LEGACY SEDIMENTS IN SOUTHEASTERN UNITED STATES COASTAL PLAIN STREAMS

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 14, 2010

Keywords: Stream and floodplain geomorphology, Coastal Plain,
American-European settlement, soil erosion, legacy sedimentation

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Abstract

Soil erosion and sedimentation are natural processes that occur throughout the landscape. However, athropogenic disturbances may result in an increase in either of these processes, or both. Many studies reported the extensive sedimentation generated by the lack of conservative practices in the agricultural methods applied during the settlement of the American-Europeans (Trimble, 1974; Lowrance et al., 1989; Jackson et al., 2005). Yet, the effect of this sediment in the stream's hydrology and geomorphology and the duration the alluvium may remain onsite is unknown. This research addressed the impacts of the disturbances caused by the early settlers on the hydrology and geomorphology of Coastal Plain streams and floodplains. The goals were to estimate legacy, mid-term (30 years), and current sedimentation, and discuss the implications of the sediment originated during the settlement on the streams' ecology, hydrology, and geomorphology. The study area consisted of two watersheds at Fort Benning, Georgia: Bonham Creek and Sally Branch. Five different methodologies were used to address legacy, mid-term, and current sedimentation; and an additional simulation exercise using WEPP technology was applied. Research on the historical development of the study area showed increases in population from 1830 to 1930. Farmland area declined after 1910, indicating the end of the cotton-era in the South. Results from soil coring showed that the floodplains of the streams are evenly buried under an average 179 cm, with corresponding mass of 2,338 kg m^{-2}, of sediment that originated during the settlement

period. Organic carbon concentration within this sandy loam sediment averaged 25,854 mg kg^{-1}. Morphologically, the streams showed a pattern of deep channel incision leaving the floodplain high and dry. The dendrogeomorphic data showed stability on the floodplains, with little sediment redistribution/scouring (0.4 cm yr^{-1}) over the past 25 years. Results from our modeling exercise showed that WEPP did not accurately account for the sediment delivery to floodplains in the early settlement scenarios when compared to the field study estimates. In summary, there is evidence of the significant sedimentation the streams underwent during settlement, and that this sediment has affected stream ecology, hydrology, and geomorphology.

Acknowledgments

First, I would like to thank Dr. B. Graeme Lockaby for his support, guidance and invaluable input towards this project. He has been an exceptionally supportive educator and mentor throughout my graduate experience. I would also like to thank my committee members Dr. Jon Schoonover, Dr. Kathryn Flynn and Dr. Christopher Anderson for their critical ideas and different perspectives on research findings during my graduate tenure. Funding for this research was provided by the SERDP (Strategic Environmental Research and Development Program – Department of Defense), US Army Research Office; Research Triangle Park, NC and it was greatly appreciated. Robin Governo is also gratefully acknowledged for field, laboratory and planning assistance. Herbert (Tug) Kesler, Dan Gorham, Nathan Click, Sherry R. Bloomfield, Jody Tomphson, Jon Dow, Nick Bradley, David Budenstain, Mitch Brown, Rachel Jolley, Don Vestal, Dr. Mark Dougherty, Anurag Srivastava, Patti Staudenmaier, Dr. Joey Shaw, and Madhu Narayan are thanked for their irreplaceable dedication towards laboratory, field and/or office assistance. Lastly, I would like to specially thank my family: Arnaldo, Fatima and Andre Luis, and Ana Luiza Paula for their love and support through my career.

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Chapter 3

1. INTRODUCTION

Riparian ecosystems are the transitional zones characterizing the interface between terrestrial and aquatic environments. Considered ecotones, riparian areas are affected by continuous exchange of energy, nutrients, compounds, and organisms on the landscape at various temporal and spatial scales. These ecosystems are characterized by Naiman et al. (2005) to be among the most diverse, dynamic and complex natural systems. As a result, they encompass a great variety of environmental conditions, ecological patterns and processes, as well as animal and plant communities. These systems have been extensively studied from many different perspectives; as a result, a wide array of definitions exist. According to Gregory et al. (1991), most of the definitions are based on underlying hydrologic, topographic, edaphic, and vegetative criteria. Naiman et al. (2005) for instance, defined these systems in terms of their interrelationships between biotic and abiotic communities, fluxes, and processes, usually encompassing complex landscapes shaped by geomorphologic events, hydrologic dynamics as well as plant and animal communities.

Most definitions agree upon the uniqueness of riparian forests and their capacity for promoting interactions between and within the landscape (Mitsch and Gosselink, 2000). The interactions across landscapes are defined by exchanges between the uplands and the aquatic ecosystems; whereas the interactions within landscapes are characterized by the exchanges within the different reaches of these aquatic systems. Due to their interconnectivity between and within the landscape, these forests process large fluxes of energy and nutrients, and support significant biotic diversity (Mitsch and Gosselink,

2000) at various scales. As a result of their importance within the landscape mosaic, these systems have been historically linked to society's welfare (Lockaby, 2009), dictating the quality of human life and often improving human wellbeing.

Geomorphically, floodplain forests are complex and dynamic fluvial landforms. The landscape complexity and diversity of these systems are the result of their primary shaping forces, described as the cut-and-fill process (Naiman et. al., 2005). This process depends basically on water mediated erosion in certain areas (cut) followed by transportation and subsequent deposition of this alluvial sediment on the lower reaches of the streams (fill). Therefore, we can infer that this portion of the landscape is continuously eroding in some places while aggrading in others. Generally, the resulting riparian ecosystems may occur as two main types of landforms: (i) narrow strips of streambank, or (ii) broad alluvial valleys. The type of landform which the riparian zone will assume is, however, dependent upon a wide array of factors, including surface and sub-surface geology, slope gradient, and hydrology. Headwater linkages with downstream systems also play an important role in defining the stream network environment (Gomi et al., 2002).

1.1 Southeastern Coastal Plain Riparian Forests

In the Southeastern Coastal Plain of the United States, most of the few remaining undisturbed riparian forests occur in broad alluvial valleys and are often called floodplain forests (or bottomland hardwood forests). Magilligan (1985) affirmed that floodplain width strongly influences sedimentation patterns, highlighting the role that Coastal Plain riparian forests play on landscape ecological integrity. Furthermore, Hupp et al. (2005) reported that these singular ecosystems reach their greatest development along the unconstrained, low-gradient and slow-flowing rivers and streams of the Southeastern Coastal Plain province. According to Lockaby (2009) the net primary productivity (NPP) of these floodplain forests in the Southeast, can range from among the highest to the lowest in the temperate zone, emphasizing the complexity of these systems.

Extending for approximately 1.2 million km^2 (Hupp et al., 2005), the Coastal Plain province is the most extensive physiographic region in the Southeastern United States. It borders the Piedmont Highlands to the north and the Ozark Highlands to the northwest. Hupp (2000) affirmed that the region is essentially built upon sediment deposition of both alluvial and marine systems (caused by sea level rise and retreat). Consequently, the streams and rivers within this region have been greatly influenced by marine sediment depositions throughout their geomorphological extent. According to Hupp (2000) and Hupp et al. (2005), during oceanic regression (ocean retreat), there was a downcutting of sediments in the stream valleys caused by water erosion known as degradation. When sea levels rose (oceanic transgression), these valleys filled with sediment and widened, resulting in aggradation of sediment.

Topographically, the Coastal Plain is basically defined by lowlands and low-gradient sloped hills. Since the landscape typically offers low variation in elevation, the rivers and streams flow slowly and meander through the landscape. Consequently, overbank flooding happens more often and lasts for longer periods of time. As a result, most of the Southeastern US floodplains tend to be zones for sediment deposition (Hupp, 2000). We can infer that functioning floodplain ecosystems in the Southeast actually depends upon upstream soil erosion and subsequent deposition on downstream reaches for many reasons, including the influx of water and nutrients.

According to Hupp et al. (2005), the floodplains in the Southeastern Coastal Plain undergo two major hydrological variations within a year: (i) the low-flow season and (ii) the high-flow season. The low-flow season occurs in the summer and fall months, when precipitation is lower and evapotranspiration is greater. During this season, the stream remains confined in the meandering channel; whereas during the high-flow season – which happens in the winter and spring months (higher precipitation and lower evapotranspiration) – the stream overflows its banks and large portions of the riparian forests may be flooded (Hupp et al, 2005). Both seasons help build a unique system along Southeastern streams and rivers. The first stage characterizes a prolonged wet season, promoting intense biogeochemical interaction, since water is the main medium through which these exchanges occur; whereas the second is a dry period, which allows plants to germinate and animals to feed promoting the occupation of the space. Wildlife habitat is improved in these systems during either season (Hupp, 2000).

1.2 Sedimentation Patterns

According to Knox (1977), the balance between natural vegetative cover and climate is imperative in controlling surface runoff and sediment yield – the major factors in soil erosion and sedimentation. The same author stated that disruption of this balance may occur as a result of climatic change, which includes changes in precipitation and temperature patterns, or as a consequence of human disturbances. Either could lead to significant increases in surface runoff and consequent increases in sediment delivery to downslope ecosystems. Consequently, floodplain forests are influenced by management of the surrounding uplands, but also affect and help maintain the integrity and functionality of downstream ecosystems.

According to Wipfli et al. (2007) headwater systems provide a variety of services to downstream environments, such as water, nutrients, food and woody debris. The same author also affirms that headwater streams sustain much of the structure, function, productivity and biocomplexity of the entire stream network. According to Gomi et al. (2002) headwaters influence the downstream reaches by providing sediments, water, nutrients and organic matter. Wipfli et al. (2007) added organic matter and biological inputs such as invertebrate to this list. The linkage between headwaters and the downstream network is emphasized by Vannote et al. (1980) which affirmed that some downstream biological communities depend on the compounds resulting from upstream processing inefficiencies.

Processes linking headwaters to downstream systems are not always continuous. As valley width, substrate size, relief, channel roughness, channel dimensions and sinuosity vary within the stream network (Gomi et al., 2002) the fluxes and intensity of processes such as sedimentation also vary. Wipfli et al. (2007) also affirmed processes linking headwaters and downstream systems are a function of the variable and complex channel geomorphology. Sediment subsidy from headwaters for instance may change as the smaller channels get clogged by debris and/or sediment becomes temporarily stored throughout the stream network, along the streambed, banks, floodplains and terraces (Gomi et al., 2002).

Mitsch and Gosselink (2000) affirmed that riparian buffers along the streams essentially function as nutrient sinks for lateral runoff from adjacent uplands and as nutrient transformers for upstream-downstream flows. However, Wipfli et al. (2007) affirmed that land uses may disrupt and alter the material transport to downstream reaches by removing the sources of these nutrients and altering storage capacity of headwater systems. Hupp et al. (2008) stated that due to the great capacity for retaining and storing sediments and adsorbed nutrients through lateral and vertical accretion, the floodplain forests in the Southeastern Coastal Plain support many biogeochemical interactions between water and land. In addition, sediments are reported as sources of nutrients, such as nitrogen (N) and phosphorus (P), to riparian vegetation (Cavalcanti and Lockaby, 2005; Hupp et al., 2005; Jolley et al., 2010; Jolley et al., 2009). However, knowledge of the impacts of sediment and nutrient delivery to these areas, as well as their origin is still limited (Hupp et al., 2005).

According to Knox (1977), vegetation and forest cover in watersheds and along streams help decrease surface runoff and sediment yield, due to an increase in precipitation interception and soil infiltration capacity. Furthermore, floodplain forests are subject to alluviation: as streams overflow their banks, sediment laden waters leave the main channel and enter the forested wetland. Velocity slows due to increased surface roughness and is followed by sediment deposition. By trapping sediments, floodplain forests also trap nutrients that are either carried by sheetflow or are attached to sediment particles (Hupp, 2000). As a consequence, most riverine forests are known for preserving and maintaining downstream integrity and water quality by retaining nutrients and sediments carried by surface runoff (Hupp, 2000; Cavalcanti and Lockaby, 2005; Jolley et al., 2009). In fact, this process has been identified as a natural function of floodplain forests (Mitsch and Gosselink, 2000) and is often taken for granted (Lockaby, 2009).

Although floodplains naturally accumulate sediments, excessive sedimentation in riparian forests may be detrimental (Jolley et al., 2009). During the European settlement of the Southeast, much forest land was converted to agriculture (Trimble, 1974; Knox, 1977; Lowrance et al., 1989; Kellison et al., 1998; Jackson et al., 2005; and Lockaby, 2009). Moreover, the riparian forested ecosystems were among the first ones to be converted due to soil fertility (Kellison et al., 1998) and proximity to water bodies (Lockaby, 2009). Swift (1984) estimated that as much as 70% of the original riparian forest areas have been converted in the United States. Lockaby (2009) affirmed that in the Southeastern US alone, as much as 75% of bottomland hardwood forests have been lost, decreasing from the original four million hectares to only one million. However, most of this converted land has proved to be inappropriate for agricultural crop usage because of the frequent flooding conditions and poorly drained soils. As a consequence, a current demand for the reestablishment of these ecosystems has led to modest restoration programs throughout the nation (Allen and Kennedy, 1989).

Currently, the remaining fragments of riparian forest are still under pressure. Studies have shown that these ecosystems are currently being exploited and modified by timber harvesting, agriculture, highway construction, channelization and urbanization

(Bazemore et al. 1991; Hupp and Bazemore, 1993; Hupp, 2000; Naiman et al., 2005; and Lockaby, 2009). Among these studies, Bazemore et al. (1991), Hupp (2000), and Hupp et al. (1993) emphasize the mismanagement of the areas surrounding these systems and their consequent degradation.

Humans have benefited from the wide array of goods and services provided by the natural functions and processes of floodplain forests. Improvement of water quality, regulation of water flow, enhancement of wildlife habitat, facilitation of groundwater recharge, generation of recreation settings and improvement of aesthetics, are among the most commonly cited services. However, the intense exploitation of riparian forests coupled with the lack of conservation measures, may reflect our late recognition of the services provided.

It seems that humans still struggle to respect and fully understand the complexity of these systems. Studies by Hupp and Bazemore (1993), Kleiss (1996), Hupp (2000) and Cavalcanti and Lockaby (2006), have shown that anthropogenic disturbances significantly increased sediment delivery to riparian areas, overwhelming their sediment holding capacity. Such high levels of sedimentation may cause severe damage to the natural integrity and functionality of these systems (Bazemore et al., 1991; Hupp and Osterkamp, 1996). In a study on riparian forests adjacent to ephemeral streams at Fort Benning, Jolley et al. (2009), found significant decline of both aboveground and belowground forest productivity, when sedimentation rates were greater than 0.1-0.4 cm yr^{-1}. Similarly, Cavalcanti and Lockaby (2005) also found decline of fine root productivity and forest production, once sediment deposition rates reached 0.3 cm yr^{-1}.

Trimble (1974), Knox (1977), Lowrance et al. (1989), Craft and Casey (2000), Jackson et al. (2005) and Walter and Merritts (2008), found that the early American-European settlers' land conversion to row-crop led to significant increases in surface runoff and consequent soil erosion in the uplands. Most of this sediment has traveled relatively short distances and as a result, remains in downslope riparian forests, altering the ecology, hydrology and geomorphology of these ecosystems and their adjacent streams.

Craft and Casey (2000) compared floodplain ecosystems with depressional freshwater wetlands in terms of sediment and nutrient retention. The study was developed in wetlands situated on the Southwestern portion of the state of Georgia. Using the isotope ^{210}Pb for sediment deposition dating, they found historical sediment deposition (over 100 years) to be much greater on forested floodplains than all the other depressional wetlands. Also, the rates of retention for phosphorus were 1.5 times greater in forested floodplains. The authors concluded, however, that the driving factor which determined the rates of sediment accumulation and nutrient content most likely was the agricultural practices performed in the surrounding areas at the turn of the century. From this, we can infer that the disruptions of the surrounding landscapes may leave a long-term imprint in these riparian forests.

There are many factors that may affect the sediment retention capacity of forested wetlands. Hall and Freeman (1994) have listed nine of the major factors that may influence the location of sediment deposition as well as the sediment trapping capacity in these systems throughout the country. The five factors which are most applicable to the Southeastern floodplain forests are listed below:

- *"Inflowing sediment load"*: Characterized by the actual amount of sediment moving into the wetland. This factor may also determine location and quantity of sediment deposition.
- *"Size distribution of inflowing sediment and wetland bed material"*: The particle size of the sediment will determine location of deposition.
- *"Velocity and turbulence of water":* The location of deposition according to the particle size of the sediment will be strongly determined by the velocity and turbulence of the water.
- *"Residence time"*: The time the water stays within the wetland will determine the amount and the particle size of deposited materials. Finer sediment grains tend to take longer to deposit.
- *"Density and type of vegetation"*: Existence of vegetation creates surface roughness within the wetland, decreasing water velocity and promoting sediment deposition (Hall and Freeman, 1994, pages 1 and 2).

Slight changes in elevation and downed woody debris are cited by Hupp et al. (2005) as additional factors that strongly influence sedimentation patterns. In summary, sedimentation patterns are dictated primarily by local hydrology, hydraulics and by the physical and biological aspects of surrounding areas. Therefore, wetlands cannot be isolated from surrounding landscapes as soil erosion/movement on upslope areas may well be delivered to the downslope wetlands, altering their sedimentation patterns and most likely causing changes in the local ecological processes.

1.3 Knowledge Gap

Filtration of floodwaters is considered a normal function of riparian forests and greatly benefits local communities; however, the filtration capacities of riparian forests vary. Barfield et al. (1998) also found that more than 90% of sediment and nutrients were trapped in riparian filter strips, and that trapping efficiency was strongly related to riparian strip length. Kleiss (1996), on the other hand, found that during a high-flow event of the Cache River in Arkansas, only about 14% of the eroded sediment was trapped in the floodplain. However, the floodplains accounted for only 3% of the total catchment area of the watershed. Consequently, the sediment holding capacities of riparian forests are extremely variable among stream/river systems as well as within the systems themselves. A thorough understanding of floodplain capacity to process fluxes of energy, sediments and nutrients would be extremely valuable. Investigations, along with empirical observation on the importance of floodplain ecosystems throughout the Southeastern US, should emphasize the expanding need for research on the hydrological, geomorphological, and ecological aspects.

The length of time sediment is retained in floodplains is unknown and often not taken into account when sediment budgets are estimated (Hupp et al., 2005). There is a need for studies addressing the lag response of human induced disturbances on stream and floodplain fluvial geomorphology. Trimble (1974) stated that most sediment deposited in the streams that originated from the settlers' row crop agriculture practices are being transported downstream and that the spatial distribution of this fluvial process is unknown. According to Hupp (2000), while the ecology of riparian forests has already been widely studied, there remains a lack of knowledge involving fluvial geomorphological processes. More specifically, long-term impacts from human intervention and land cover conversion on the fluvial geomorphology of riparian forests remains unclear. According to the EPA (2002), sediments are the major cause of river and stream impairment in the US. As stated by Martin et al. (2001), the waters of the state of Georgia have past and present problems with sediment related pollution. Sediments may smother stream-beds, suffocate fish eggs and bottom-dwelling organisms, diminish drinking water quality and interfere in recreation (EPA, 2002). The time required, as well as the nature of responses to such stresses are also poorly understood. So far, in most of the literature, authors have studied current or historical sedimentation rates and patterns. The main goal of this study is to address the knowledge gap in floodplain geomorphic changes due to human induced disturbances.

