8	3	254.3	16.0	0.8	0.71	170
Above Farm	38.2	2	256.6	29.1	0.2	0.72	60

Appendix B. Soil Core Location and Sampling Information

Site Name	Core ID	Sample No.	GPS Location (WGS 84)		Core depth (m)	Depth to refusal (m)
MBB2	A	KRB1-KRB9	-91.116977	36.862313	0.45	0.45
Cemetery Road	B	KRB10-KRB16	-91.189142	36.867859	0.35	0.35
Cemetery Road	C	KRB17-KRB27	-91.189275	36.867931	0.55	0.55
Cemetery Road	D	KRB28-KRB40	-91.189835	36.867974	1.3	1.3
Rkm31.7_site	Eb1	EB10-EB20	-91.147023	36.873569	0.7	0.7
DS_BarnesHC_35.6	Eb2	EB1-EB9	-91.177272	36.868046	0.8	1.6
NatCon1	1	KRB41-KRB50	-91.107113	36.846828	0.38	0.38
NatCon1	2	KRB51-KRB63	-91.106976	36.846999	0.55	0.57
NatCon1	3	KRB64-KRB75	-91.106855	36.847133	0.5	1.45
NatCon1	4	KRB76-KRB87	-91.106717	36.847294	0.5	0.58
NatCon2	5	KRB89-KRB99	-91.099944	36.848395	0.4	0.6
NatCon2	6	KRB100-KRB111	-91.100128	36.848442	0.5	0.56
NatCon2	7	KRB112-KRB123	-91.100346	36.84849	0.5	1.6
NatCon2	8	KRB124-KRB139	-91.100517	36.848555	1.6	1.55
NatCon2	9	KRB140-KRB151	-91.100747	36.848648	0.5	2.4
NatCon2	10	KRB152-KRB157	-91.101004	36.848755	0.22	0.22
LBB Pasture	11	KRB158-KRB162	-90.965769	36.797462	0.5	1.13
LBB Pasture	12	KRB163-KRB167	-90.96596	36.797353	0.5	0.99
LBB Pasture	13	KRB168-KRB172	-90.966175	36.797247	0.5	1.05
LBB Pasture	14	KRB173	-90.966511	36.796985	0.1	1.52
LBB Pasture	15	KRB174-KRB176	-90.967557	36.797538	0.3	0.45
LBB Pasture	16	lost core to auger	-90.967951	36.79767	N/A	0.78
NatCon1	Pit 1	KRB177-KRB181	-91.106623	36.847384	0.35	0.35
NatCon1	Pit 2	KRB182-KRB186	-91.106448	36.847511	0.27	0.27
LBB101718	17	KRB187-KRB196	-90.965719	36.797561	0.6	0.6
LBB101719	18	KRB197-KRB204	-90.966056	36.797975	0.4	0.4
Lower Nat Area	19	KRB205-KRB215	-91.063636	36.842774	0.75	0.75

Appendix C. Loss on Ignition Results (% Organic Matter Loss)

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-1	12.41	5.01	17.42	17.38	17.22	0.92
KRB-2	12.39	5.01	17.4	17.36	17.2	0.92
KRB-3	11.43	5.00	16.43	16.39	16.23	0.98
KRB-4	12.22	5.00	17.22	17.18	17	1.05
KRB-5	37.33	5.00	42.33	42.27	42.02	0.59
KRB-6	12.43	5.00	17.43	17.37	17.09	1.61
KRB-7	35.26	5.00	40.26	40.19	39.95	0.60
KRB-8	31.04	5.00	36.04	35.98	35.73	0.69
KRB-9	32.6	5.00	37.6	37.53	37.27	0.69
KRB-10	30.14	5.00	35.14	35.08	34.75	0.94
KRB-11	11.49	5.00	16.49	16.44	16.19	1.52
KRB-12	11.57	5.00	16.57	16.52	16.3	1.33
KRB-13	11.23	5.00	16.23	16.19	15.98	1.30
KRB-14	10.47	5.00	15.47	15.44	15.25	1.23
KRB-15	11.28	5.00	16.28	16.23	16.07	0.99
KRB-16	11.99	5.00	16.99	16.94	16.77	1.00
KRB-17	13.39	5.00	18.39	18.34	18	1.85
KRB-18	13.78	5.01	18.79	18.71	18.41	1.60
KRB-19	12.74	5.00	17.74	17.68	17.44	1.36
KRB-20	11.74	5.01	16.75	16.67	16.44	1.38
KRB-21	11.93	5.00	16.93	16.88	16.65	1.36
KRB-22	10.81	5.02	15.83	15.79	15.53	1.65
KRB-23	11.57	5.02	16.59	16.55	16.3	1.51
KRB-24	12.07	5.02	17.09	17.06	16.88	1.06
KRB-25	11.74	5.02	16.76	16.72	16.55	1.02

Appendix C continued. Loss on Ignition Results (% Organic Matter Loss)

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-25	11.74	5.02	16.76	16.72	16.55	1.02
KRB-26	10.56	5.01	15.57	15.53	15.39	0.90
KRB-27	10.79	5.02	15.81	15.76	15.64	0.76
KRB-28	37.33	5.01	42.34	42.30	42.01	0.69
KRB-29	30.48	5.01	35.49	35.46	35.19	0.76
KRB-30	33.12	5.00	38.12	38.09	37.85	0.64
KRB-31	34.00	5.01	39.01	38.98	38.74	0.61
KRB-32	32.96	5.00	37.96	37.92	37.75	0.45
KRB-33	32.59	5.00	37.59	37.56	37.35	0.57
KRB-34	31.04	5.01	36.05	36.01	35.78	0.65
KRB-35	32.97	5.01	37.98	37.92	37.59	0.88
KRB-36	33.21	5.01	38.22	38.16	37.87	0.77
KRB-37	33.45	5.01	38.46	38.40	38.12	0.72
KRB-38	31.07	5.00	36.07	36.01	35.78	0.63
KRB-39	30.14	5.01	35.15	35.11	34.93	0.52
KRB-40	35.24	5.01	40.25	40.21	40.04	0.42
KRB-41	11.65	5.00	16.65	16.54	16.03	3.08
KRB-42	12.43	5.01	17.44	17.36	17.06	1.73
KRB-43	11.64	5.01	16.65	16.58	16.34	1.45
KRB-44	11.08	5.00	16.08	16.00	15.80	1.25
KRB-45	10.39	5.01	15.40	15.33	15.14	1.24
KRB-46	12.22	5.00	17.22	17.15	16.98	0.99
KRB-47	12.07	5.00	17.08	17.01	16.88	0.76
KRB-48	13.17	5.00	18.17	18.10	17.93	0.94
KRB-49	11.80	5.01	16.81	16.74	16.62	0.72
KRB-50	11.74	5.00	16.33	16.26	16.15	0.68

Appendix C continued. Loss on Ignition Results (% Organic Matter Loss)

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-51	13.18	5.01	18.19	18.07	17.66	2.27
KRB-52	11.11	5.00	16.12	16.03	15.77	1.62
KRB-53	12.39	5.01	17.40	17.32	17.09	1.33
KRB-54	13.39	5.01	18.39	18.32	18.12	1.09
KRB-55	10.81	5.00	15.81	15.74	15.55	1.21
KRB-56	11.49	5.01	16.50	16.43	16.24	1.16
KRB-57	11.53	5.00	16.53	16.46	16.27	1.15
KRB-58	12.74	5.00	17.74	17.67	17.48	1.08
KRB-59	11.56	5.01	16.57	16.50	16.33	1.03
KRB-60	11.43	5.00	16.43	16.36	16.22	0.86
KRB-61	10.47	5.01	15.48	15.41	15.28	0.84
KRB-62	10.76	5.00	15.76	15.69	15.48	1.34
KRB-63	11.74	5.01	16.74	16.67	16.55	0.72
KRB-64	11.99	5.00	16.99	16.93	16.61	1.88
KRB-65	10.79	5.00	15.79	15.73	15.50	1.46
KRB-66	10.56	5.01	15.56	15.51	15.32	1.22
KRB-67	13.78	5.01	18.79	18.74	18.57	0.89
KRB-68	12.34	5.00	17.34	17.29	17.13	0.92
KRB-69	12.18	5.01	17.18	17.13	16.98	0.89
KRB-70	33.12	5.01	38.13	38.08	37.96	0.32
KRB-71	10.88	5.01	15.89	15.82	15.71	0.71
KRB-72	10.50	5.01	15.50	15.45	15.34	0.68
KRB-73	32.59	5.00	37.60	37.53	37.42	0.29
KRB-74	11.57	5.00	16.58	16.52	16.42	0.61
KRB-75	12.41	5.00	17.41	17.35	17.26	0.54

Appendix C continued. Loss on Ignition Results (% Organic Matter Loss).

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	postburn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-76	11.23	5.00	16.24	16.11	15.48	3.87
KRB-77	11.63	5.00	16.64	16.56	16.17	2.33
KRB-78	11.12	5.00	16.12	16.05	15.76	1.83
KRB-79	11.74	5.01	16.75	16.68	16.43	1.53
KRB-80	12.10	5.00	17.10	17.04	16.81	1.36
KRB-81	36.85	5.01	41.86	41.79	41.59	0.49
KRB-82	35.24	5.01	40.25	40.18	40.01	0.43
KRB-83	13.47	5.00	18.47	18.40	18.23	0.94
KRB-84	33.20	5.00	38.20	38.14	37.98	0.41
KRB-85	32.96	5.00	37.96	37.89	37.75	0.38
KRB-86	31.04	5.00	36.04	35.98	35.84	0.38
KRB-87	30.48	5.01	35.48	35.42	35.29	0.36
KRB-89	31.06	5.00	36.06	36.04	35.53	1.42
KRB-90	30.14	5.06	35.20	35.17	34.76	1.17
KRB-91	11.49	5.02	16.51	16.49	16.21	1.70
KRB-92	11.32	5.05	16.37	16.33	16.15	1.10
KRB-93	11.11	5.05	16.16	16.36	16.17	1.16
KRB-94	10.39	5.02	15.41	15.40	15.27	0.84
KRB-95	11.08	5.02	16.10	16.09	15.96	0.81
KRB-96	12.39	5.02	17.41	17.41	17.27	0.80
KRB-97	12.42	5.05	17.47	17.47	17.26	1.20
KRB-98	11.79	5.03	16.82	16.82	16.64	1.07
KRB-99	12.74	5.01	17.75	17.73	17.45	1.58
KRB-100	11.73	5.00	16.73	16.76	16.32	2.63
KRB-101	10.80	5.04	15.84	15.78	15.44	2.15

Appendix C continued. Loss on Ignition results (% organic matter loss).

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-102	33.99	5.01	39.00	39.01	38.69	0.82
KRB-103	11.93	5.03	16.96	16.93	16.66	1.59
KRB-104	12.21	5.01	17.22	17.23	17.01	1.28
KRB-105	11.56	5.00	16.56	16.56	16.37	1.15
KRB-106	11.56	5.01	16.57	16.56	16.32	1.45
KRB-107	11.53	5.00	16.53	16.53	15.51	6.17
KRB-108	10.75	5.00	15.75	15.74	15.51	1.46
KRB-109	11.43	5.02	16.45	16.44	16.18	1.58
KRB-110	13.17	5.00	18.17	18.16	17.88	1.54
KRB-111	11.65	5.03	16.68	16.67	16.37	1.80
KRB-112	32.59	5.01	37.61	37.52	37.13	1.03
KRB-113	37.33	5.01	42.34	42.26	41.93	0.78
KRB-114	35.25	5.01	40.26	40.19	39.92	0.66
KRB-115	32.96	5.02	37.98	37.92	37.70	0.58
KRB-116	30.48	5.00	35.48	35.42	35.23	0.56
KRB-117	36.86	5.00	41.86	41.80	41.62	0.43
KRB-118	33.20	5.00	38.21	38.16	37.98	0.45
KRB-119	31.04	5.02	36.06	36.00	35.83	0.48
KRB-120	33.12	5.02	38.14	38.09	37.93	0.43
KRB-121	32.97	5.00	37.97	37.92	37.77	0.40
KRB-122	12.41	5.00	17.41	17.36	17.22	0.82
KRB-123	10.88	5.00	15.89	15.84	15.71	0.84
KRB-124	11.74	5.01	16.76	16.69	16.42	1.66
KRB-125	13.47	5.01	18.48	18.42	18.26	0.91
KRB-126	11.57	5.02	16.59	16.55	16.41	0.81
KRB-127	12.18	5.01	17.19	17.15	17.04	0.64

Appendix C continued. Loss on Ignition results (% organic matter loss).