Obstacles to preventing and/or ameliorating impacts caused by excessive sedimentation include confusion regarding whether the source of sediment is historical or current. Identification of land use legacy and its possible impacts on the downslope streams and riparian areas is an important scientific question worldwide which has only been investigated to a small extent. This is probably due to the complexity of the question and lack of reliably effective approaches. The lack of information on this topic represents a major obstacle to the design and implementation of environmentally-compatible land management activities (e.g. installation of BMPs). It is also possible that the original geomorphology of disturbed riverine systems affects the success of conservation and restoration projects. Ultimately, the present study will generate important knowledge about the current services that ecosystems, such as wetlands are providing to improve human well-being.

1.4 Objectives

The objective of this study is to improve our understanding of the processes involved in soil erosion, subsequent sediment transport and finally deposition into the riparian forests. This includes better comprehension of how anthropogenic disturbances affect streams' hydrologic and geomorphologic features. The investigation will focus on the floodplains of two adjacent third order streams (Bonham Creek and Sally Branch) located within the Fort Benning Military Installation, near Columbus GA. It also discusses the best approach to address sediments originated from historical anthropogenic disturbances on the basins. The specific objectives with this study are:

- Estimate the historic (Chapter 2) and current (Chapter 3) sediment deposition rates on the Bonham Creek and Sally Branch floodplains and, if possible, within the stream channels (Chapter 3);
- Assess the extent of impact on the stream eco-geomorphology due to historical anthropogenic disturbances within the basins (Chapter 2);
- Verify the accuracy of the Water Erosion Prediction Project (WEPP) in modeling the sediment delivery to floodplain forests as a consequence of the American-European agricultural practices during settlement (Chapter 2); and to

- Discuss and explore the implications of excessive sediment accumulation on the integrity and functionality of streams and their floodplain forest ecosystems (chapters 2, 3 and 4).

1.5 Hypothesis

The hypotheses tested in this study were:

- Rates of historical (settlement period) sedimentation will be much higher than the current rates due to different land cover and management practices between the two periods.
- Agricultural practices during the cotton-era (from early 18^{th} to mid 19^{th} century) generated extensive soil erosion in the uplands and substantial sedimentation in the valley bottoms, which led to significant change in the hydrology and geomorphology of Coastal Plain streams and floodplains.
- The floodplains are presently at stable conditions in terms of sediment aggradation and/or degradation.
- Legacy sediments deposited in the floodplains of the studied streams are likely being slowly flushed out of the system.
- Disturbances, such as road crossings, represent an important source of current sediment in streams.

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2. HISTORICAL HUMAN DISTURBANCES AND LEGACY SEDIMENTATION

2.1 ABSTRACT

William Bartram described the Southeastern US during his travels, from 1773 to 1777, as a region with fertile soils, abundant water resources, and exuberant forests (Harper, 1998). Many studies have reported the extensive sedimentation generated by the lack of soil conservation practices in the agricultural methods applied during settlement (Trimble, 1974; Lowrance et al., 1989; Jackson et al., 2005). Fewer studies have attempted to quantify the capacity of riparian systems to retain sediments along with the duration that the sediments remain onsite. In addition, there is confusion regarding the origin (historical vs. current land use) of the suspended sediments in rivers and streams. This project examines the impacts of poor agricultural practices on streams and floodplains of the Southeastern Coastal Plain in terms of sedimentation. The study area consists of two watersheds at Fort Benning, GA. Three different methodologies were applied to characterize the legacy sediment deposited atop the historical floodplain. Soil carbon content and stream morphology were also analyzed in order to fully understand the consequences of the legacy sediment. Research on the historical development of the study area showed increases in population from 1830 to 1930. Farmland area showed a substantial decline after 1910, indicating the end of the cotton-era in the South. Results from soil coring showed that the floodplains of the streams were buried under an average 179 cm of sediment during the settlement period. The mean corresponding mass of sediment was 2,338 kg m^{-2}. Organic carbon concentration within this sediment averaged

25,854 mg kg^{-1}. Morphologically, the streams showed a pattern of deep channel incision leaving the floodplain high and dry. Lastly, results from a modeling exercise showed that WEPP did not accurately account for the sediment delivery to floodplain areas in the early settlement scenarios when compared to the field study estimates. In summary, the results suggest that these streams underwent extensive sedimentation in the cotton era, and this sediment has altered stream hydrology and geomorphology.

2.2 INTRODUCTION

Great uncertainty exists regarding human-induced impacts on natural landscapes before the settlement period. The idea that the Americas were pristine before the arrival of the settlers is disputed by many authors (Denevan, 1992). According to Denevan (1992), the Native American landscape was humanized, and actively managed by the native populations.

Regardless of the disturbances created by Native Americans, the naturalist William Bartram found the Southeastern US to be quite primitive in the 18th century. When Bartram was traveling throughout the “American South,” between 1773 and 1777, his reports depicted the region as having exuberant natural resources and populated by Native Americans. In fact, Bartram described the region, which is crossed by the Chattahoochee River just south of the Fall Line (boundary between the Piedmont and Coastal Plain physiographic regions), as:

> "… a very delightful territory, exhibiting a charming rural scenery of primitive nature, gently descending and passing alternately easy declivities or magnificent terraces supporting sublime forests, almost endless grassy fields, detached groves and green lawns for the distance of nine or ten miles, we arrived at the banks of the Chata Uche river opposite the Uche town, where canoes, by means of which, with the cheerful and liberal assistance of the Indians, ferried over their merchandize, and afterwards driving our horses altogether into the river swam them over: the river here is about three or four hundred yards wide…" (Harper, 1998).

Bartram's descriptions of the region did indeed show human occupancy in the area, which leads us to the idea that the region was managed by the local population. However, according to Lockaby (2009), the style of agriculture utilized by Native Americans would represent minimal soil disturbances and consequently generate little soil erosion.

2.2.1 Historical Riparian Forest Exploitation

Riparian areas have been used by humans for many different products and purposes. Swift (1984) estimated the total area covered by riparian forests in the United States to be approximately 30.5 to 40.5 million hectares before American-European settlement. The same author also estimated total loss of these ecosystems due to land cover conversion after settlement to be around 70%, which leaves approximately 10 to 15 million hectares. Moreover, the remaining 10-15 million hectares are not really secure, and most of these areas consist of fragments of heavily disturbed forests.

Historically, an enormous quantity of topsoil was eroded in the Southern US during agricultural land conversion by the early settlers (Neary et al., 1989). This settlement period, also known as the “cotton-era” in the Southeastern U.S., extended from approximately 1820 to 1930 (Lockaby, 2009). Increasingly studies are showing that the single incised channel, high bank erosion and anomalous high suspended sediments do not represent the original morphology of eastern U.S. streams and rivers (Lowrance et al., 1989; Martin et al., 2001; Jackson et al., 2005; Fitzpatrick et al. 2008; Walter and Merritts, 2008). Human induced disturbances altered the geomorphology of these systems. Other studies throughout the U.S. (Trimble, 1974; Knox, 1977; Knox, 1987; Jackson et al., 2005; Fitzpatrick et al., 2008; and Walter and Merritts, 2008) have shown the effects of human disturbance on the hydrology and geomorphology of streams and rivers.

2.2.2 Legacy Sediments in the Bottomlands

Trimble (1974) stated that the Southern Piedmont is one of the most severely eroded agricultural areas in the United States, and that much of it now is unsuitable for agricultural use. In his study, Trimble (1974) stated that some gullies have reached depths of approximately 30 meters, though such depth is extreme, and the normal gully depth ranges between 7 and 15 meters. The same author affirms that most of the eroded material ended up being deposited into the valley bottoms and streams, filling them to various degrees, often leading to “swamping” of the adjacent floodplains. The estimated total volume of soil eroded from the Piedmont uplands was on the order of 25 cubic kilometers (6 cubic miles) (Trimble, 1974).

Similar studies of anthropogenic disturbance that led to floodplain sediment filling were also conducted by Knox (1977) in the Platte River in Wisconsin and Knox (1987) within the southwestern Wisconsin and northwestern Illinois in the Upper Mississippi Valley; Lowrance et al. (1989) in the Tifton Uplands in Southwestern Georgia; Jackson et al. (2005) on Murder Creek in Georgia; Peck et al. (2007) in the Cuyahoga River in Ohio; Fitzpatrick et al. (2008) on Halfway Creek Marsh in Wisconsin; and Walter and Merritts (2008) along several Piedmont Mid-Atlantic streams. The common theme in these studies is the significant historical impact that humans have had on the integrity of the stream systems, and the consequent legacy sediment that will take centuries to export.

According to Trimble (1974), early settlers cleared and farmed the land with few soil conservation techniques until the land was perceived to be depleted and eventually abandoned. Such agricultural practices generated extensive soil erosion (Trimble, 1974; Knox, 1977; Knox, 1987; Hupp, 2000; Craft and Casey, 2000; and Jackson et al., 2005) from the uplands. Peck et al. (2007) and Walter and Merritts (2008) also attributed the legacy sediment on the floodplains in their study area to slackwater sedimentation from milldam construction for generating power.

In addition to all the agricultural development occurring during the settlement period, Knox (1987) affirmed that precipitation was frequently above-average, especially during the spring season when crops were not large enough to protect the soil against the energy of raindrops. Furthermore, soil infiltration capacities and organic matter had decreased due to poor agricultural practices (Knox, 1987), consequently increasing soil erosion potential.

Land conversion done by early settlers also caused larger and more frequent floods in the Platte River in Southwestern Wisconsin (Knox, 1977) leading to an increase in yields of both stream bedload and suspended sediments. Using an original land survey (1832 and 1833), the author was able to identify changes in the low flow width of the channel as a result of the historic land clearing within the watershed. The drainage areas smaller than 130 to 155 km^2 (headwater watersheds) showed shallower and wider low flow widths whereas larger basins seemed to present narrower widths when compared to their counterparts of the early 1830s. Furthermore, Knox (1977) still found an increase in the ratio between width and depth of bankfull after settlement, indicating sediment accretion on the floodplain. In fact, the author found alluviation on the floodplains derived from the early agricultural practices ranging from 0.5 to 4.0 m in depth and averaging 3.7 m.

A decade later, Knox (1987) investigated the legacy sediments in streams feeding the Upper Mississippi River. The author found post-settlement overbank sedimentation rates ranging from 0.3 to 5.0 cm yr^{-1}, causing burial of the historical floodplain by as much as 1.5 m. Knox (1987) stated that the amount of sediment burying the floodplain varied according to the drained area. Watersheds draining less than 50 km^2 have undergone floodplain burial ranging from 30 to 50 cm. In drainage basins greater than 50 km^2, burial depths ranged between 50 and 80 cm. The depths considered anomalous by the author (1.0-1.5 m) were only associated with the larger tributaries and main valleys flowing directly into the Mississippi River. These findings draw attention to the human capacity to alter the hydro-geomorphology of streams and floodplain ecosystems.

Legacy sediment depositions found by Lowrance et al. (1989) in southwestern Georgia, ranged from 600 to 7250 m^3 ha^{-1} in volume. In another study, Jackson et al. (2005) reported approximately 1.6 m of sediment deposition on the Murder Creek floodplain in Georgia since the pre-settlement era. Similarly, Fitzpatrick et al. (2008) found as much as 1.8 m of legacy sediment deposited along the marsh on the floodplain of Halfway Creek in Wisconsin, and 1.38 million m^3 of alluvium. Walter and Merritts (2008) reported findings of sediment deposition thickness ranging from 1 to 5 meters in the Upper Piedmont region of Virginia, Maryland, Pennsylvania, and Delaware.

Jackson et al. (2005) found no relationship between thickness of legacy sediment and basin area, elevation, stream order, or average valley slope. The authors stated that sediment was evenly distributed throughout the entire stream network. Walter and Merrits (2008), on the other hand, reported that depth to historic floodplain varied according to the distance from dams and distance of samples from the confluence (i.e. reaches) of tributaries in the Little Conestoga Creek in Pensylvania. Lowrance et al. (1989) also reported variations in legacy sediment thickness as downslope distance increased (the further from uplands the thicker the accumulation), and Jackson et al. (2005) and Fitzpatrick et al. (2008) reported different physical properties of the legacy sediment (bulk density and particle size) according to depth.

2.2.3 Consequences of the Legacy Sediments

Regeneration of forest communities and improvement of agricultural practices following the first extensive impact caused by the settlers reduced sediment delivery to the valley bottoms and streams. The stream beds (filled with sediment) started to undergo water-mediated erosion, and began to export this legacy sediment. The increased bank heights led to an increase in erosion within the stream channel (Knox, 1987), which continued to slowly flush out most of the alluvium deposited on the valley bottoms and stream, leading to consequent stream channel incision, deepening the channel and often leaving the floodplains high and dry (Hupp et al., 2005). The result of this exportation of sediment is reflected in the high levels of turbidity and suspended sediments observed in these streams (Walter and Merritts, 2008). Therefore, we can infer that these buried stream systems continue to act as a source of sediments, exporting legacy sediment as suspended sediment loads and stream bedload movement. Such inference may possibly explain the high suspended sediments in some streams in the eastern U.S., especially in streams at the Fort Benning military reservation (Sharif and Balbach, 2008; and P. Mulholand 2008 – personal communication).

In the Murder Creek study, Jackson et al. (2005) found sedimentation rates to be on the order of 6,170 to 9,800 times greater in the 1800's and early 1900's cotton-farming era than the current annual rates. The authors estimated that the system would require from six to ten millennia to export the legacy sediment that had been deposited in the valley bottoms and floodplains of the watershed. In conclusion, the authors stated that the system is currently "bleeding out" its deposited legacy sediments. Magilligan (1985) showed that application of some soil conservation techniques in the Galena River Basin in the post-settlement period (after 1940), returned the stream system to stabilized conditions, reducing bankfull capacity and bankfull width which normalized stream flow and sediment loads, resulting in reduced flood variability and also frequency of large floods.

2.2.4 Study objectives

The main goal of this study was to improve the understanding of sedimentation patterns in Southeastern Coastal Plain streams, especially systems that have been historically disturbed. Determination of the intensity of the settlement by gathering local historical information was defined as the first objective. Specific objectives were to estimate total floodplain sedimentation generated during the cotton era, and to assess the magnitude of the impacts of the settlers on the streams. This investigation also aimed at discussing implications and consequences of this legacy sediment in terms of hydrological and geomorphological responses in two different stream systems. Lastly, a computer based model (WEPP) was used to verify the likelihood of estimating legacy sediment footprint in floodplains in a much quicker, faster and simpler manner.

2.2.5 Study hypotheses

The following hypotheses were tested with this study:

- Floodplains underwent significant sedimentation that originated from the lack of soil conservation practices in the American-European settlers' agriculture, and this sediment is still retained within the floodplains.
- Thickness and mass of legacy sediment will not differ between streams because watersheds have similar characteristics (geologic formation, soil series, mean slope) and have undergone similar historical disturbances.
- Physical properties of the legacy sediment such as particle size will vary within a stream and throughout the sample corroborating the findings of Jackson et al. (2005) and Fitzpatrick et al. (2008).
- Legacy sediment carbon concentrations will vary between streams due to differences in hydrology, which could dictate decomposition rates; and within a stream due to microtopography, hydrology and past sediment influx.
- The Water Erosion Prediction Project (WEPP) computer-based model can provide quick and reliable estimates of sedimentation from row-crop practices during the settlement.

2.3 METHODS

2.3.1 Study site

This research was conducted at the Fort Benning Military Installation near Columbus, Georgia, USA (Figure 1), where disturbance created by military training and construction equipment has generated extensive sediment movement into downslope and bottomland areas. The military installation covers approximately 73,500 hectares in Chattahoochee, Muscogee and Marion counties of Georgia which correspond to the Lower Piedmont and Upper Coastal Plain region (along the Fall Line) and Russell County in east-central Alabama which corresponds to the Upper Coastal Plain (Kane and Keeton, 1998). According to Garten et al. (2003), the mean annual temperature is 18.4^{o}C and mean annual precipitation ranges from 105 to 123 cm, occurring regularly throughout the year (Garten et al., 2003; and Mulholland et al., 2005). The project was established along two adjacent watersheds located in the Upper Coastal Plain region, but just immediately south of the Piedmont Fall Line: Bonham Creek, which drains 1,273 ha, and Sally Branch, draining 2,531 ha (Baht et al., 2006) (Figure 2). The average slope on Bonham Creek is 5.04%, and its average elevation is 125.5 m. At Sally Branch, average slope and elevation are 5.42% and 136.8 m (Baht et al., 2006).

The watersheds are located in the northern portion of Chattahoochee County, Georgia, and both have had similar land uses and management practices since the American-European settlement. The dominant soil on both watersheds is from the Troup series, which is a loamy sand material originating from marine deposits, somewhat excessively drained, kaolinitic, thermic Grossarenic Kandiudults. On the floodplains, the soil is classified as the Bibb Series, characterized by recent loamy and sandy alluvial sediment, very deep and poorly drained, siliceous, acid (thermic Typic Fluvaquents) (USDA – NRCS Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/app/).

2.3.2 Study Design

All methodologies of this study were applied within the boundaries of the study area which were located in the lower reaches, or third order portions of Bonham Creek and Sally Branch. For gathering data that address historical sedimentation rates, as well as sediment sources, patterns and dynamics, the following methodologies were used:

2.3.2.1 Historical Records

Historical information on the landscape of the study site was extracted from "The Travels of William Bartram" by Harper (1998), "Man-Induced Soil Erosion on Southern Piedmont" by Trimble (1974), and "Fort Benning: The Land and the People" by Kane and Keeton (1998). Data characterizing the period prior, during and after European-settlement on the study area were gathered using the historic decennial census of population and housing produced by the U.S. Census Bureau (http://www.census.gov/prod/www/abs/decennial/index.htm). Since Chattahoochee County was created in 1854 from portions of Muscogee (created in 1825) and Marion (created in 1827) Counties, the historic data consists of all three counties. The data gathered at the county level were: (i) total population, (ii) slave population, and (iii) farm acreage. Note that total population numbers included the number or slaves. The timeframe during which data were available varied; for example, agricultural information such as farm acreage starts to appear in the census only after 1850. The data were gathered in order to show evidence of the time period in which deforestation and consequent agricultural activities resulting in erosion may have taken place.

2.3.2.2 Soil Cores

Soil cores were used to estimate the amount of soil that had been deposited on the forested floodplains. Streambank profiles where the streams had cut down below the historical floodplain surface were also used. The depth of the historical floodplain (pre-settlement) was estimated (in the field) by the discontinuity in the soil profile. This discontinuity was characterized by an abrupt change in texture and particle size from soils with higher clay content lying above a stratigraphic layer of sand and loamy sand material (C.R. Hupp, 2008 – personal communication; J. Shaw, 2008 – personal communication). Layers of organic material, dead non-decayed matter and charcoal above the sandy layers also helped support this identification criterion.

Soil cores were taken at 10 m intervals located on transect-gridlines that were 50 m apart and perpendicular to the streams (Figure 3). Sections representing different reaches along both streams were established. Three sections: lower, middle and upper were established along Bonham Creek, and two: lower and upper were established on Sally Branch. Each section was placed approximately 50 meters apart and all had several transects oriented perpendicular to the stream and extended to the outer edges of the floodplains. Both sides of the floodplain were sampled.