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-128	10.50	5.01	15.51	15.46	15.35	0.70
KRB-129	13.78	5.02	18.80	18.75	18.65	0.53
KRB-130	11.23	5.01	16.24	16.19	16.10	0.60
KRB-131	10.56	5.01	15.57	16.70	16.61	0.53
KRB-132	11.12	5.02	16.13	16.60	16.51	0.57
KRB-133	12.34	5.01	17.35	16.09	16.00	0.58
KRB-134	11.53	5.01	16.54	17.31	17.22	0.51
KRB-135	11.49	5.01	16.50	16.50	16.41	0.53
KRB-136	31.06	5.01	36.07	16.45	16.36	0.54
KRB-137	11.74	5.01	16.75	36.02	35.94	0.24
KRB-138	12.39	5.01	17.41	17.35	17.27	0.46
KRB-139	11.93	5.01	16.94	16.99	16.82	0.99
KRB-140	12.07	5.00	17.07	16.99	16.55	2.59
KRB-141	11.08	5.02	16.09	16.04	15.69	2.13
KRB-142	10.38	5.07	15.45	15.40	15.16	1.57
KRB-143	12.74	5.01	17.75	17.71	17.50	1.17
KRB-144	11.65	5.02	16.67	16.63	16.44	1.11
KRB-145	11.56	5.02	16.58	16.54	16.37	1.00
KRB-146	13.38	5.03	18.42	18.35	18.19	0.85
KRB-147	12.21	5.01	17.22	17.18	17.04	0.85
KRB-148	10.80	5.03	15.83	15.79	15.65	0.89
KRB-149	11.56	5.01	16.57	16.52	16.39	0.80
KRB-150	13.16	5.01	18.17	18.12	17.04	5.97
KRB-151	10.47	5.02	39.01	15.44	15.31	0.85

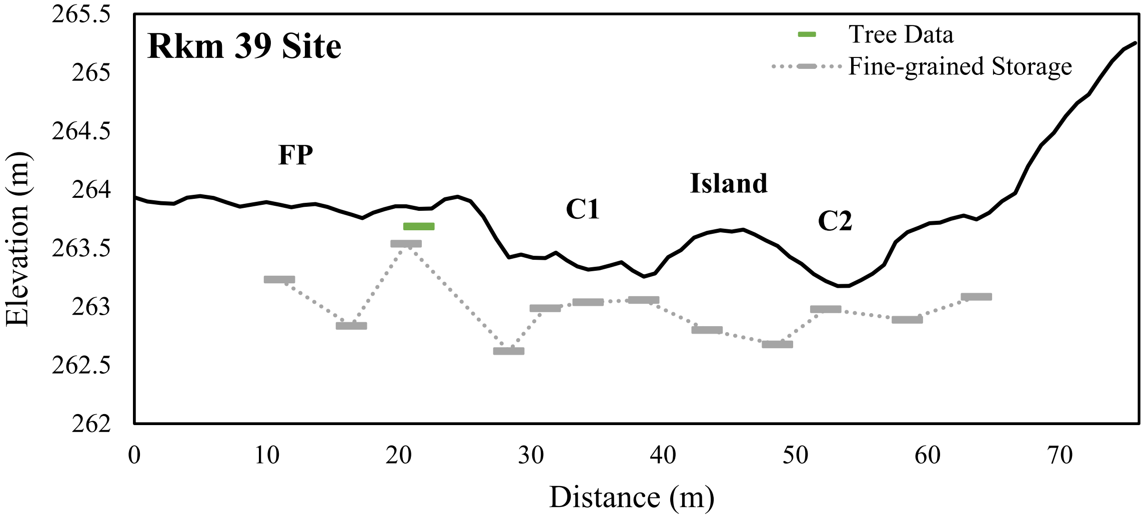
Appendix C continued. Loss on Ignition results (% organic matter loss).

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight (g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-152	33.99	5.01	16.12	38.92	38.52	1.02
KRB-153	11.11	5.02	16.82	16.07	15.79	1.73
KRB-154	11.79	5.02	15.80	16.76	16.54	1.34
KRB-155	10.78	5.03	17.12	15.77	15.57	1.23
KRB-156	12.09	5.03	16.35	17.07	16.90	1.01
KRB-157	11.32	5.01	16.44	16.29	16.14	0.94
KRB-158	11.43	5.02	17.44	16.38	16.14	1.47
KRB-159	12.42	5.04	16.67	17.40	17.21	1.09
KRB-160	11.64	5.03	18.20	16.60	16.44	0.96
KRB-161	13.17	5.04	38.49	18.12	17.97	0.80
KRB-162	33.45	5.02	40.26	38.41	38.22	0.49
KRB-163	35.24	5.02	37.61	40.20	39.91	0.72
KRB-164	32.59	5.01	37.97	37.55	37.33	0.58
KRB-165	32.96	5.00	38.13	37.89	37.70	0.52
KRB-166	33.12	5.00	37.97	38.07	37.89	0.48
KRB-167	32.97	5.02	42.35	37.94	37.77	0.44
KRB-168	37.33	5.01	35.49	42.29	42.02	0.65
KRB-169	30.48	5.00	38.20	35.43	35.22	0.58
KRB-170	33.20	5.01	36.05	38.03	37.85	0.47
KRB-171	31.04	5.02	41.87	36.01	35.84	0.48
KRB-172	36.85	5.01	5.01	41.82	41.67	0.35
KRB-187	30.14	5.00	35.14	35.13	34.84	0.83
KRB-188	37.33	5.01	42.34	42.32	42.07	0.61
KRB-189	31.04	5.01	36.05	36.04	35.80	0.66
KRB-190	33.45	5.01	38.46	38.44	38.21	0.61