Soil cores were sampled using an AMS slotted soil probe with 2.9 cm diameter. Length extensions were attached to the soil probe according to the depth required. Each soil core was segmented into 30 cm increments within its entire length. The data collected on each increment included:

- Soil color: Each 30 cm increment was color coded according to the “Munsell Soil Color Charts”;
- Live and dead protruding roots: Roots sticking out of every core were counted in order to give proxies of depths of live and dead vegetative mass underground;
- Bulk density: Known volumes of soil were collected onsite from each core at every depth increment and placed into soil tins. Samples were then transported back to Auburn University, School of Forestry and Wildlife Sciences Soils Laboratory. The samples were oven dried at 105^{o}C, then placed into a desiccator to cool per Blake and Hartge (1986). Bulk density (BD) values were calculated in order to estimate mass of alluvium overlying the pre-settlement period floodplain soil surface. Extrapolation of the bulk density of each 30 cm increment to one square meter allowed calculation of the mass in grams per square meter for every increment in each soil core;
- Particle size: Soil texture was estimated in the field and, particle size analyses were performed in the School of Forestry and Wildlife Sciences Wet Chemistry Laboratory using the hydrometer method (Gee and Bauder, 1986). Samples used

for analysis were bulk density samples combined (2 to 3 samples) according to proximity, local topography and equivalent depths. Compositing samples was necessary to get the minimum sample weight described in Gee and Bauder (1986). A total of 337 samples were analyzed in the laboratory for particle size. The alluvium was then classified according to the NRCS Soil survey manual (http://soils.usda.gov/technical/manual/) recommendation;

- Carbon content: The loss on ignition (LOI) method according to Abella and Zimmer (2007) was applied in the School of Forestry and Wildlife Sciences Wet Chemistry Laboratory. A total of 337 samples were analyzed using the LOI method. A sub-set of samples reflecting a representative range of LOI values were sent to the University of Georgia (UGA), Agricultural and Environmental Services Laboratories - Soil Laboratory for organic carbon content determination. A regression analysis was performed between the LOI and the UGA soil lab organic carbon content results for predicting carbon content in all the samples (Figure 4). The regression analysis explained almost 73% of the variation estimating carbon by the LOI method ($p<0.0001$ and $r^2=0.7291$). Therefore, organic carbon content was predicted for all samples using this model. The equation provided by the regression model (1) permitting the prediction was:

$$(1)\ \text{Predicted C }(\%) = 0.789 + [0.716 \text{ x } (\text{LOI }(\%))]$$

For all creek sections, relative elevations were set for each plot using a stadia rod and surveying level. Elevations were set using a CST/berger PAL/SAL "N" Series (TM) automatic level. A cross sectional elevation of the creek channel (top-of-bank, bottom-of-bank, and center-of-creek) was also taken relative to plot elevations along each transect. This method allowed for comparisons among the depth of the legacy sediment onto the floodplains taking into consideration the local micro-topography.

2.3.2.3 Water Erosion Prediction Project (WEPP) modeling

The Water Erosion Prediction Project (WEPP)(USDA – National Soil Erosion Research Lab, 2009) was used to verify the likelihood of predicting legacy sediment using a modeling tool instead of collecting field data. Simulations were done using the 2008 version of the WEPP hillslope model for Windows.

The modeling exercise began with the hand delineation of smaller watershed that feed Bonham Creek and Sally Branch because Lin and Lin (1997), and Baffaut et al. (1997) showed that WEPP predictions are strongly correlated with slope length. Delineation was made using a 1:50,000 (10 meter contour line interval) digital orthophoto quadrangle produced by the Fort Benning Range Division (Figure 5). A total of 9 tributaries were randomly selected on Bonham Creek and 7 on Sally Branch and their lengths and gradients were calculated, and recorded as a slope profile to be modeled – 38 total, 22 on Bonham Creek basin and 16 on Sally Branch’s. The prevailing soil series on each slope was determined using the interactive web soil survey portal provided by the USDA Natural Resource Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/).

Climate data for each watershed was created using the CLIGEN model which is embedded within the WEPP model. The closest climatic station to the study site is the Talbotton station, located in Talbot County, 45 miles northeast of the research site. A set time length of one hundred years for the climate file was created using Version 4.3 of the CLIGEN stochastic model. The time period was selected, based on the number of years over which each scenario was simulated (100 years).

Land cover and management practices were determined by researching historical information – since pre-settlement of the American-Europeans era – for the Fort Benning region. Research and site visits showed strong evidence of historical cotton and corn farming (Figure 6) during the American-European settlement (early 1800's through early 1900's), followed by long years of forested land cover with few roads, and culminating in a landscape composed of cleared land (as a consequence of recent construction of a new tank training range). Assumptions of management practices were made aiming to best mimic reality at each time period when land cover was altered. Assumptions were based on information gathered relative to land cover on each time period simulated. The scenarios that best describe the land cover and management cycles of the region have been described below in order of occurrence:

- Pre-settlement, unmanaged, forest land cover with 90 days of leaf senescence from the trees. This scenario was referred to as "FOR".

- Forest (90 days senescence) followed by clearcutting and fire for clearing the residues which are assumed to be the practices of the settlers when establishing farms. This scenario was referred to as “FORCF”.
- Fallow followed by cotton tilled with moldboard plow at depth of 20.3 cm, where tillage was assumed to take 1 month to be completed and planting of cotton was also done a month after tillage. This was done to mimic the settlers’ agricultural practices to the best extent possible. This scenario was referred to as “FC”.
- Fallow. According to Trimble (1974) early American-European settlers cleared and farmed the land, with few soil conservation techniques, until the land was perceived to be depleted and eventually abandoned. This scenario was referred to as “F”.
- Regeneration of forests (90 days of leaf senescence) representing the 85 to 90 year time period since the region became military property in 1918 (Kane and Keeton, 1998). This scenario was referred to as “RFOR”.
- Forest (90 days senescence) followed by clearcut leaving 12.2 m strips of forest as a streamside management zone (SMZ) called Best Management Practice (BMP) and current ryegrass with low fertilization application two weeks after the clearcut on the uplands. Such features were based on site visits and ground-checking (Figure 7). This scenario was referred to as “RBMP”.

Each slope was simulated using all the above mentioned scenarios. Modeled runoff, soil loss and sediment yield of each slope, produced for every scenario, were averaged among all the slopes of the respective catchment (Bonham Creek and Sally Branch) for producing total averages on both streams.

2.3.3 Statistical Analysis

All statistical analyses were performed using the SAS version 9.1 English package (SAS Institute 2008-2009). Data from the historic census of population and housing (slave population, total population, and farmland area) were summed and averaged. Percentage change in farmland through the decades was calculated for interpretation and comparisons. Students' t-tests were used to compare legacy sediment depths and masses, bulk density, sediment particle size, and percent carbon content between streams, and between the sides of the floodplains. T-tests were also used to compare modeled data (runoff, sediment yield and soil loss) between streams. Analysis of variance (ANOVA) (PROC GLM with Tukey's HSD) were performed to determine differences in legacy sediment depths and masses, percent carbon content, and bulk density among the sections of the streams. ANOVA was also used to verify differences in bulk density of the legacy sediment according to the depth increment within the cores. Relationships between legacy sediment depth and mass, and percent organic matter (LOI) and percent carbon content were determined with linear regression analysis. Relationships were considered significant at alpha=0.05 (p-value<0.05), unless otherwise stated; however, results at 90% significance level (alpha=0.10, p-value<0.10) were reported for informational purposes.

2.4 RESULTS AND DISCUSSION

2.4.1 Historical Records

The information gathered from the “Travels of William Bartram” about the area is much more descriptive than quantitative. Bartram traveled through the area where the present study was conducted between 1775 and 1776 (Harper, 1998). The traveler-botanist wrote the following description:

> “…after leaving our encampment we traveled over a delightful territory, presenting to view variable sylvan scenes, consisting of chains of low hills affording high forests, with expansive savannas, Cane meadows and lawns between, watered with rivulets and glittering brooks; towards the night we came to camp in the banks of the Pintchlucco, a large branch of the Chata Uche river.” (Harper, 1998)

The river Bartram refers to as “Pintchlucco” may have been the present Pine Knot Creek, which is a watershed adjacent to Sally Branch on its northeastern portion. The “Chata Uche” river refers to the Chattahoochee River (Harper, 1998). Continuing his journey towards the south of Pine Knot Creek, Bartram probably crossed the territories comprised by the Sally Branch and Bonham Creek watersheds respectively. His path is described as:

> "… The next day's journey was over an uneven hilly country, but the soil generally fertile and of quality and situation favourable to agriculture and grazing, the summits of the ridges rough with ferruginous rocks, in high cliffs and fragments, scattered over the surface of the ground; observed also high cliffs of stiff reddish brown clay, with veins or strata of ferruginous stones, either in detached masses or conglomerated nodules or hematites with veins or masses of ocher." (Harper, 1998)

A qualitative analysis of Bartram's historical records pointed out the undisturbed natural condition of the studied watersheds. His descriptions of the region include its irregular hilly landscape, fertile soils, abundant water resources, majestic forests, expansive savannas, thick cane meadows and "charming rural scenery of primitive nature." Bartram's descriptions of the area do not mention any human-made structures or disturbance, conveying the impression that the local landscape was still in a primitive natural state. Furthermore, Bartram mentions the fertility of the soil, abundance of water and favorable landscape; conveying the idea of strong agricultural and grazing potential. It is likely that settlers noticed such conditions and established agricultural fields in the studied basins when they arrived.

Trimble (1974) affirmed that colonization of the Southeastern U.S. started in Virginia around the 1700s and reached Alabama by the 1830s. The author noted that the colonists reached middle Georgia by 1810 and that their main crop in this region was cotton (Trimble, 1974). Thus, the reason this period is often called the "cotton-era" (Lockaby, 2009) (Figure 8). Kane and Keeton (1998) emphasized that the area surrounding Bonham Creek and Sally Branch watersheds were anthropogenically disturbed during the early 1800s by mill construction (Figure 9). The authors suggest a probable sawmill that required the force of diverted waters from Pine Knot Creek to power the saws. In fact, an old water wheel filled with sediments was found on the lower floodplains of Sally Branch (Figure 6). In addition, Trimble (1974) developed a map of erosive land use (ELU) for the year of 1860 (Figure 10). According to the author, the greatest erosive land use was identified in the regions just north of the study site in the middle-western portion of Georgia.

The data in the U.S. Census indicate that the population of Euro-American settlers in Georgia in 1749 was approximately 6,000 (U.S. Census Bureau, 1790). By 1775, the population in the state had grown to 27,000 (U.S. Census Bureau, 1790) and had jumped to nearly 517,000 by the beginning of the cotton-era (U.S. Census Bureau, 1830). According to the 1930 census of the United States (U.S. Census Bureau, 1930), by the end of the settlement period (1930), Georgia had a population of 2,895,832.

The state of Georgia reported the number of slaves in the first published census of 1790. Trimble (1974) stated that erosive land use is highly correlated with slavery; therefore, the number of slaves was considered an index of agricultural activity and a proxy for estimating erosion potential. In 1790, there were 29,264 slaves in Georgia (U.S. Census Bureau, 1790). Within the three counties that encompass the study area, numbers of slaves were first reported on the Fifth Census of Population and Housing (U.S. Census Bureau, 1830). This is due to the date in which the counties were founded. The numbers of slaves in the three counties in 1830 was 1,349. By 1840, this number had increased 330% to a total of 5,771 slaves (U.S. Census Bureau, 1840). Slave numbers continued to increase during the following decades, reaching 13,732 slaves in 1860 (Figure 11) (U.S. Census Bureau, 1850; and U.S. Census Bureau, 1860).The number of slaves increased between 1830 and 1860 by more than 900% in the three counties, jumping from 1,349 to 13,732 slaves.

In terms of total population, at the beginning of the cotton-era (1830), Muscogee, Marion and Chattahoochee counties had a total population of 4,940 (U.S. Census Bureau, 1830). This number increased to as much as 73,420 in 1930 when the cotton-era ended (U.S. Census Bureau, 1830, 1840, 1850, 1860, 1870, 1880, 1890, 1900, 1910, 1920, 1930). During this 100 year period (1830-1930), the population in these counties underwent an approximate 14% increase in population per year. This resulted in a total accumulated population increase on the order of approximately 1,500% throughout the entire period. The greatest increase in population occurred from the 1830s to the 1850s. From 1830 to 1840, the population increased by almost 235% (from 4,940 to 16,511 people). From 1840 to 1850, it increased by 78%, to 29,398 people. In the later decades, population was still increasing, but at a much lower rate.

Agricultural data, including farmland area, became part of the Census of Population and Housing only during the 1850's census (Figure 12) (U.S. Census Bureau, 1850). The total farmland area in the three counties in this study varied from 158,000 hectares in 1850 to as much as 171,500 hectares in 1860, and declined to 166,800 hectares in 1910. Farmland then dropped significantly (36.5 %) to 106,000 hectares in 1930. Overall, the area dedicated to farming on the three counties decreased by 52% in 1930 compared to the average farmland area calculated for the period between 1850 and

1910 (162,094 ha). In 1918, the region which comprises the study area was bought by the military, and by 1919 Fort Benning military reservation was established (Kane and Keeton, 1998).

Farmland was used as an important proxy for erosion potential in the present study because, according to Trimble (1974), the exploitation of land was done extensively as opposed to intensively (production associated with yields/laborer rather than yield/acre), indicating conversion of large areas of forest for agricultural implementation. Trimble (1974) plotted a map showing the erosive land use (ELU) based on the percentage of area in row-crop equivalents. His map shows greatest ELU of over 5.5% intensity for the region which is just north of Bonham Creek and Sally Branch. The author showed substantial production of tobacco and cotton in this region in 1860 (Figure 13).

2.4.2 Soil Cores

A total of 168 soil cores were collected to analyze the legacy sediment that was deposited atop the historical floodplain soil surface; 118 from Bonham Creek and 50 from Sally Branch (Figure 14 depicts an example of a sampled core with depth of 126 cm). Overall, in most of the sampled cores from Bonham Creek, the top 100 cm were composed of a black (usually 10YR 2/1 Munsell color), highly organic, friable, loamy and somewhat mucky material. Conditions tended to vary between either side of the floodplain (the narrow-side seemed swampier with muckier alluvium than the west side) and among the sections as well (the historical floodplain tended to be buried deeper on the upper sections). Below the top 100 cm, keeping in mind variations among sections and between sides, the alluvium usually increased in clay content and presented higher values (4 or above) and chromas (3 or above). The lighter more purely colored sediment indicates fast vertical accretion according to Knox (1987). Rapid deposition occurred with no time to add organic material into the soil matrix; improving the clarity and purity of the colors, which otherwise would have been a rich, dark, organic soil due to overbank flooding.

On the majority of Sally Branch's cores, the upper 100 cm often varied from dark grayish brown to olive brown soil color (values around 4 and chromas around 2 or 3), sandy and loamy, extremely friable, and highly compacted. The same pattern of increasing soil values and chroma coloration with depth was also observed on Sally Branch's floodplain, supporting Knox's (1987) theory of rapid sediment deposition associated with color.

2.4.2.1. Legacy Sediment Thickness

At Bonham Creek, the mean thickness of the legacy sediment was 179 ± 4 cm. Thickness ranged from 90 cm on the lower sections of the stream to > 300 cm on its upper sections. For Sally Branch, mean depth of the historical floodplain was 178 ± 8 cm, ranging from 104 cm in the lower section to >300 cm in the upper. These findings support the hypothesis that floodplains underwent significant sedimentation due to poor agricultural practices during settlement. Sediment thickness was equally distributed on both streams (no significant difference between streams), supporting the premise that watersheds with similar physical characteristics and historical management practices would present similar sediment deposition.

Our soil core findings point out the importance of riparian floodplain forests in trapping sediment from upland sources. The mean thickness of the legacy sediment, across both floodplains, averaged 179 cm which were similar but greater to depths (160 cm) in the Murder Creek Basin, Georgia reported by Martin et al. (2001) and Jackson et al. (2005), and greater than the depths found by Fitzpatrick et al. (2008) in Halfway Creek averaging the upper and lower marsh (152 cm). Our soil core results were within the 100 to 500 cm range reported by Walter and Merritts (2008) on Mid-Atlantic Piedmont creeks, the 30 to 300 cm range on the Cuyahoga River in Ohio (Peck et al., 2007), and within the 50 to 400 cm range reported by Knox (1977) in the Platte River watershed in Wisconsin. However, it's important to highlight that the legacy sediment thickness observed at Bonham Creek and Sally Branch was fairly consistent throughout both streams.

In the Trimble (1974) study, estimates of upland erosion were made for the Southern Piedmont region. The estimated soil erosion depth from the uplands ranged from 4.8 to 31.2 cm over the entire Piedmont physiographic region. Therefore, the 5 to 30 cm soil erosion range might well have accumulated on the valley bottoms resulting in the 1.6 m of deposited alluvium reported by Jackson et al. (2005) in a Southern Piedmont watershed, and in the current findings of 1.75 m of alluvium deposited on floodplains of streams just south of the "physiographic divide".

Knox (1987) also reported various degrees of burial of the pre-settlement floodplain in the lead-zinc region of the Upper Mississippi Valley, and showed that ranges were a function of the drainage area. For watersheds smaller than 50 km^2, similar to Bonham Creek (12.7 km^2) and Sally Branch (25.3 km^2), Knox (1987) reported a mean legacy sediment thickness ranging between 30 and 50 cm. However, Bonham Creek and Sally Branch may have experienced more significant sedimentation due to the physiographic region where they are located which is dominated by sandy soils, and also due to the precipitation patterns (quantity and intensity) that occur in the Southeastern U.S.

According to Knox (1987) the deposition of sediment on the floodplains caused the stream bank to become higher, leading to increased in-stream channel erosion. This shift made stream overbank floods less frequent and less likely to extend throughout the entire floodplain, thus altering ecological patterns by modifying the local hydro-geomorphology.

2.4.2.2. Mass of Legacy Sediment

The average bulk density was 1.34 ± 0.02 Mg m^{-3} and 1.33 ± 0.02 Mg m^{-3} for Bonham Creek and Sally Branch soils respectively. These values are lower than the mean bulk density of 1.63 Mg m^{-3} reported by Jackson et al. (2005) in Murder Creek. The lowest mean bulk density was at the top 30 cm on Bonham Creek and Sally Branch (0.95 ± 0.03 Mg m^{-3} and 1.09 ± 0.03 Mg m^{-3} respectively) (Figures 15 and 16). The highest mean bulk density found on Bonham Creek was at 180 cm (1.67 ± 0.07 Mg m^{-3}) (Figure

15), and the highest mean bulk density found on Sally Branch was at 210 cm (1.81 ± 0.06 Mg m^{-3})(Figure 16). Bulk density values increased with depth likely as a result of compaction from the pressure the upper layers put on underlying alluvium. In addition it seems that the compacted sand (1.84 ± 0.27 Mg m^{-3}) underneath the legacy sediment has played an important role in acting as a solid base. The sediment sitting over the sand took the weight of the layers of sediment above resulting in heavy compaction.

Based on the values of bulk density found on Bonham Creek and Sally Branch, mass of sediment for each floodplain was calculated. Remembering that bulk density samples were taken at every depth increment in each core, the mass of sediment was calculated for each meter square at every 30 cm increment. Following the same trend as bulk density, mass of sediment increased according to depth (Figure 17) supporting the premise that layers of sediment atop are compressing and compacting the layers underneath. Conservative estimation of the mass of legacy alluvium for Bonham Creek averaged 2,304 ± 103 kg m^{-2}. At Sally Branch, the corresponding mass of alluvium was 2,370 ± 153 kg m^{-2}. A t-test indicated no significant statistical difference in the mass of legacy sediment between the streams ($p=0.7275$).

Both streams were sampled at different locations along the stream in order to address variability of sediment deposition due to the likelihood that erosion was not evenly spread throughout the watershed. In addition, Gomi et al. (2002) states that the role that headwaters systems play within the stream network and its linkages to downstream reaches are poorly understood. Wipfli et al. (2007) stated that land use can significantly influence the linkages between headwater systems and downstream reaches.

At Bonham Creek, a total of 37 cores were taken on the lower section, 30 on the middle section, and 51 on the upper section. The mean depths of the legacy sediment in the lower, middle and upper sections were 185 ± 19 cm, 175 ± 7 cm, and 179 ± 5 cm respectively. Equivalent legacy sediment mass per area was 2,399 ± 281 kg m^{-2} on the lower section, 2,201 ± 196 kg m^{-2} on the middle section, and 2,344 ± 136 kg m^{-2} on the upper section (Table 1). It was observed that both streams seemed to be braided towards the upper reaches, often having multiple channels. However, analysis of variance (ANOVA) comparing mean depths and mass of historical sediment among sections showed no significant statistical differences among the sections.

At Sally Branch, 21 cores were sampled on the lower section and 29 on the upper section. The mean depth of the legacy sediment sitting atop the historical floodplain was 150 ± 12 cm on the lower section and 201 ± 7 cm on the upper section (Table 1). The equivalent mass per area for each section was 1,998 ± 198 kg m^{-2} for the lower and 2,672 ± 206 kg m^{-2} for the upper section (Table 1). Based on a t-test, significant statistical differences in depth of the legacy sediment were found between the lower and the upper sections at Sally Branch ($p=0.0008$), as well as mass of legacy sediment ($p=0.0266$) supporting the hypothesis of variation in thickness of legacy sediment within the stream. However the results could be biased by an old elevated road noticed in the lower section of the floodplains of Sally Branch. The soil required by the construction of an elevated road might have come from excavation of the sediments from the floodplain, therefore removing sediment deposited locally. No significant statistical difference on the mean mass of legacy sediment was found between the two sections of Sally Branch ($p=0.104$).

The traffic resulting from the construction of the road may have caused compaction in the sediment which could have led to an increased mass of sediment per square meter in the lower section.

Comparisons between the sides of the floodplains were also performed for verifying the likelihood of evenly spread erosion on the watershed. It is important to define if sedimentation varied within the stream network to better understand alterations in local floodplain hydrology and geomorphology. Different characteristics were consistently associated with each side of the floodplain, one side was “wet” and swampier, often presenting patches of muckier soils whereas the opposite side was relatively “dry” presenting mostly mineral clayey soils. For this comparison purposes the different sides were referred to as “wet-“ and “dry-side”. At Bonham Creek, 52 soil cores showed a mean depth of sediment on the wet-side of 181 ± 6 cm. The corresponding mass per area of this sediment was 1,983 ± 133 kg m^{-2}. On the dry-side, 66 cores showed a mean depth of 175 ± 6 cm with a corresponding mass of 2,704 ± 140 kg m^{-2} (Table 2). T-tests showed no significant differences in the mean depths of sediment between sides of the floodplain of Bonham, however significant differences in mean mass of sediment between the sides ($p=0.0004$) was found, partially supporting the hypothesis that mass of legacy sediment would vary within a floodplain. As illustrated in the Hodges’ (1998) diagram, floodplains can back swamps at the upland interface. These locations have lower elevations and tend to accumulate water from upland runoff, and sediments with small particle size (clay). The surface runoff water from uplands may be trapped in this swamp slowing decomposition of organic matter down due to the saturated environment, allowing soils to become more organic (mucky), which is less dense than mineral. Therefore, bulk density and sediment mass values are lowered.

Further analyses relating the mass of alluvium to the thickness of the legacy sediment were performed. Overall (using data from both streams) a regression model (Equation 2) (Figure 18) explained approximately 50% of the variation in depth as a function of mass ($p<0.0001$).

$$\text{(2) Mass } (\text{kg m}^{-2}) = -403.82345 + [15.24379 \text{ x } (\text{Depth (cm)})]$$

Regression analysis showed a significant positive relationship (Equation 3) between mass and depth of the legacy sediment for Bonham Creek ($p<0.0001$, $r^2= 0.4099$) (Figure 19).

$$\text{(3) Mass } (\text{kg m}^{-2}) = -295.00402 + [14.51824 \text{ x } (\text{Depth (cm)})]$$

A similar positive relationship between mass and depth was also found on Sally Branch ($p<0.0001$, $r^2=0.7505$), and is portrayed by equation 4 (Figure 20).

$$\text{(4) Mass } (\text{kg m}^{-2}) = -610.46539 + [16.68638 \text{ x } (\text{Depth (cm)})]$$

These findings are important for further investigation of the legacy sediment. The regression analysis showed the relationship of depths – which is much quicker and simpler to assess – to the mass of the legacy sediments sitting atop the pre-settlement floodplain surface. It could aid in studies developed in a much broader scale, dealing with a greater number of streams, where intensive sampling of each stream would be too costly. It may also result in advances for ecological assessment as well as stream restoration and/or maintenance projects, since this approach has the potential to reliably predict alluvium accumulation, and determine more accurate original conditions of the streams and the historical anthropogenic effects on Southeastern Coastal Plain floodplains.

2.4.2.1 Relative Elevation and Cross Sectional Profiles

Bankfull-width measured among all the transects averaged 4.54 ± 0.26 m on Bonham Creek and 8.42 ± 1.19 m at Sally Branch. Bank height ratios (referred to as “bank height”) averaged 1.99 ± 0.15 m and 2.68 ± 0.22 m for Bonham Creek and Sally Branch respectively. On both streams, bank height ratios were greater than the average bank height of 1.58 m found by Jackson et al. (2005) in Murder Creek in Georgia. Such bank heights are likely to constrain stream-flow within the channel altering the hydrology of the streams. Significant statistical differences between the two streams’ mean bankfull-width and bank height were identified using a t-test (bankfull-width $p=0.0017$, and bank height $p=0.0195$ at $alpha=0.05$). Sally Branch has a deeper and wider stream-channel than Bonham Creek. The disparities result from differences in area (Sally’s catchment area is almost twice the size of Bonham’s), slope gradient (average slope on Sally is 5.4%, on Bonham it is 5.0%), and elevation (Bonham’s average elevation is 125 m, while

Sally Branch is almost 137 m)(Bhat et al., 2006). These statistical differences may indicate the greater potential of Sally Branch to scour the legacy sediment, opening the stream channel wider and deeper.

Entrenchment ratios were 0.91 for Bonham Creek and 0.77 for Sally Branch and width to depth ratios were 0.45 for Bonham Creek and 0.38 for Sally Branch. Even though sinuosity and stream slope were not surveyed with this study based on three out of five parameters, Bonham Creek and Sally Branch were categorized as “C5” streams under Rosgen classification (Rosgen, 1994).

For Bonham Creek, bankfull-width averaged 4.52 ± 0.57 m, 4.85 ± 0.19 m and 4.32 ± 0.55 m for the lower, middle and upper sections respectively. Bank heights of the same sections averaged at 2.49 ± 0.22 m, 1.50 ± 0.12 m and 1.98 ± 0.22 m respectively (Table 3). An ANOVA test showed that in this stream, there were no differences among the sections in terms of bankfull-widths. However, significant differences comparing the sections in terms of bank heights were found ($p=0.0229$, $r^2=0.53$). The lower section had a significantly higher bank height than the middle and the upper sections, which showed no differences. In addition to the analysis on the different sections, regression analysis for predicting changes in bank-width and bank height based on the data gathered at the transect level (determined by the 50 m intervals) were also performed, however, no statistically significant differences were observed.

For Sally Branch, bankfull-width averaged 12.0 ± 1.63 m and 6.03 ± 0.57 m for the lower and upper section respectively. For bank height, the lower section averaged 2.16 ± 0.13 m and the upper, 3.02 ± 0.28 m (Table 3). A significant difference was found between the lower and upper sections with regard to bankfull-width (p=0.0286) and bank heights (p=0.0275). A significant regression model (Figure 21) was found when predicting changes in bankfull-width based on the stream reach (p=0.0033, r^2=0.6402) (Equation 7). However no significant regression model was fit for bank heights.

$$(5)\ \text{Bankfull} - \text{width (m)} = 12.964 + [-0.0178 \text{ x (Stream reach (m))}]$$

Knox (1977) also reported significant changes in the stream widths of the Platte River in Wisconsin. The author affirmed that stream low flow width increased in the lower reaches of the stream, and this increase was caused by an increase in bedload, which in turn, made the stream shallower. Similar patterns were observed at Sally Branch, where the lower section showed wider channels with shallower heights.

The differences observed between the sections in bank-heights (Bonham Creek), and bankfull-width and bank-height (Sally Branch) supports the premise that energy delivered by stream water increased downstream, resulting in increased legacy sediment scouring in the lower reaches.

According to Knox (1987) increased bank heights, as a consequence of the excessive sediment deposition in the floodplains, increase the erosive energy of the water within the stream channel. This condition would speed the lateral channel migration of the stream by down-cutting streambanks. The same author stated that by shifting laterally, the stream channel would create an asymmetry between the high cut-bank and the low bank. Cross-sectional profiles on Sally and Bonham showed similar trends: the bank heights were so high, that the floodplains were acting more as low terraces with little sign of frequent floods, rather than active floodplains.

Representative cross-sectional profiles of the floodplains of Bonham Creek and Sally Branch along with the identified historic floodplain surface are depicted from Figures 22 to 25 (remaining cross-sectional profiles in appendices). Note the presence of geomorphological features such as levees and the changes in elevation allowing formation of sloughs and back swamps as proposed by Hodges (1998). A defined sandy-layer indicating discontinuity in the soil profile in Sally Branch streambanks was observed during field data collection. Atop the sandy-layer (historical floodplain surface), several dead non-decayed tree stumps and charcoal accumulations were found, signifying the presence of vegetation and past fires, and indicating that the current streambed is lower than the historical streambed/floodplain surface (Figures 24 and 25). Larger catchment area, steeper grade, and higher elevation on the Sally Branch watershed likely increased the energy delivery by water in the stream-channel causing more water-mediated erosion, resulting in a greater capacity to carve through the legacy sediment.

2.4.2.2 Particle Size and Texture Class Determination

Bonham Creek's legacy sediment consisted of 59.0 ± 0.6 % sand, 23.0 ± 1.0 % silt and 18.0 ± 0.7 % clay. On Sally Branch, sand content was similar, with 62 ± 0.70 % sand, 22 ± 1.36 % silt and 16 ± 1.00 % clay (Figure 26). Fitzpatrick et al. (2008) described one of their cores from the legacy sediment texture as silty fine- to medium-grained sand, with clay content hardly approaching 20%. Their second core showed stratified fine- to very coarse-grained sand particle size.

The upper 30 cm of the legacy alluvium at Bonham Creek was classified as a loam soil based on textural condition. A sandy clay loam predominated between 30 and 90 cm. The next 150 cm (90-270 cm) were characterized by a sandy loam material (Figure 27). The upper 60 cm of the legacy alluvium along Sally Branch was characterized by a sandy loam texture, followed by sandy clay loam between 60 and 90 cm, and a sandy loam texture between 90 and 180 cm depth. From 180 to 240 cm, alluvium was classified as loamy sand (Figure 28).

2.4.2.3 Organic Matter and Carbon Content

Mean predicted organic carbon concentration in the legacy sediment of the floodplain at Bonham Creek was 26,612 ± 2,047mg kg^{-1}, and organic carbon concentration at Sally Branch was 25,097 ± 982 mg kg^{-1}. These concentrations of organic carbon indicate rapid deposition of sediment on the floodplains not allowing enough time for organic matter to be incorporated. Organic carbon content of the legacy sediments of Bonham Creek and Sally Branch was 59.64 kg m^{-2} and 56.79 kg m^{-2} respectively. Wigginton et al. (2000) found similar carbon content (55.9 kg m^{-2}) in floodplains in the later stages of succession on Fourmile Creek, near Aiken, SC. No statistical differences in organic carbon concentration and content were found between the streams' floodplains ($p=0.6465$).

Comparing the sides of the floodplain, the legacy sediment in the wet-side of the floodplain of Bonham Creek showed significantly higher organic carbon concentration ($p<0.0001$) than the sediment in dry-side (40,271.6 ± 5,411 and 19,781.7 ± 1,085 mg kg^{-1} respectively) (Table 2). The wet-side of Bonham had a more constricted floodplain, consisting of swampy conditions as described in the diagram proposed by Hodges (1998), therefore presenting slower decomposition rates and higher organic carbon. Seepage of water in this side of the floodplain might also have facilitated higher organic carbon concentrations. Observations of the muckier quality of the alluvium on the wet-side of the floodplain were also noted during field-work. For Sally Branch, the organic carbon concentration in the alluvium on one side of the floodplain was 25,981.6 mg kg^{-1} and no evidence of statistical differences from the organic carbon concentration on the floodplain's other side (23,617.3 mg kg^{-1}) was found (Table 2).

2.4.3 Water Erosion Prediction Project Model

The three parameters estimated using the WEPP model – runoff, soil loss, and sediment yield – responded very strongly to land cover and land management practices. The forested scenarios (FOR and RFOR) showed the lowest estimations whereas the human disturbed scenarios (F and FC) showed the highest estimations (Table 4). Students-t tests were performed for comparing mean runoff, sediment yield and soil loss between the two watersheds in each scenario. No statistical difference was found.

The results for each slope under the FC scenario were multiplied by a hundred, which represents the approximate number of years during which the watersheds were under those management practices during the settlement (from approximately 1820 to 1920). One year of the results of the FORCF, and F scenarios were also summed up to mimic the establishment of the settlers and their abandonment of the farmed lands. The resulting number of 4,438.6 Mg ha^{-1} for Bonham Creek and 3,470 Mg ha^{-1} for Sally Branch represents the sediment delivery to the floodplains of the streams modeled by WEPP during the entire period of settlement. Adjusting the units to allow for comparison of the results obtained with the modeling with the estimations from the field study, Bonham Creek showed a total sediment delivery during the settlement period on the order of 450 kg m^{-2}, which is much lower than our field estimates of sediment deposition of 2,241 kg m^{-2}. For Sally Branch, the modeled results were also much lower than the field estimates of sediment deposition, 350 kg m^{-2} against 2,263 kg m^{-2} respectively. The thickness of sediment that would accumulate on the floodplains of Bonham Creek and Sally Branch was predicted based on the regression equations (3 and 4 respectively). According to WEPP, 45.9 and 60.4 cm of sediments would bury the floodplains of Bonham Creek and Sally Branch respectively. Both predicted burial depths are also much lower than the field estimates (176 and 171 cm respectively).

Based on these calculations, we can assume that the model does not represent precisely the impacts caused by the agriculture developed by settlers in the basins. The WEPP model did not accurately simulate the condition of the watershed for several reasons. One of them is the fact that WEPP did not accommodate options for accurately model scenarios without soil conservation practices, such as lack of terracing, and plowing parallel to the field slope, which probably were the techniques used by the early settlers. A second reason is the model incapability of accounting for concentrated flows (Bill Elliot, 2008, personal communications). Therefore, we can infer that WEPP certainly did not take into account the gullies of 7 to 15 m reported by Trimble (1974) on the Southern Piedmont region.

2.5 SUMMARY AND CONCLUSIONS

This study addressed how anthropogenic disturbances caused by the early American-European settlers altered the geomorphology of two streams and their floodplains in the Southeastern Coastal Plain of the United States.

Intensive agricultural development was identified within the area encompassing the study sites during the mid 1800's and early 1900's with increasing total population, slaves and farmland area. These data was used as a proxy of increased erosive land use on the watershed which could lead in significant sedimentation in the valley bottoms. By 1920 and 1930, a drastic decrease in farmland area was verified representing the decline of agriculture in the region. As hypothesized, the poor agricultural practices performed by the early settlers caused intensive soil erosion in the basins and massive quantities of sediment to be deposited in the streams and floodplains. The pre-settlement floodplain surface is buried under 179 cm of sediment which represents an equivalent mass of 2,338 kg m^{-2}. This significant sedimentation likely caused the streams and floodplains to deviate from their original fluvial geomorphology dynamism by "clogging" the systems.

It may also have reduced the complexity of the interactions among sedimentary, biological, and hydrological systems within Bonham Creek and Sally Branch.

The legacy sediment was characterized mostly by high amounts of sand and silt; however, this content varied among the sections and depths, supporting the hypothesis that physical properties of the legacy sediment would vary across the floodplains. Organic carbon concentration in the legacy sediment was relatively low, averaging 26,612 mg kg^{-1} on Bonham Creek and 25,097 mg kg^{-1} on Sally Branch. However, these concentrations highlight the rapid deposition of sediment in the floodplain not allowing time to incorporate organic material into this alluvium. The organic carbon concentrations yielded an organic carbon content of 59.64 kg m^{-2} on the floodplains of Bonham Creek, and 56.79 kg m^{-2} of organic carbon on the floodplains of Sally Branch.

This study identified major hydrological and geomorphological changes in the streams due to excessive sediment deposition in the floodplains. The average bank heights found were 1.99 m on Bonham Creek and 2.68 m on Sally Branch. A conclusion that Sally Branch presents greater potential of exporting the legacy sediment due to its larger catchment area, steeper grade, and higher average elevation was made. Nonetheless, the bank heights on both streams disconnect them from their floodplains, leaving the floodplains drier and acting more like a low terrace. There was no evidence of present overbank flooding on either stream for the 2 years of this study. The deeply incised channel represents a major ecological change to the floodplains. The kidney function of these systems is compromised with the disconnection between stream-water and floodplain. The floodplain also has little input of water and/or nutrients from overbank flooding which may alter the vegetation composition on the floodplains. Lastly, the incised channels depict increased water-mediated erosion potential in the channel which may alter the living organisms within the aquatic environment as well.

The Water Erosion Prediction Project (WEPP) model was used to compare the modeled sediment delivery to floodplain areas with the estimations from the field study. The WEPP model results did not match our conservative field estimates of mass of sediment accumulated in the floodplains, which led to a rejection of the hypothesis that the computer-based model would reliably estimate legacy sediments. Reasons for the poor model prediction were explained by the failure of the model to simulate scenarios that lacked conservation measures, especially soil conservation techniques (plow according to the contour, etc), and by the limitations of the model in accounting for concentrated flows such as gullies. This was likely the means through which most erosion occurred in the sandy soils present in the Coastal Plain physiographic region.

Finally, this study reveals that the deeply incised stream channels with high floodplains are not the original morphology of Southeastern Upper Coastal Plain streams. It highlights the importance of assessing the original conditions of the streams before projects of restoration, construction, and/or management of streams and floodplain forests can take place based on altered realities. Further investigations of the impact of the early settlers on geomorphology of streams, and their ecology and hydrology are still required in order to complete the puzzle. Effects of legacy sediment on water quality are still unknown. Historic disturbances may have caused a shift in floodplain species composition, altering habitat for the biota of these systems, however, studies linking biological modifications such as botanical and animal due to geomorphological and hydrological alterations in Coastal Plain stream systems remains undocumented.

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Table 1: Mean depths (±SE) of the historical floodplain with equivalent mass of legacy sediment and organic carbon content within the sediment for each section on either stream.