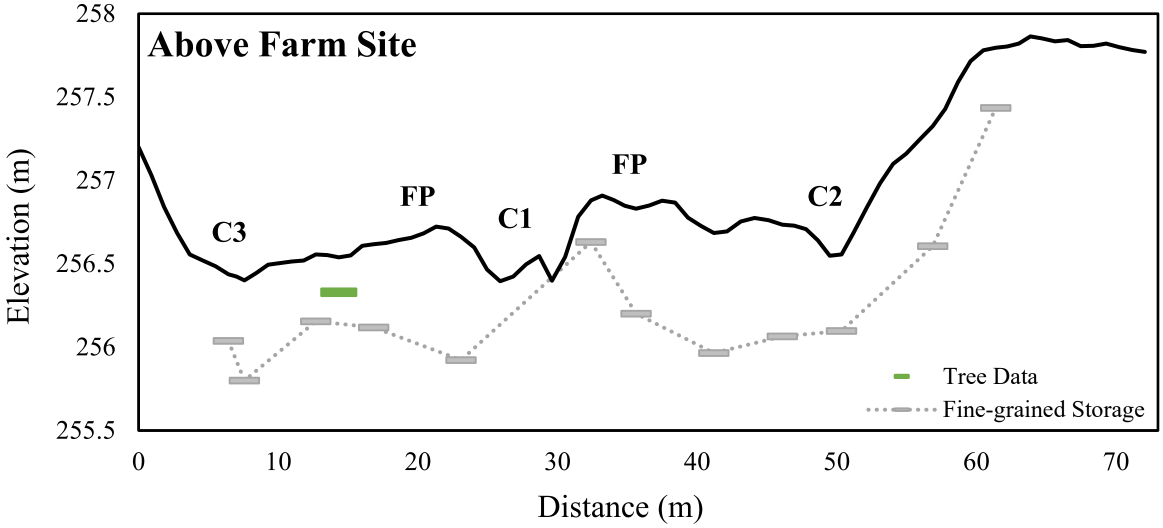
Appendix C continued. Loss on Ignition results (% organic matter loss)

Sample ID	Crucible Tare weight (g)	sample weight (g)	total weight(g)	Post burn 105 C weight (g)	600 C post burn total weight (g)	% OM
KRB-191	36.86	5.00	41.86	41.84	41.62	0.52
KRB-192	32.60	5.01	37.60	37.59	37.37	0.56
KRB-193	33.13	5.00	38.13	38.11	37.90	0.54
KRB-194	31.07	5.02	36.08	36.07	35.88	0.53
KRB-195	30.48	5.02	35.50	35.48	35.29	0.54
KRB-196	35.24	5.02	40.26	40.24	40.05	0.46
KRB-197	12.74	5.01	17.75	17.69	17.23	2.62
KRB-198	11.53	5.01	16.54	16.49	16.16	2.01
KRB-199	12.10	5.02	17.12	17.07	16.79	1.68
KRB-200	10.39	5.01	15.40	15.35	15.08	1.80
KRB-201	13.47	5.02	18.49	18.45	18.02	2.31
KRB-202	10.79	5.02	15.81	15.77	15.56	1.35
KRB-203	10.81	5.02	15.83	15.80	15.63	1.08
KRB-204	11.64	5.00	16.65	16.62	16.49	0.81
KRB-205	12.07	5.02	17.09	17.04	16.67	2.20
KRB-206	11.80	5.01	16.81	16.77	16.48	1.75
KRB-207	11.49	5.01	16.50	16.46	16.22	1.45
KRB-208	11.93	5.02	16.96	16.93	16.74	1.08
KRB-209	10.56	5.00	15.56	15.52	15.36	1.04
KRB-210	11.23	5.00	16.24	16.21	15.98	1.40
KRB-211	13.18	5.01	18.19	16.17	16.00	1.02
KRB-212	11.12	5.00	16.12	16.09	15.96	0.54
KRB-213	11.11	5.02	16.13	16.11	15.97	0.85
KRB-214	11.65	5.02	16.67	16.65	16.45	1.21
KRB-215	11.57	5.02	16.59	16.57	15.96	3.64

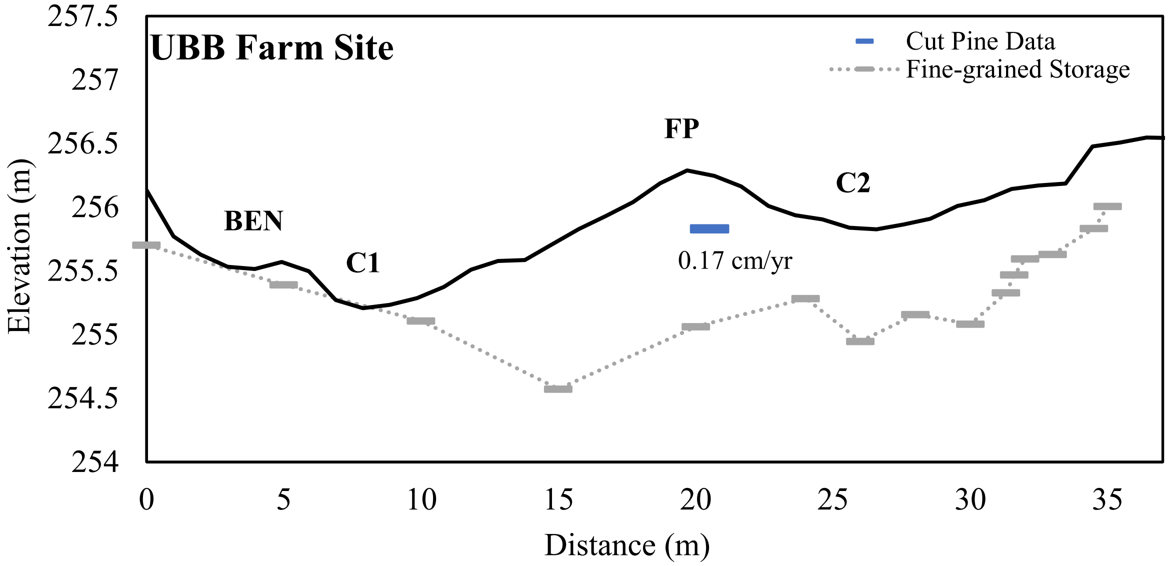
Appendix D. Fine-grained Storage Depths and Stratigraphic Boundaries Identified within Valley Cross-sections.



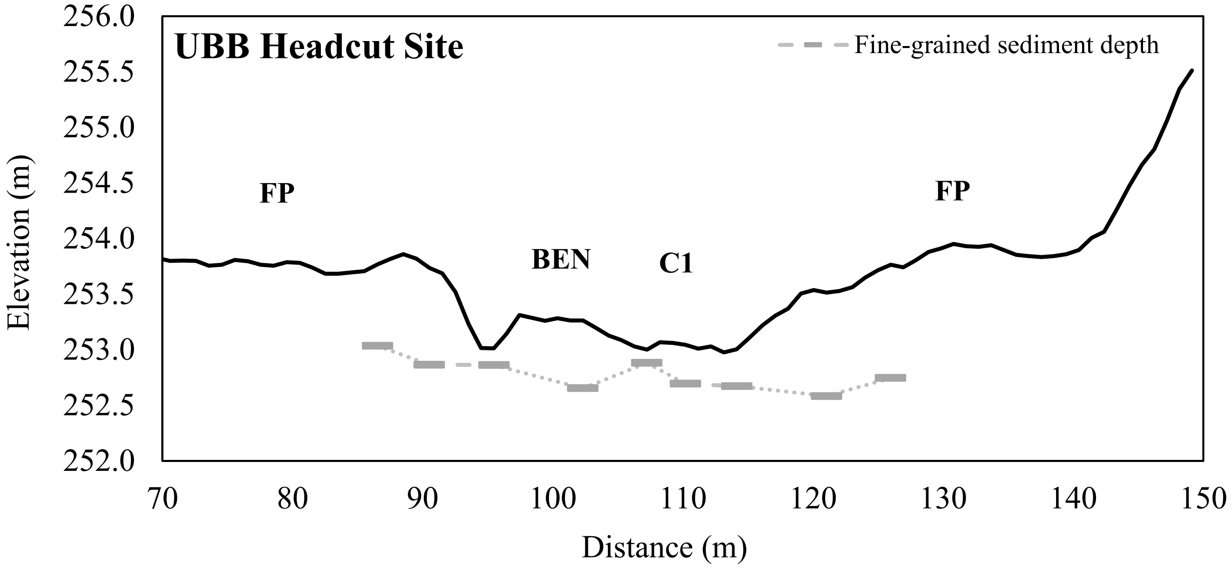
Appendix D-1. Cross-section with depth to fine-grained sediment refusal and the depth of the tree cored for sedimentation rates at river kilometer 39.



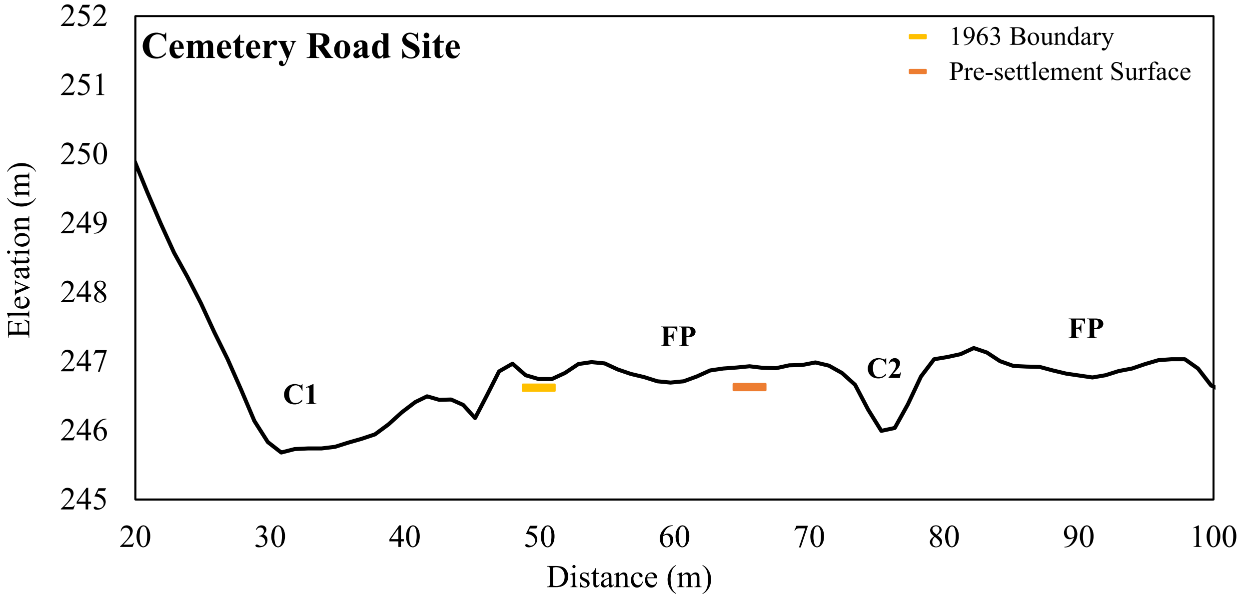
Appendix D-2. Cross-section with depth to fine-grained sediment refusal and the depth of the tree cored for sedimentation rates at Above Farm site.



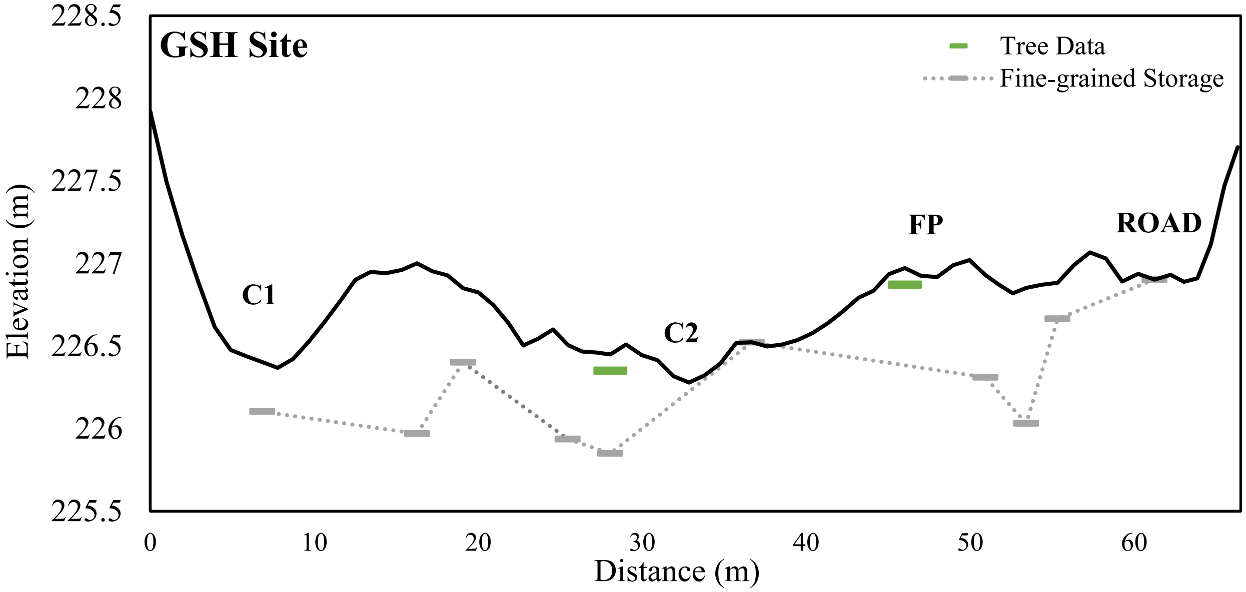
Appendix D-3. Cross-section with depth to fine-grained sediment refusal and depth of old growth pine stump at upper Big Barren Farm site.