Stream	Section	Depth of Hist. Floodplain -cm-	Mass of Sediment –kg m^{-2}-
Bonham	Lower	185 ± 19	2,399 ± 281
	Middle	175 ± 7	2,201 ± 195
	Upper	179 ± 5	2,344 ± 136
Sally	Lower	150 ± 12	1,998 ± 198
	Upper	201 ± 7	2,672 ± 206

Table 2: Mean depths (±SE) of the historical floodplain with equivalent mass of legacy sediment and organic carbon content within the sediment for each side of the floodplain on both streams.

Stream	Floodplain Side	Depth of Hist. Floodplain -cm-	Mass of Sediment -kg m^{-2}-	Organic Carbon -mg kg^{-1}-
Bonham	Wet	181 ± 6	1,983 ± 133	40,271 ± 5,411
	Dry	175 ± 6	2,705 ± 140	19,781 ± 1,085
Sally	Wet	172 ± 13	2,276 ± 213	25,981 ± 1,727
	Dry	186 ± 7	2,488 ± 223	23,617 ± 1,203

Table 3: Mean bankfull-widths and bank heights (±SE) for each section on Bonham Creek and Sally Branch.

Stream	Section	Bankfull Width -m-	Bank Height -m-
Bonham	Lower	4.52 ± 0.5	2.49 ± 0.2
	Middle	4.85 ± 0.1	1.5 ± 0.1
	Upper	4.32 ± 0.5	1.98 ± 0.2
Sally	Lower	12.0 ± 1.6	2.16 ± 0.1
	Upper	6.03 ± 0.5	3.01 ± 0.2

Table 4: Mean annual runoff, sediment yield, and soil loss (±SE) for scenarios modeled with WEPP on Bonham Creek and Sally Branch.

Stream	**Scenario**	**Runoff -mm-**	**Sediment Yield -Mg ha^{-1}-**	**Soil Loss -Mg ha^{-1}-**
Bonham	FOR	30.8 ± 4.2	0.4 ± 0.1	0.4 ± 0.1
	FORCF	34.2 ± 4.4	0.5 ± 0.1	0.6 ± 0.1
	FC	137.3 ± 9.3*	48.7 ± 10.3*	53.1 ± 10.6*
	F	225.1 ± 11.9**	96.0 ± 19.9**	103.1 ± 19.1**
	RFOR	30.8 ± 4.2	0.4 ± 0.1	0.4 ± 0.1
	RBMP	84.0 ± 4.1***	1.9 ± 0.7	2.7 ± 1.0
Sally	FOR	29.5 ± 4.5	0.4 ± 0.1	0.4 ± 0.1
	FORCF	32.2 ± 4.7	0.4 ± 0.1	0.4 ± 0.1
	FC	130.8 ± 8.0*	38.0 ± 5.3*	42.5 ± 5.5*
	F	212.9 ± 9.9**	81.8 ± 10.0**	90.2 ± 10.5**
	RFOR	29.5 ± 4.5	0.4 ± 0.1	0.4 ± 0.1
	RBMP	85.9 ± 4.0***	1.3 ± 0.2	1.9 ± 0.3

*, **, *** indicates scenarios statistically different within each parameter (runoff, sediment yield, soil loss).
FOR = Forest perennial scenario
FORCF = Forest perennial followed by clearcut and fire
FC = Fallow followed by cotton plantation wild moldboard plow of 20.3 cm depth
F = Fallow conditions
RFOR = Regeneration of forest perennial scenario
RBMP = Ryegrass with 12.2 m of streamside management zone

Figure 1: Geographic location of Fort Benning.

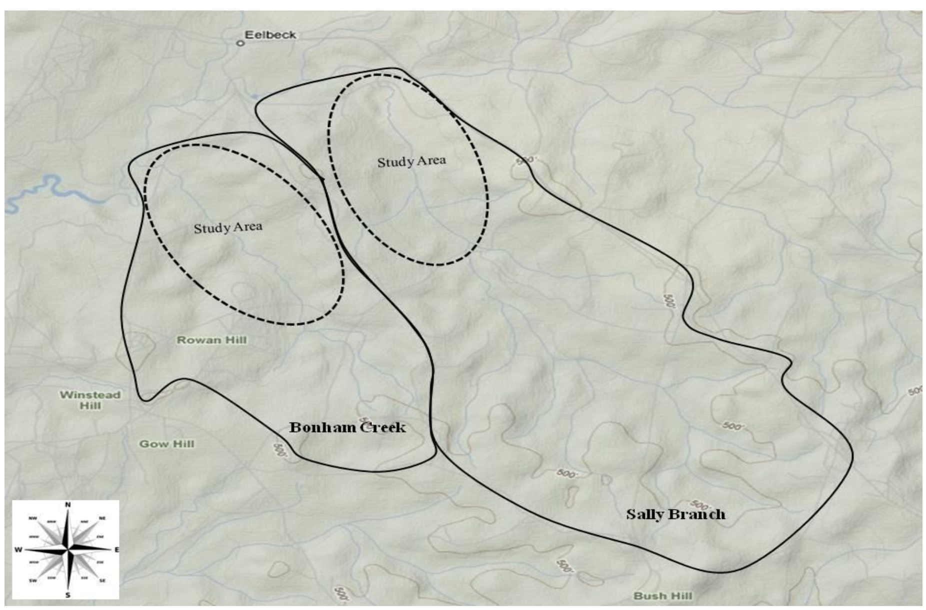

Figure 2: Aerial photograph produced from Google of the terrain encompassing Bonham Creek and Sally Branch watersheds (Source: GoogleMaps.com).

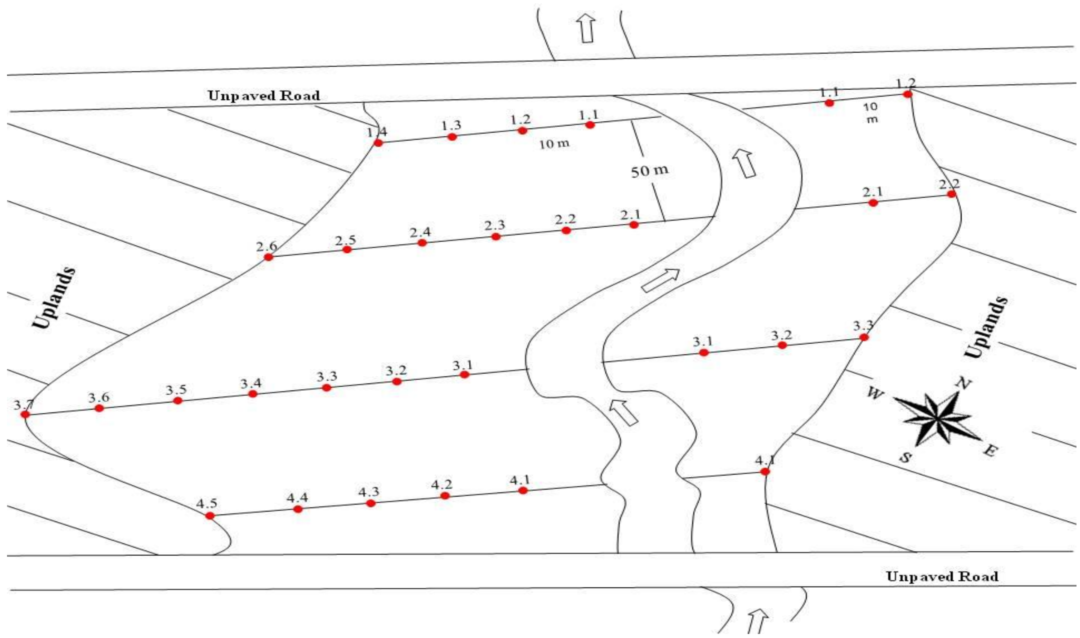

Figure 3: Representative schematic of sampling transects and plots for the soil coring (dots) on Bonham Creek and Sally Branch.

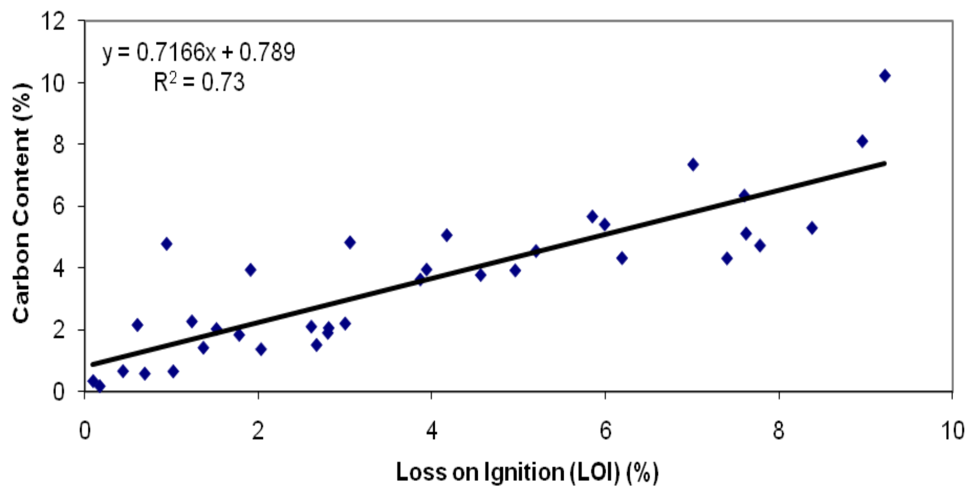

Figure 4: Linear regression between loss-on-ignition and carbon content results for predicting carbon content in the legacy sediment based on the LOI results.

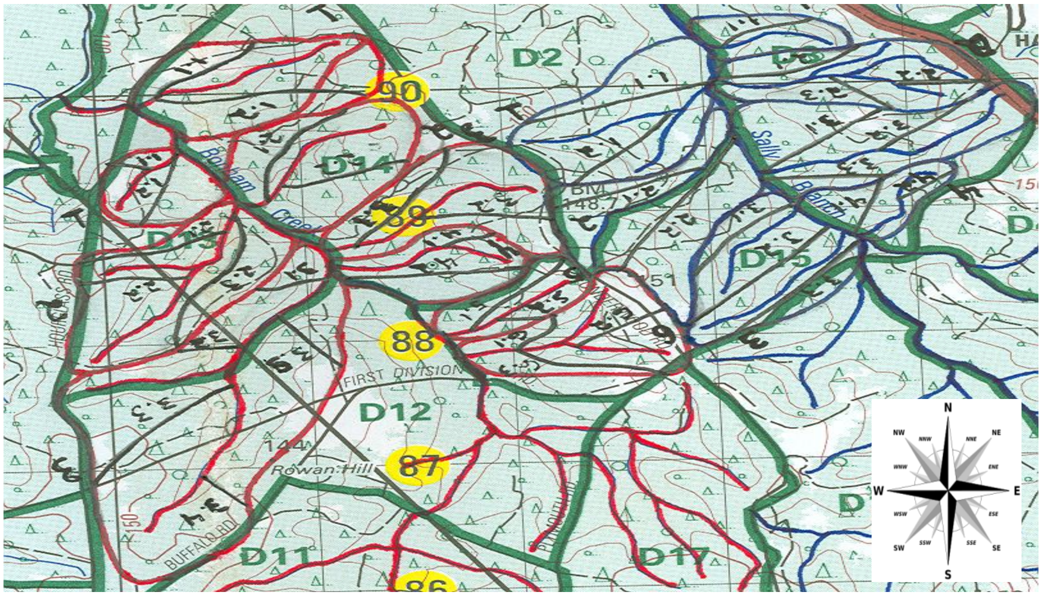

Figure 5: Digital orthophoto quadrangle produced by the Fort Benning Range Division highlighting Bonham Creek (red) and Sally Branch (blue) tributary watersheds. Note: The black lines represent the selected slopes for calculation and use in the WEPP model.

Figure 6: Old water-wheel filled with sediment found on the lower reach of Sally Branch’s floodplain.

Figure 7: Clearcut on Bonham Creek's watershed leaving 12.2 m buffer zones (far left) along the stream.

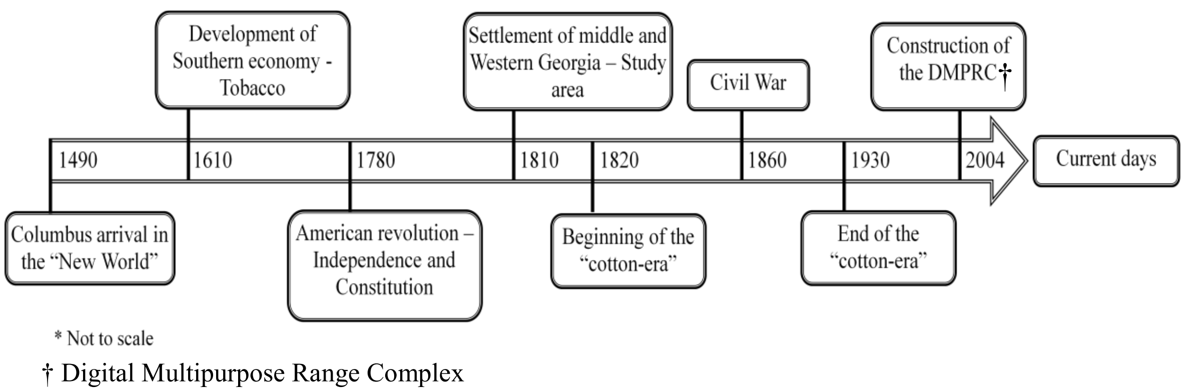

Figure 8: Timeline of main events that affected the study area.

Figure 9: Dam constructed in the mid-1800s on the land that is now included in the Fort Benning Military Installation (Source: Kane and Keeton, 1998).

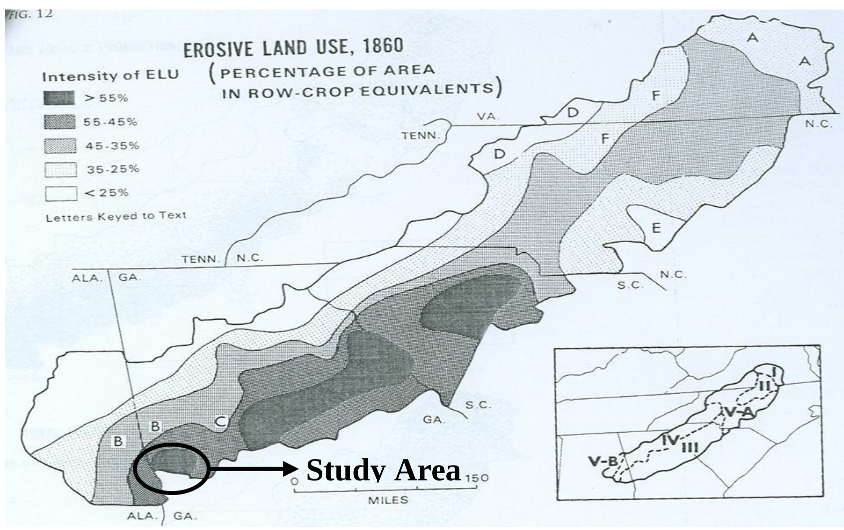

Figure 10: Map of erosive land use (ELU) for the Southern Piedmont region for the period of 1860 (Source: Trimble, 1974).

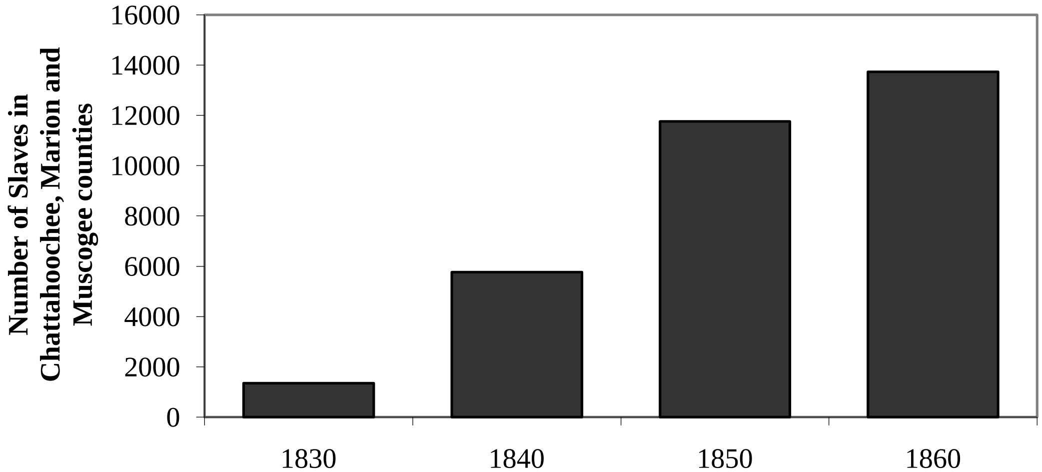

Figure 11: Numbers of slaves in the Chattahoochee, Marion and Muscogee counties, Georgia by decade.

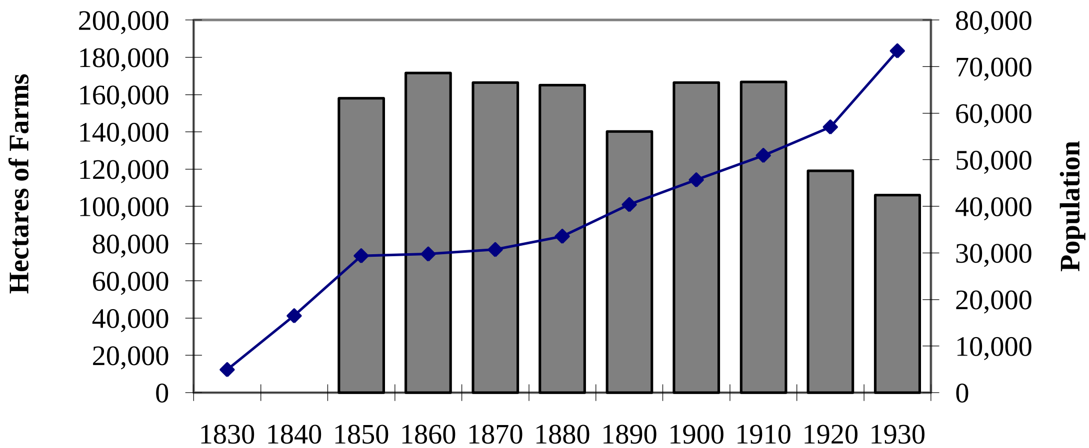

Figure 12: Hectares of farmland (bars) and total population (line) in Muscogee, Marion and Chattahoochee counties by decade. Note: Agricultural data was not available prior to the 1850 census.

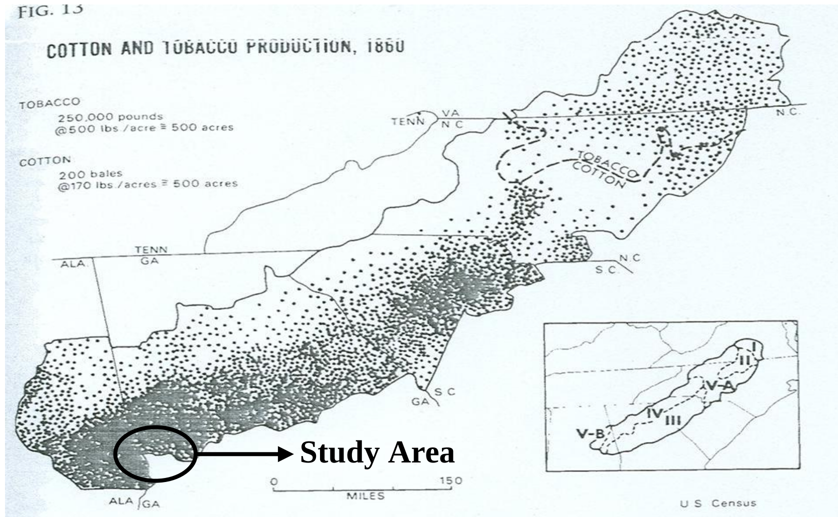

Figure 13: Map of pounds of tobacco and bales of cotton produced in the Southern Piedmont region in of 1860 (Source: Trimble, 1974).