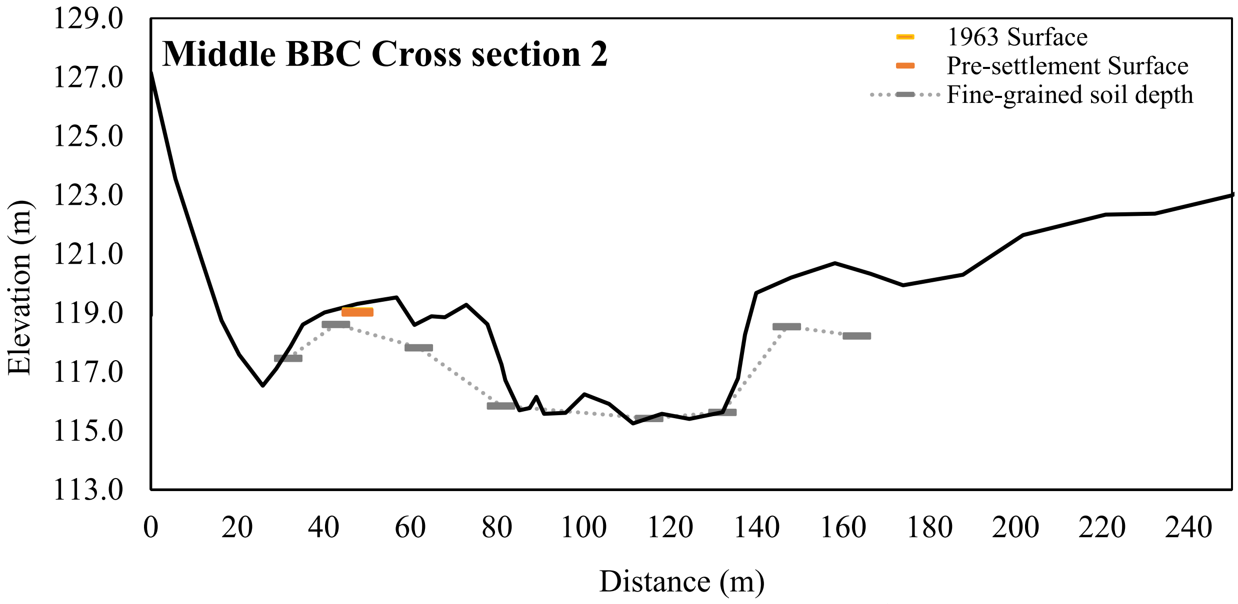
Appendix D-4. Cross-section with depth to fine-grained sediment refusal at upper Big Barren Head-cut site.



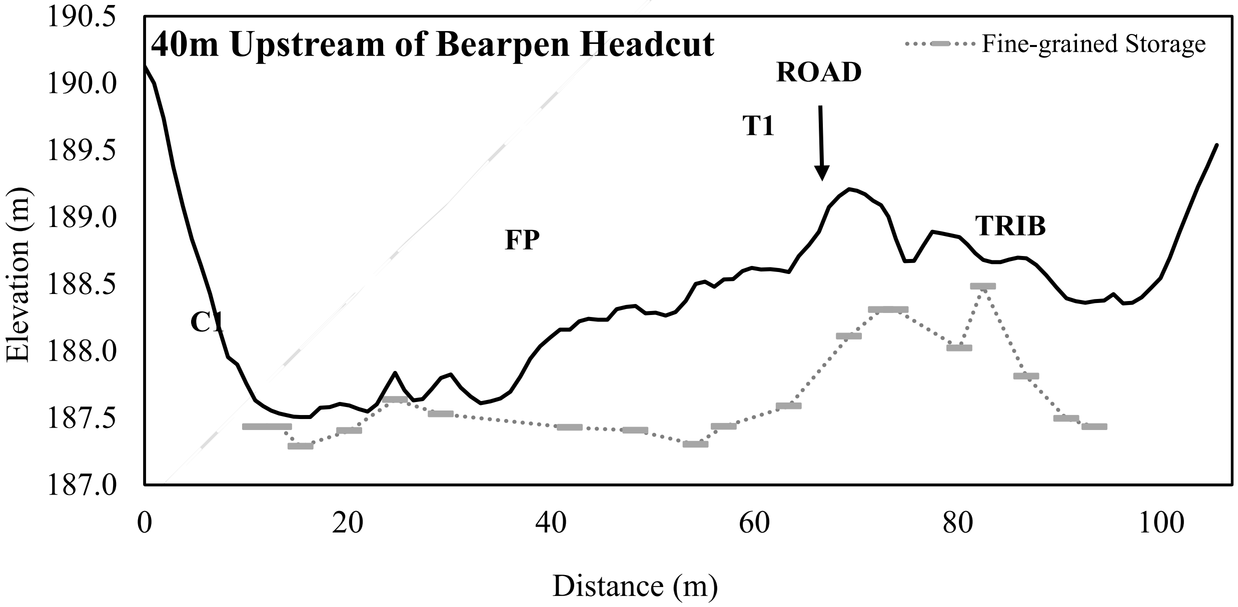
Appendix D-5. Cross-section with stratigraphic boundary information at Cemetery Road site.