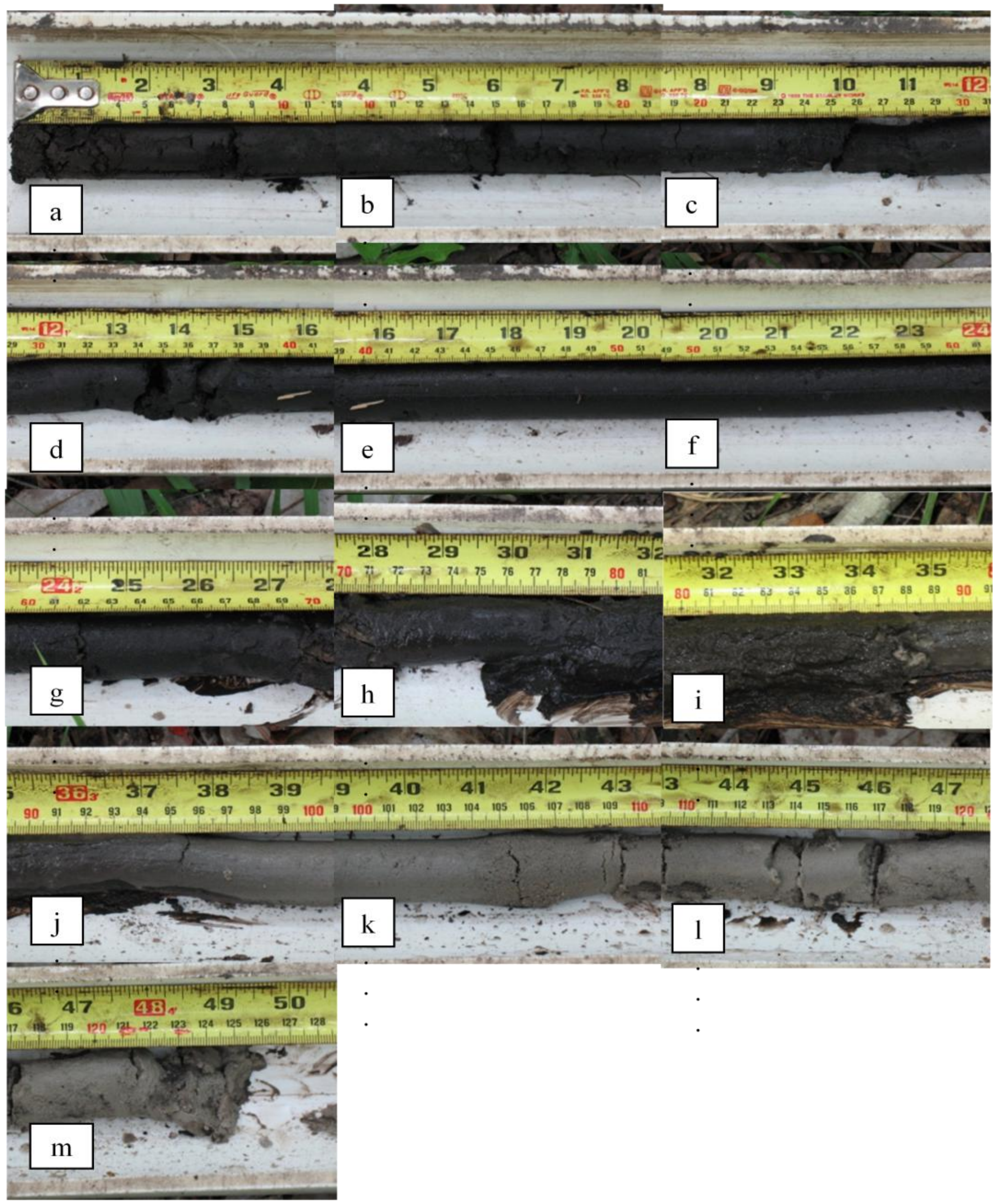

Figure 14: A soil core showing 10-cm increments (a. 0-10cm; b. 10-20 cm; c. 20-30 cm; d. 30-40cm; e. 40-50 cm; f. 50-60 cm; g. 60-70 cm; h. 70-80 cm; i. 80-90 cm; j. 90-100 cm; k.100-110 cm; l. 110-120 cm; m. 120-125 cm) removed from the Bonham West floodplain at Ft. Benning, GA.

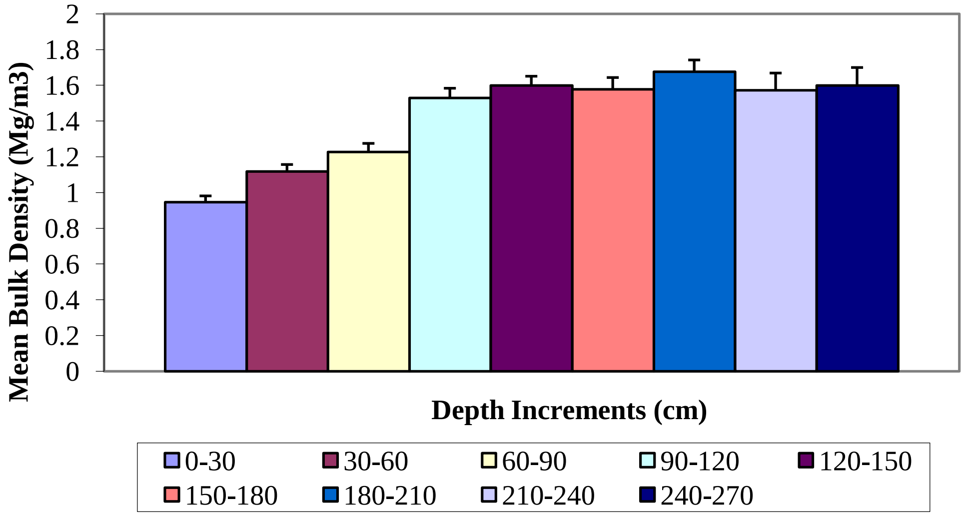

Figure 15: Mean (±SE) bulk density (Mg m^{-3}) for each 30 cm increment from soil cores collected on Bonham Creek's floodplain.

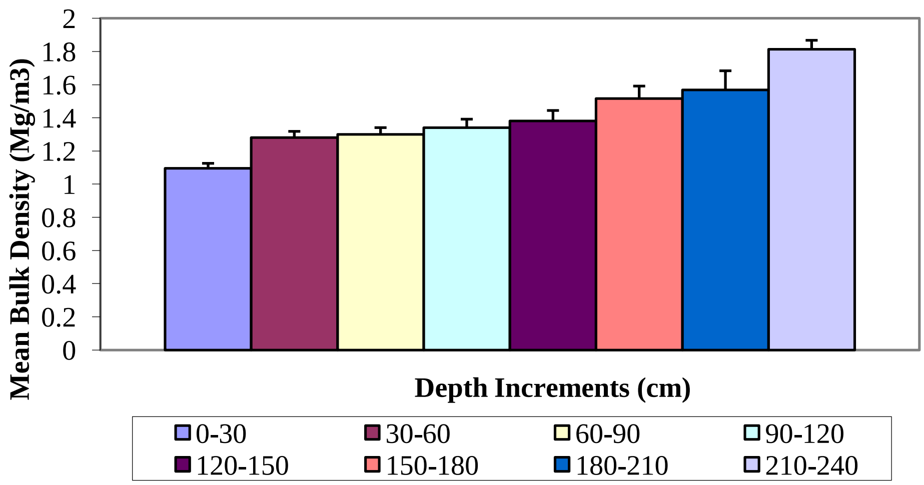

Figure 16: Mean (±SE) bulk density (Mg m^{-3}) for each 30 cm increment from soil cores collected on Sally Branch's floodplain.

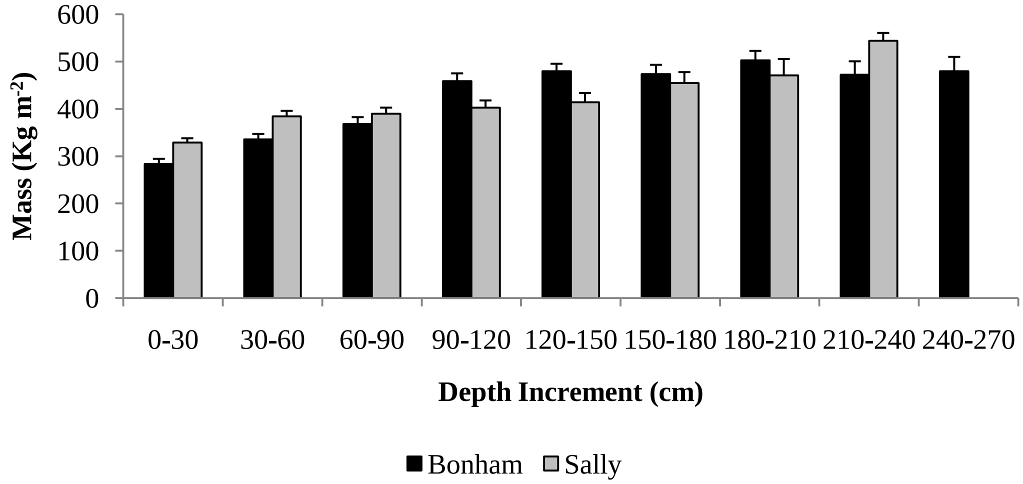

Figure 17: Mean (±SE) mass of legacy sediment per depth increment found in the floodplains of Bonham Creek and Sally Branch.

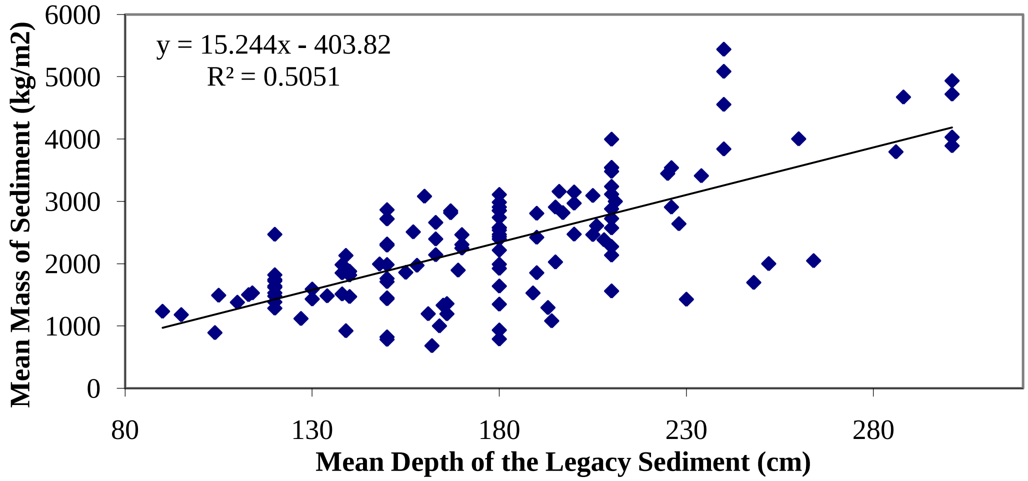

Figure 18: Linear regression between mean depth of legacy sediment and mass from Bonham Creek and Sally Branch.

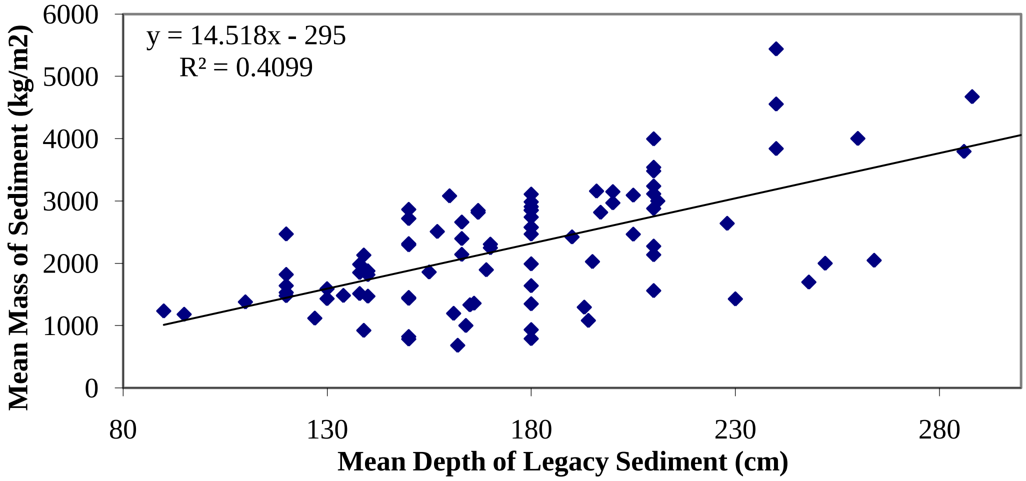

Figure 19: Linear regression between mean depth of legacy sediment and mass using Bonham Creek's data-set.

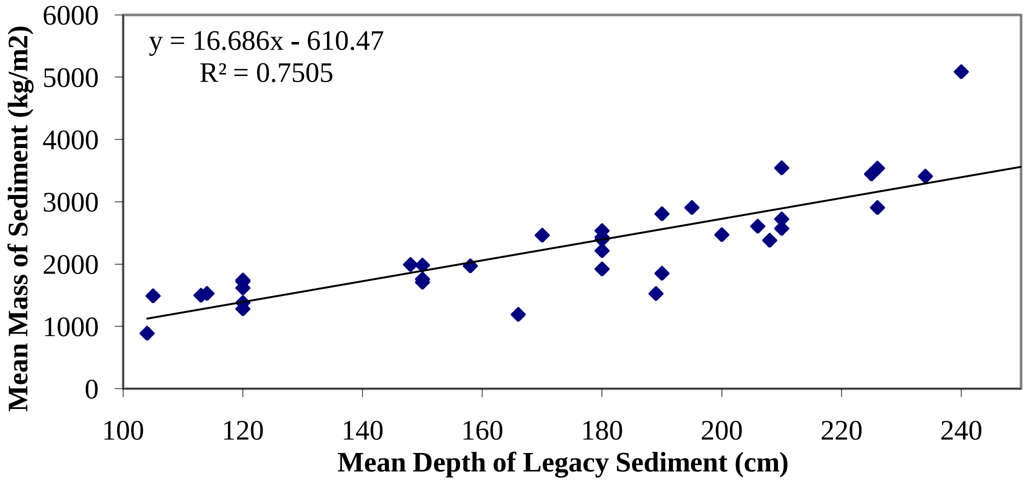

Figure 20: Linear regression between mean depth of legacy sediment and mass using Sally Branch's data-set.

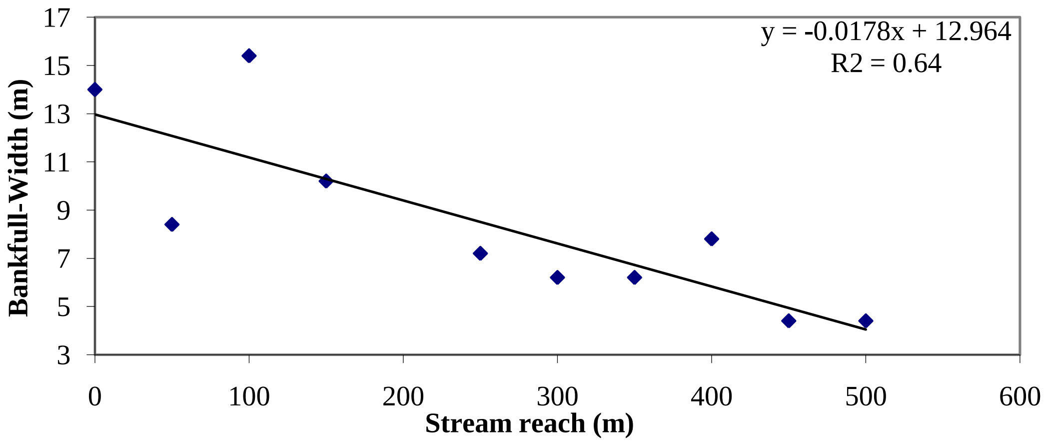

Figure 21: Linear regression between bankfull-width and the transect intervals on Sally Branch. Note: zero corresponds to the furthest downstream bankfull-width measurement and transects were set 50 m apart upstream from that.

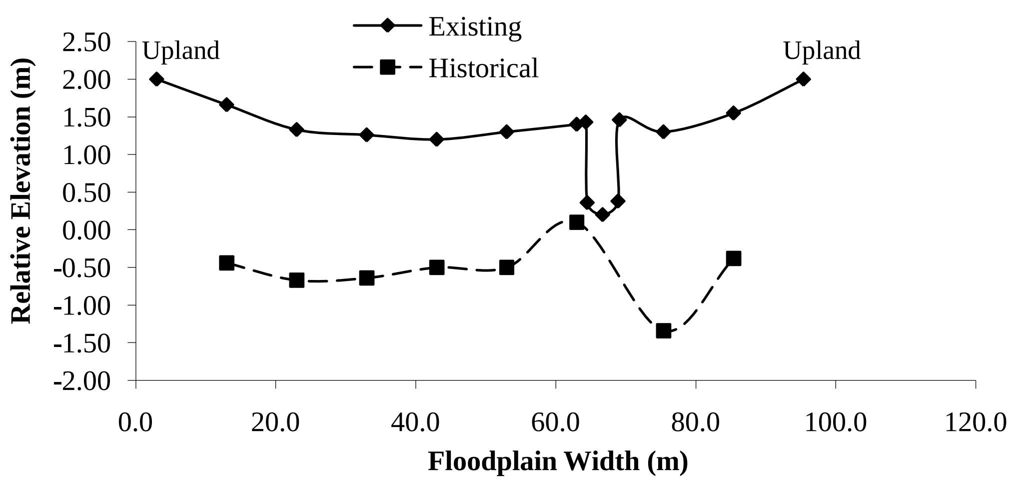

Figure 22: Cross sectional profile of transect 2 on the middle section of Bonham Creek along with the historical floodplain profile (dashed line).

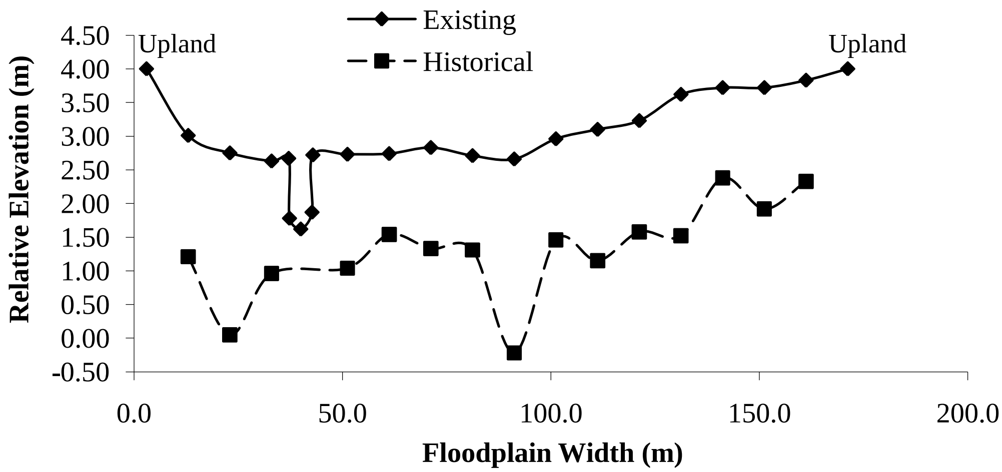

Figure 23: Cross sectional profile of transect 5 on the upper section of Bonham Creek along with the historical floodplain profile (dashed line).