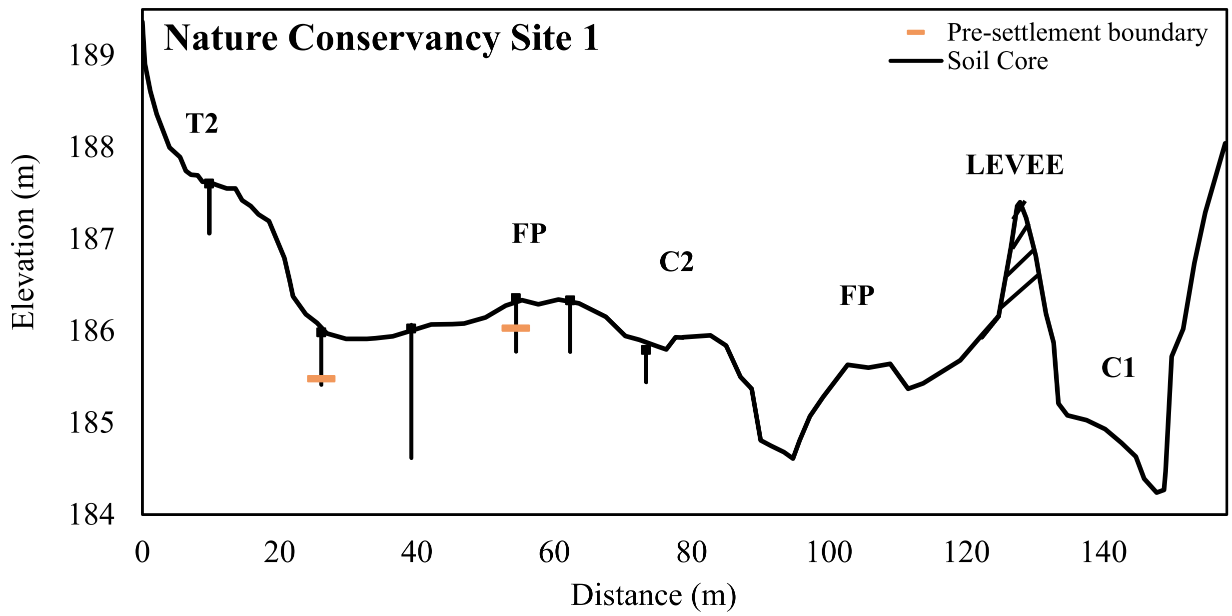
Appendix D-6. Cross-section with fine-grained depth to refusal information with stratigraphic boundary information at German Shepard site.



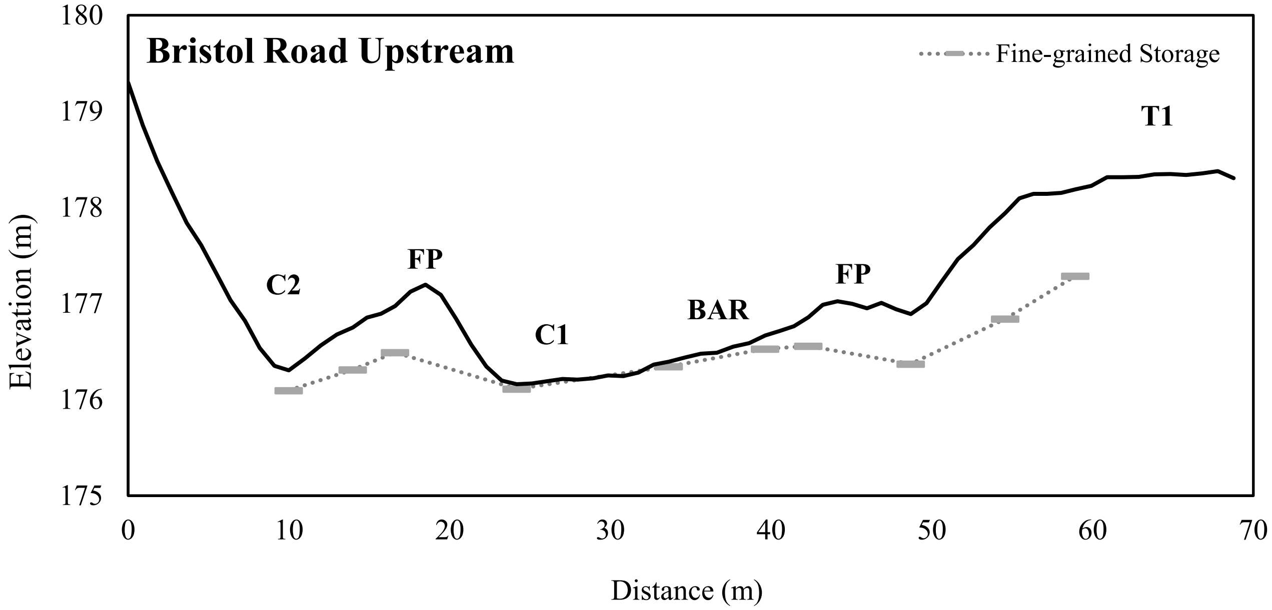
Appendix D-7. Cross-section with fine-grained depth to refusal information and stratigraphic boundary information at middle Big Barren site 2.



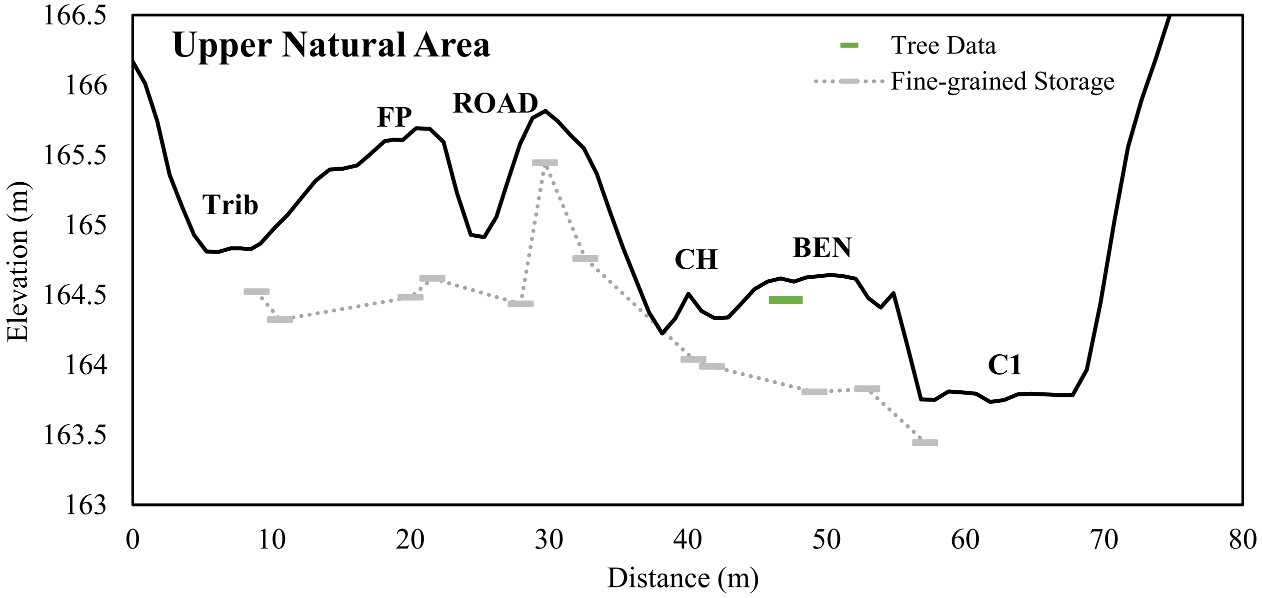
Appendix D-8. Cross-section with fine-grained depth to refusal information at upstream of Bearpen Head-cut site.