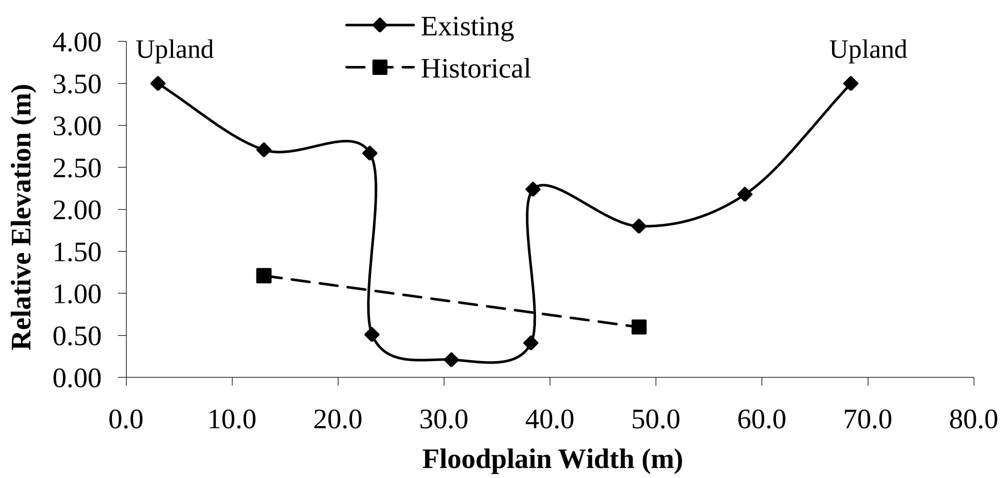

Figure 24: Cross sectional profile of transect 3 on the lower section of Sally Branch along with the historical floodplain profile (dashed line).

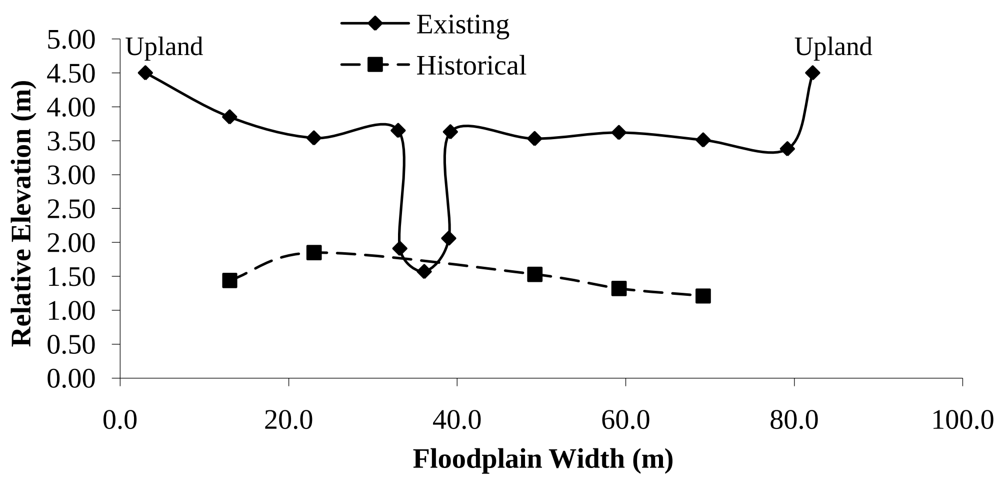

Figure 25: Cross sectional profile of transect 3 on the upper section of Sally Branch along with the historical floodplain profile (dashed line).

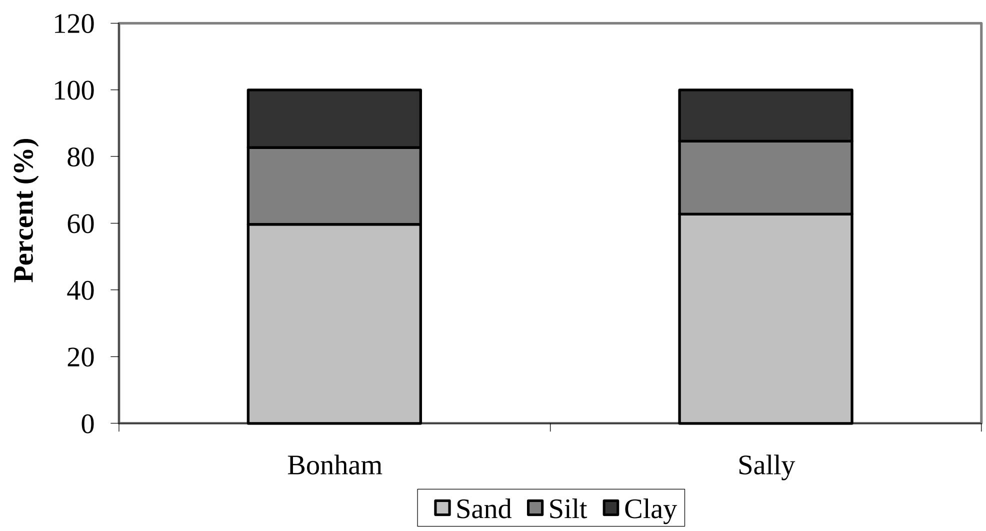

Figure 26: Mean legacy sediment particle size for Bonham Creek and Sally Branch.

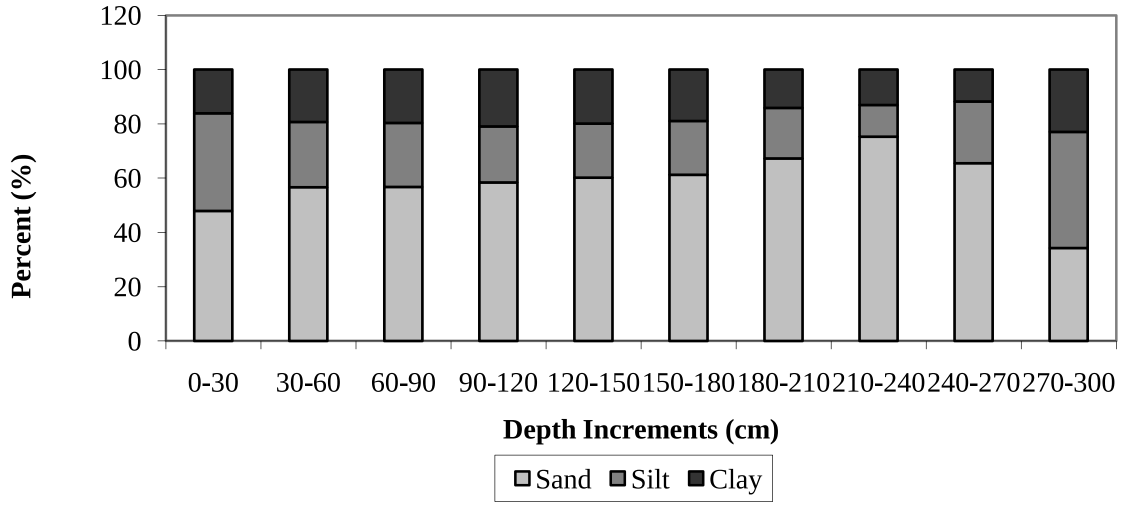

Figure 27: Mean legacy sediment particle size for each 30 cm increment of Bonham Creek’s floodplain.

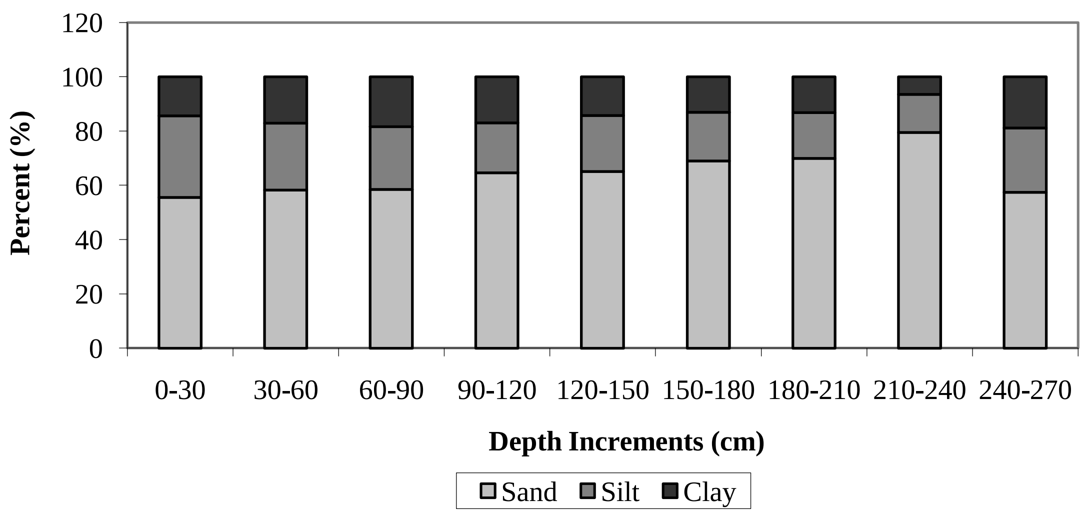

Figure 28: Mean legacy sediment particle size for each 30 cm increment of Sally Branch’s floodplain.

3. CURRENT SEDIMENTATION

3.1 ABSTRACT

Soil erosion and sedimentation are natural processes that occur throughout the landscape. Anthropogenic disturbances may result in an increase in either of these processes, or both. This study addressed these processes and estimated the amount and origins of sediment, in two small watersheds in the Upper Coastal Plain region of the Southeastern U.S. Three different methodologies were used in this study, including: sediment pins along stream-crossings, horizontal sediment pins in the streambank, and dendrogeomorphic analysis. Sediment pin methodologies were coupled with precipitation data obtained at the National Oceanic and Atmospheric Administration (NOAA) website for better understanding of the patterns occurring during the two years of the study. Results indicated significant amounts of sediment yield through newly created stream-crossings. The streambank of both streams eroded at an average rate of 1.25 cm month^{-1}. The dendrogeomorphic technique indicated that both floodplains were relatively stable. Net scouring of sediment for the past 25 years was estimated (0.4 cm yr^{-1}) and was negatively related to tree age. Scouring likely occurred due to disconnection of the streams from their floodplains as a result of intensive sedimentation during the settlement era. This investigation showed the importance of fully understanding the original stream geomorphology and accounting for historical disturbances that may alter physical patterns and current processes.

3.2 INTRODUCTION

Sedimentation is the result of natural processes that occur throughout the landscape. The basic model explaining the sedimentation process starts with the detachment of soil particles, followed by transportation, and later deposition. Sedimentation is subsequent to soil erosion and sediment particle transportation processes; together they are considered to be basic geomorphic processes in catchments (Naiman et al., 2005).

The amount of sediment delivered to, or passing a certain point, is measured as sediment yield (White, 2005). Sediment yield is strongly dependent upon water runoff and may increase as a result of increasing surface runoff. Disruption of either vegetation or climate, or both, will inevitably lead to an increase in sediment loads delivered to streams. Meade et al. (1990), and Knox (1977), affirmed that sediment yield depends upon natural factors, including climate, geology and relief; as well as anthropogenic factors, such as land use, land management, and vegetation cover. Both studies point out the capacity of humans to influence the process of sedimentation through management of vegetation.

In order to study erosion and sedimentation patterns and possible effects on ecosystem integrity, many authors such as Cavalcanti and Lockaby (2005), Maloney et al. (2005), Baht et al. (2006) and Jolley et al. (2009) defined their study sites based on the degree of anthropogenic disturbance in the landscape. In the Cavalcanti and Lockaby (2005) and Jolley et al. (2010) studies, comparisons were made between highly disturbed, moderately disturbed, and control plots based on the degree of sedimentation. Baht et al. (2006) and Maloney et al. (2005) also installed their experimental plots based on the level of anthropogenic disturbance surrounding the areas of interest.

Common disturbances that may represent a major sediment source in forested watersheds are roads and trails (Brooks et al., 1997; and Appelboom et al., 2002). Appelboom et al. (2002) affirmed that road construction and maintenance may in fact contribute as much as 90% of the total eroded sediments in forested areas. These roads and trails exhibit low surface roughness, offering fewer barriers to stop or slow water runoff, thus leading to an increase in the overall surface erosion. In addition to the sediment contribution, roads are likely to contain more pollutants due to traffic (Brooks et al., 1997), and therefore, have greater potential to diminish the water quality of streams in the vicinity.

Many studies (Trimble, 1974; Craft and Casey, 2000; Jackson et al., 2005; Fitzpatrick et al., 2008; and Walter and Merrits, 2008) explain current geomorphological processes on stream systems, especially related to sedimentation, as a result of historical modifications that affected physical and biological properties on these systems, leaving a long-term footprint on them.

According to Hall (1994), wetland sedimentation studies are complicated because of the variation in hydrology as well as the movement of different soil particle sizes (sand, silt, and clay). The presence and/or absence of vegetation also complicates the analysis of the deposition and erosion processes by increasing spatial variation related to surface roughness (Hall, 1994).

3.2.1 Geomorphic Processes of Floodplain Forests

According to Naiman et al. (2005), rivers are generally defined by three different geomorphic zones: (i) the erosional zone in the headwaters, characterized as a region where erosion exceeds deposition; (ii) the transfer zone in the lowlands, characterized as a highly dynamic region in which erosion is balanced with deposition; and (iii) the depositional zone, characterized as a region in which deposition exceeds erosion, usually in the form of river deltas and alluvial fans.

Even though sediment may be considered to be in constant motion over long time scales, most Coastal Plain forested floodplains reveal net aggradation of sediment from two distinct sources: (i) runoff from adjacent lands and (ii) over-bank floods (Hupp, 2000). Lowrance et al. (1989) stated that Coastal Plain riparian forests are effective sinks for sediment, associated nutrients, and contaminants, buffering the streams from the runoff and discharges of the surrounding areas. These systems play an important role in maintaining and sustaining water quality.

Filtration of floodwaters is considered a normal function of riparian forests that greatly benefits society (Cavalcanti and Lockaby, 2006). However the filtration capacities of riparian forests vary. Riparian ecosystems may act as transportational and erosional zones as well (Naiman et al., 2005; and Magilligan, 1985). According to Lockaby et al. (2005), the capacity of different types of wetlands to trap and retain sediments (and associated nutrients and contaminants) is still somewhat poorly understood. Craft and Casey (2000) for instance, found sediment and nutrient retention to be much greater in floodplain forests when compared to depressional wetlands in Southwestern Georgia. Rates of phosphorus retention were reported to be 1.5 times greater in these riverine systems which may help avoiding eutrophication of the water, highlighting their importance in buffering the aquatic environment from terrestrial contaminants and improving water quality.

The capacity of floodplain forests for trapping sediments is also described in the literature as highly variable in both time and space (Knox, 1977; Knox, 1987; Meade et al., 1990; Hupp and Bazemore, 1993; Walling and He, 1998; Craft and Casey, 2000; Hupp, 2000; Cavalcanti and Lockaby, 2005; Hupp et al., 2005; and Hupp et al., 2008). Overall, it depends significantly upon hydrologic loads, hydraulic forces, physical properties of the landscape, and biotic and abiotic interactions within the ecosystem and its surroundings (Hall and Freeman, 1994).

Knox (1987) estimated the sediment deposition in the floodplains of an Upper Mississippi Valley Tributary since the Holocene era using the radiocarbon dating method. According to Knox (1987) an average rate of 0.04 cm yr^{-1} of sediment was deposited on the floodplains from the Holocene era until the period prior to American-European settlement. A sediment deposition rate of 0.29 cm yr^{-1} was estimated for the period between 1820 and 1890 which is a period when according to the author settlement hadn’t yet begun heavily. From 1890 to 1925, the sedimentation rate increased to 1.29 cm yr^{-1}. After 1925, rates decreased stabilizing back at 0.30 cm yr^{-1}, which is similar to rates found prior to settlement in the area, observed between 1820 and 1890.

Walter and Merritts (2008) affirmed that excessive historical sediment deposition resulted in the formation of flat terraces and lower inset floodplains, and that the sediment down-cutting process performed by the stream-channel led to a current bankfull height (discharge) much lower than the actual streambanks. These consequences have profound impacts on stream hydro-geomorphology and represent major obstacles to full ecological recovery of these systems. However, Jackson et al. (2005) stated that even with altered geomorphology due to historical sedimentation, Murder Creek in Georgia has reached a new dynamic balance stage, with higher sediment exports than inputs.

Walling and He (1998) found spatial variability in the pattern of sediment deposition in five streams in England. They reported that most sediment tended to be deposited near the stream channel, decreasing the amount of sediment deposition towards the outer edges of the floodplain. The same authors also suggested that suspended sediment concentrations and sediment deposition rates could be expected to decrease downstream as deposits occur along the floodplains.

Using the dendrogeomorphic technique, Hupp and Morris (1990) found mean sedimentation rates to be as high as 0.6 cm yr^{-1} on the Black Swamp along the Cache River in Arkansas. The authors associated the high sedimentation rates with geomorphologic features such as sloughs, local microtopography, and vegetation composition. A similar study using the dendrogeomorphic technique found mean sedimentation rates to range from 0.7 to 5.7 cm yr^{-1} in the floodplain of the Chickahominy River in Virginia (Hupp et al., 1993). Sedimentation rates, in this case, were associated with stream gradients, stream energy delivery, percent area of wetland, hydroperiod, and land use. In the Hupp et al. (1993) study, the higher sedimentation rates were associated with older trees. Such association was explained by the correlation of the age of the trees to the time during which urban expansion occurred and to their proximity to urban sites, which also determined higher rates of trace elements in the sediment. Thus, once again, an alteration in the surrounding landscape was reported to impact sedimentation and associated contaminant loads within the wetland.

Hupp et al. (2008) developed a study to address sedimentation rates in the Atchafalaya Basin in Louisiana – a tributary of the Mississippi River – which has the largest continuous forested riparian wetland in North America. The authors found mean sedimentation rates ranging from 0.02 to 0.42 cm yr^{-1} which accounted for potential trapping of sediment on the order of 6,720,000 Mg annually. This highlighted the importance of such systems for retaining sediments and associated contaminants, and carbon storage. Their findings also pointed out the role that riparian forests play in withholding sediments and contaminants that would otherwise flow into the stream channel and terminate in estuaries in the Gulf Coast.

3.2.2 Sedimentation Effects

High sedimentation rates in riparian forests may be extremely detrimental to these systems by changing the habitat of biota from more coarsely grained aquatic environments to highly silted environments (Hupp, 2000). In addition, sediments still have the potential to diminish the habitat's biodiversity by causing burial and suffocation of living organisms. Moreover, excessive sedimentation has been reported to disrupt biogeochemical cycles, a situation detrimental to the ecological integrity of floodplain ecosystems.