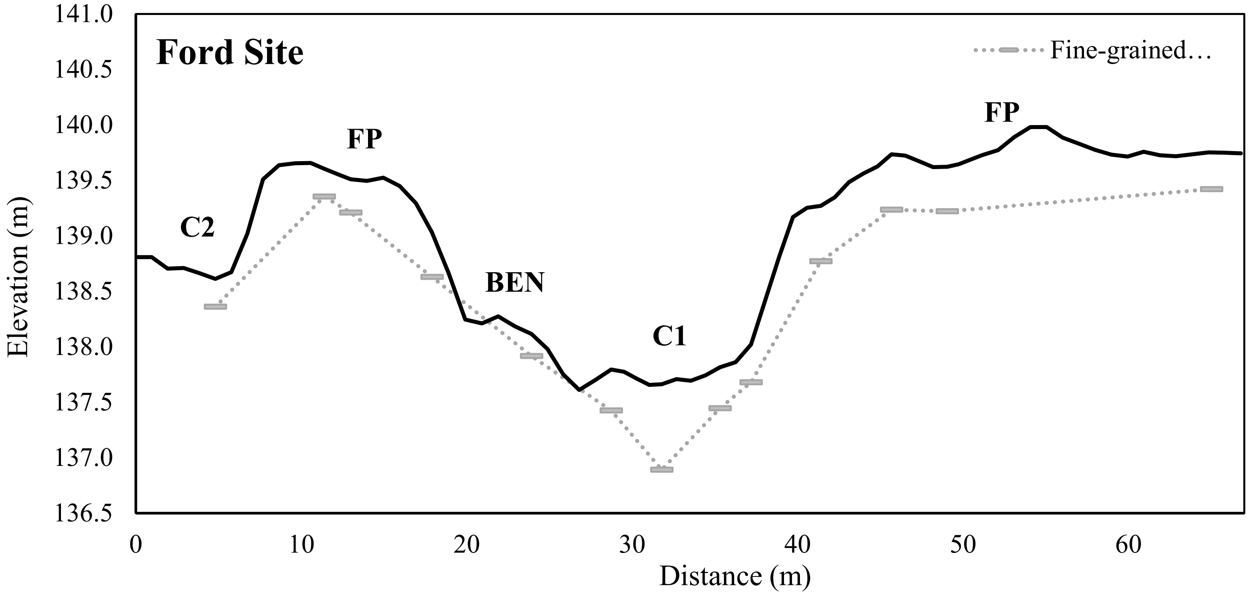
Appendix D-9. Cross-section floodplain and terrace soil cores and stratigraphic boundary information at Nature conservancy site 1.



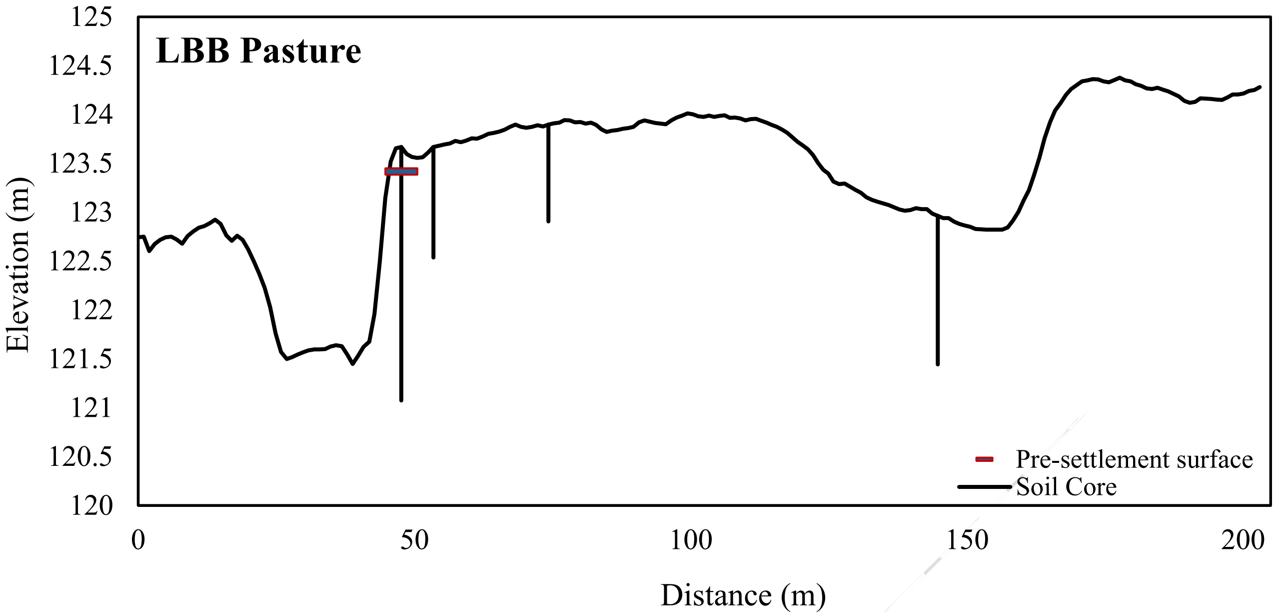
Appendix D-10. Cross-section with fine-grained depth to refusal information at Bristol road site.



Appendix D-11. Cross-section with fine-grained depth to refusal and stratigraphic boundary information at upper Natural Area site.



Appendix D-12. Cross-section with fine-grained depth to refusal information at Ford site.



Appendix D-13. Cross-section floodplain and terrace soil cores and stratigraphic boundary information at lower Big Barren pasture site.