Cavalcanti and Lockaby (2006) found that when sediment accumulation rates exceeded 0.20 cm yr^{-1} major reductions in litterfall biomass occurred. Tree basal growth, aboveground net primary productivity (NPP), leaf area index (LAI) and patterns of vegetation composition were also negatively impacted. Lockaby et al. (2005) found that rates of sediment accumulation at 0.20 cm yr^{-1} for 25 years caused decomposition rates, nitrogen mineralization and microbial biomass carbon and nitrogen to decline in the riparian forests of ephemeral streams at Fort Benning, Georgia. Supporting the previous study, Jolley et al. (2009) also found significant declines in litterfall, woody biomass productivity, fine root production, and leaf area index when sedimentation rates ranged from 0.10 to 0.40 cm yr^{-1}. However, such ecosystems may adapt and evolve under the different conditions set by the new sediment content, as shown by Lockaby et al. (2005), where patterns of litter decomposition, N mineralization, and microbial biomass seemed to regain a low equilibrium status once the long-term sedimentation rate of 0.32 to 0.50 cm yr^{-1} was reached. The systems slowed their metabolism but reached a new stage of balance under the new conditions.

Many studies still attempt to understand the role that sediment plays in the integrity of riparian ecosystems. Sediment can be a subsidy bringing associated nutrients necessary for plant/animal development, or a stress transforming habitats, causing suffocation of organisms, and perhaps disconnecting the aquatic and terrestrial environments.

3.2.3 Rationale

Sedimentation is considered a major concern because of its potential to significantly diminish the ecological function and integrity of streams and floodplain ecosystems. More specifically, the National Water Quality Inventory produced by the EPA in 2002 stated that sedimentation is the major cause of river and stream impairment in the U.S. Hupp (2000) and Neary et al. (1989) affirmed that sediments are currently the largest contributor and the single most important water quality problem in the U.S. This is especially evident in the Southeastern region due to its abundance of water resources (Neary et al., 1989). Martin et al. (2001) even emphasized that the State of Georgia has past and present problems with sediment related pollution. Even though it is known that floodplains may undergo aggradation or export of sediments, very few investigations actually report sediment degradation from the floodplains.

Ongoing geomorphological processes in streams may be significantly affected by historic disturbances. Extensive historical sedimentation has been reported in many regions throughout the U.S., including the southeastern Coastal Plain (Lowrance et al.,1989; and Craft and Casey, 2000). It is important to assess and try to understand current hydro-geomorphological processes in the streams as they might be a reflection of changes that happened long ago.

3.2.4 Study objectives

The main goal of this study was to assess the ongoing geomorphological processes on the floodplains of Bonham Creek and Sally Branch in terms of sediment retention and scouring as a response to historical anthropogenic disturbances. Current processes were assessed to determine effects of excessive sedimentation on the hydro-geomorphology of streams and floodplains. The current and mid-term (last 30 years) sedimentation rates were estimated and implications were discussed and compared between two Coastal Plain streams.

3.2.5 Study hypothesis

The following hypotheses were formulated to be tested with this study:

- Current disturbances in the streams, such as road-crossing, will generate significant soil movement.
- Floodplains are stable in terms of current erosion and/or sedimentation.
- Floodplains of both streams will be slowly exporting legacy sediment from the floodplain.

3.3 METHODS

3.3.1 Study site

This project was conducted at the Fort Benning Military Installation near Columbus, Georgia, USA (Figure 1) where disturbance created by military training and construction vehicles has generated extensive sediment movement into downslope and bottomland areas. The Military Installation covers 73,500 ha encompassing parts of Chattahoochee, Muscogee and Marion counties in Georgia and Russell County in east-central Alabama. Chattahoochee, Muscogee and Marion counties are in the Lower Piedmont and Upper Coastal Plain region (right on the Fall Line), while Russell County is in the Upper Coastal Plain. The latitude and longitude of the military installation in this area is 32.34^{o} N and 85^{o} W respectively. The project was established along two streams located in the Upper Coastal Plain region, immediately south of the Piedmont physiographic divide.

The climate in this area is characterized as humid subtropical with mean annual precipitation of 1,233 mm occurring regularly throughout the year (NOAA's National Weather Service Forecast Office – http://www.weather.gov/climate/xmacis.php?wfo=ffc). Currently, the main source of sediments delivered to the riparian areas comes from the unpaved sandy roads and trails used for military traffic and construction equipment (Lockaby et al., 2005). According to the author, sediment moves downslope in the concentrated flows of ephemeral streams and is deposited wherever channels widen and surface roughness increases.

Two adjacent watersheds were selected for the proposed study: Bonham Creek, which drains 1,273 ha (3,145.65 acres), and Sally Branch, which drains 2,531 ha (6,254.24 acres) (Baht et al., 2006). Both watersheds have had similar land cover type and management practices since the American-European settlement period.

The prevailing soil on both watersheds is the Troup series, which is a loamy sand material originating from marine deposits, that is somewhat excessively drained (kaolinitic, thermic Grossarenic Kandiudults). On the floodplains, the soil is from the Bibb Series, characterized by recent loamy and sandy alluvial sediment; these are very deep and poorly drained soils (siliceous, acid, thermic Typic Fluvaquents)(USDA – NRCS Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/app/). The over-story and mid-story vegetation cover in the floodplains of the streams is dominated by *Acer rubrum* L., *Carpinus caroliniana* W., *Ilex opaca* A., *Liquidambar styraciflua* L., *Magnolia virginiana* L., *Nyssa sylvatica* M., *and Quercus nigra* L. Both watersheds are also influenced by the construction of a new tank training site on their uplands called the Digital Multi-Purpose Range Complex (DMPRC) which has recently converted extensive forest to open areas of grasslands. According to Mulholland et al. (2009, unpublished report) this land cover is affecting 23.4% of the catchment area on Bonham Creek and 12% on Sally Branch respectively.

3.3.2 Study Design

All methodologies of this study were applied within the boundaries of the study area which were located in the lower reaches, or third order portions of Bonham Creek and Sally Branch. For gathering data that effectively addresses current sedimentation rates, as well as sediment patterns and dynamics, the following methodologies were used:

3.3.2.1 Sediment pins

Sediment pins were used to assess soil movement within the studied watersheds. This methodology was applied in order to verify sediment export from the roads and from streambank erosion. Sediment pins were vertically placed in the soil along the streambanks immediately adjacent to the road-crossings to account for sediment contribution by unpaved roads, whereas pins accounting for streambank sloughing were horizontally installed into the side of the streambank in an undisturbed stretch of the streams. Sediment pins consisted of 120 cm rebar with a 2.5 cm radius metal washer welded onto the bar at 60 cm. The sediment pins were pushed into the ground until the washer was flush with the soil surface, serving as the reference mark for each pin. The depth to the washer or depth to the soil below the washer was measured twice a month. Sediment loss or accumulation was calculated for individual pins by the amount of gain or loss of soil, compared to the reference mark.

3.3.2.1.1 Sediment contribution from the roads

Four monitoring road-crossings were established long Bonham Creek (lower, mid-lower, mid-upper, and upper sections) and at three road-crossings along Sally Branch (lower, middle, and upper sections) accounting for different sections of the study area (Figure 2). Locations of all sediment pins along Bonham Creek were near newly constructed stream crossings upstream of the Hourglass Road crossing of Bonham Creek. Along Sally Branch, the first road-crossing sampled was located at the creek intersection with Resaca Road (Figure 3). The two other sampled crossings were upstream from that point. These crossings are approximately 400 meters apart. For each crossing, sediment pins were installed 1 m apart, on both sides of the road along the streambank stretching until the end of the impacts caused by the construction of the road-crossing (approximately 15 m) (Figure 2), providing a representative sample of sediment deposition or scouring along the banks due to the road-crossing establishment. At each road-crossing, monitoring occurred on both sides of the streambanks, and upstream and downstream from the crossing. A total of 316 sediment pins were established over the 7 monitored road-crossings. Measurements were performed twice a month during 2007 and 2008. In addition, soil bulk density samples from the soil surface (top 15 cm) were collected according to Blake and Hartge (1986) prescriptions. Samples were taken from each side of the stream, up and downstream of every crossing in Bonham Creek and processed in the laboratory.

Mass of soil accumulating or scouring from the streambanks was calculated using bulk density measurements according to Equation (1). The amount of sediment accumulation or export (in g m^{-2}) were based on the two year mean sedimentation rates obtained using the sediment pins method.

$$(1)\ \text{Net mass of sediment (g m}^{-2}) = \frac{10{,}000\ (\text{cm}^3)\ x\ BD\ (g\ cm^{-3})}{1\ (\text{m}^2)}$$

3.3.2.1.2 Sediment contribution from streambank sloughing

A total of 32 pins (16 in each streambank) were installed 5 m apart from each other and 60 cm above from the water level when the streams where at low flow stage.

Pins were installed in the streambanks immediately upstream from the mid-lower crossing at Bonham Creek and at the middle crossing in Sally Branch (Figure 2). Installation occurred in July of 2008 and measurements were taken twice a month from July through December of 2008.

3.3.2.2 Precipitation

Precipitation data for the "Columbus Area" station in Georgia were gathered from the National Oceanic and Atmospheric Administration (NOAA) – National Weather Service Forecast Office website (http://www.weather.gov/climate/xmacis.php?wfo=ffc). Monthly averages were collected from January 2007 to December 2008 to help interpret sedimentation data obtained using the sediment pins.

3.3.2.3 Dendrogeomorphic Analyses

The dendrogeomorphic approach was used to determine sedimentation rates on the floodplains over the last 2 to 3 decades. This methodology was applied on plots using a stratified sampling scheme on the floodplains of both streams. Plots were located 10 m apart on parallel transects extending perpendicular to the stream all the way to the edges of the floodplain. Transects were set 50 m apart on the floodplain (Figure 4). Three sections (lower, middle, and upper) of the stream were established along Bonham Creek, and two sections were established on Sally Branch (lower and upper). The distance between each section was approximately 50 m. The selection of trees for this methodology was based on diameter at the root collar (between 3 and 30 cm) and location (sampling occurred clockwise starting at magnetic north). A maximum of three trees per plot were sampled.

The dendrogeomorphic technique was developed by Sigafoos (1964) as a method to estimate contemporary soil erosion and/or accretion in forested landscapes. It has been successfully used at Fort Benning by Cavalcanti and Lockaby (2005) to estimate sedimentation along riparian forests of ephemeral streams. The technique basically consists of the association of sediment accumulation or scouring with the age of the tree. It entails identifying the root-collar of a tree (sometimes excavating down when the root-collar is buried by sediment accumulation) and determining its age by counting the growth rings at this location. Tree age at the soil surface (whether below or above the root-collar) is also determined based on tree rings. The age at the soil surface is then subtracted from the age estimated at the root-collar. Afterwards, the depth from the root-collar (soil surface when the tree germinated) to the current soil surface is measured. Finally, this distance is divided by the difference in ring counts from the two locations on the tree. The result is an average rate of either sediment deposition (root-collar buried) or scouring (root-collar exposed), associated with the years of growth required to expose/bury the portion of the tree at the soil surface (Equation 2).

$$(2)\ \text{Sedimentation (cm yr}^{-1}) = \frac{|\ \text{Distance from Soil Surface to Root−Collar (cm)}\ |}{|\ \text{Age Soil Surface (yr)} - \text{Age Root−Collar (yr)}\ |}$$

3.3.2.4 Cesium-137 methodologies

Sedimentation rates since the early 1960's were estimated using the Cesium-137 (^{137}Cs) atmospheric fallout method reviewed by Ritchie and McHenry (1990) and described by Kleiss (1993). This methodology was directed by Dr. Jerry C. Ritchie (USDA – Hydrology and Remote Sensing Laboratory). Ritchie and Ritchie (2007) affirmed that widespread global dispersal of ^{137}Cs began with thermonuclear weapons testing in 1945. Measurable concentrations began to appear in the soil in 1954 (Kleiss, 1993), and peaked in 1963 and 1964 immediately before the Atmospheric Nuclear Test Ban was adopted (Kleiss, 1993 and Fitzpatrick et al. 2008).

3.3.2.4.1 Cesium-137 sediment fingerprinting

Determination of major sources of sediments that were deposited on the floodplains was also made using the Cesium-137 method. To trace the sources of sediment, 10 samples on Bonham Creek and 12 samples on Sally Branch were collected by scraping the topsoil/sediments from streambanks, streambeds, floodplains and surroundings uplands. Random soil surface (upper 10 cm) samples were collected from floodplain areas (3 on each basin), uplands (3 on Bonham and 5 on Sally), streambanks (2 on each stream), and from the bedload (2 on each stream). Samples were processed and analyzed in the same manner as the Cs-137 sediment accretion samples. Tracing is based on the association of similar radioactive activities of the isotope ^{137}Cs found in different parts of the watershed (uplands, floodplains, streambanks and streambeds), thus, similar radioactive activities found in different samples are attributed to the same source.

In other words, if high radioactivity level is identified in the uplands and in the bedload sediment of the streams, but similar levels are not found anywhere else, we can infer that the sediment traveling in the stream as bedload originated in the uplands.

3.3.3 Statistical Analysis

All statistical analyses were performed using the SAS version 9.1 English package (SAS Institute 2008-2009). Bimonthly data from the sediment pins were averaged for interpretation of sediment yield from roads and streambanks. Student's t-tests were used to compare Bonham Creek and Sally Branch in terms of sediment movement from the roads, streambanks, and floodplains. Analyses of variance (ANOVA) (PROC GLM with Tukey's HSD) compared the sediment pin data among the sections, and among the locations of the sampling points in regard to the stream-crossings (i.e. east vs. west, and upstream vs. downstream of the crossings). ANOVA (PROC GLM with Tukey's HSD) were also used to verify differences in floodplain scouring among the sections, and differences in sedimentation/scouring according to the distance of the sampling points from the stream. Sampled tree-age and degree of sedimentation/scouring relationships in both streams were determined with linear regression analysis. Relationships were considered significant at alpha=0.05 (p-value<0.05), unless otherwise stated; however, results at 90% significance level were reported for informational purposes.

3.4 RESULTS AND DISCUSSION

3.4.1 Sediment Pins

3.4.1.1 Road contribution

The pins placed along the road-crossings showed that, over a two year monitoring period, Bonham Creek exported an average of 1.9 ± 0.5 cm month^{-1} of sediment, while Sally Branch exported 1.2 ± 1.1 cm month^{-1}. A time series of sediment movement from the Bonham Creek and Sally Branch is depicted along with monthly precipitation averages from the NOAA National Weather Service Forecast Office (http://www.weather.gov/climate/xmacis.php?wfo=ffc) in Figure 5. Even though 2007 was characterized as an extreme drought year by NOAA National Climatic Data Center (receiving only 96 cm of precipitation over the year) a large quantity of soil movement occurred. This movement is attributed to the lack of vegetative cover during this period. In 2008, precipitation more closely resembled the thirty year average (129 cm); however no further sediment export was seen. This trend is attributed to the growth of vegetation along the banks surrounding the stream-crossings (Figure 5), which may have retained sediment washing from the roads.

Sediment export estimated with the sediment pins may partially explain high suspended sediments reported by Houser et al. (2006) and Sharif and Balbach (2008). Houser et al. (2006) investigated tributaries of Bonham Creek and Sally Branch, in order to assess nutrient loads and suspended sediments during baseflow and stormflow events.

The authors found mean suspended sediment during baseflow events for catchments with less than 7% of the basins disturbed (such as one of the Bonham Creek tributaries) to be 4.0 mg L^{-1}. For catchments in the Coastal Plain region with over 7% of the basin disturbed (such as the Sally Branch tributaries), the authors found TSS to be as much as 10.1 mg L^{-1}. During stormflow events, the authors found TSS that ranged from 57 to 300 mg L^{-1} for basins with relatively little disturbance (< 7%), and from 847 to 1881 mg L^{-1} on highly disturbed catchments (> 7%). At Bonham Creek, Sharif and Balbach (2008) found suspended sediment concentrations that ranged from 50 to 600 mg L^{-1}, with one event showing as much as 2,500 mg L^{-1}. At Sally Branch, the authors reported levels from 6 to 35 mg L^{-1}. Results from both studies (Houser et al., 2006; and Sharif and Balbach, 2008) relate to the contribution of sediment from road-crossings and streambank sloughing.

Monthly soil movement at each road-crossing is illustrated for Bonham Creek and Sally Branch in Figures 6a and 6b, respectively. Notable variability of sediment movement between and within stream crossings can be seen. Most of the monitored crossings showed a net export of sediment from the streambank. Some road-crossings, including the mid-upper on Bonham Creek and the lower on Sally Branch (Figures 6a and 6b) showed exceptionally high soil loss (4.2 ± 1.0 cm $month^{-1}$ and 3.4 ± 1.5 0 cm $month^{-1}$ respectively) throughout the two years of monitoring. The lower road-crossing on Bonham, however, unlike the other three road-crossings at this creek, showed net aggradation of sediment (0.9 ± 0.8 cm $month^{-1}$) on the streambank. The mean sedimentation at each road-crossing for Bonham Creek and Sally Branch can be seen on

Table 1. It is important to highlight that the pins located in middle and upper road-crosses in Sally Branch were replaced by “rip-rap” sediment control measures in June of 2007 (Figures 6b and 9).

The mean bulk density of the topsoil (15 cm) sediment on the streambanks along the road-crossings, where sediment pins were placed, was 0.89 Mg m^{-3}. Overall, Bonham Creek exported approximately 670 kg m^{-2} of sediment over the two year monitoring period. Based on the mean sedimentation rate of each road-crossing, mass of soil accumulating or scouring was determined. The mass of sediment ranged from 92 kg m^{-2} of aggradation in the crossing in the lower reach, to as much as 470 kg m^{-2} of sediment scouring in the crossing situated in the mid-upper reach (Table 2).

Sediment accretion and/or export was also observed at the road-crossing level, taking into account the location of the pins in relation to the road-crossing, i.e. upstream or downstream of the road-crossing. Mean sediment scouring along the banks of Bonham Creek was 0.69 ± 0.59 cm immediately downstream of the road-crossings and 3.29 ± 0.74 cm immediately upstream of it. On Sally Branch, such comparisons were not performed because most sediment pins were replaced by “rip-rap” sediment control measurements.

Comparisons between sedimentation upstream and downstream of the crossings showed that sediment accumulation occurred only immediately downstream of the road-crossings for Bonham Creek ($p=0.0078$). These findings corroborate with the findings reported by Bazemore et al. (1991), where the authors investigated the interference in water-flow caused by highway-crossings in West Tennessee and found greater sedimentation rates downstream of crossings in four out of eleven study sites in

Tennessee streams. On the other seven sites, the authors found no significant difference (Bazemore et al., 1991); therefore, their general conclusion was that highway crossings do not affect sedimentation patterns. Similar comparison was not possible on Sally Branch because data sets on the middle and upper crossings were incomplete.

On Bonham Creek, comparison of erosion/sedimentation occurring either upstream or downstream of each road-crossing separately, showed significantly greater scouring of sediments upstream of the lower and mid-upper crossings ($p=0.0062$, and $p=0.0013$, respectively) while the upper crossing showed greater sediment scouring ($p=0.0257$) downstream (Figure 7). On Sally Branch, the lower crossing showed greater sediment scouring downstream of the crossing ($p=0.0104$) (Figure 8), however no inferences can be made on either the middle or upper crossing due the incomplete data set.

Even though the results obtained with the sediment pin method showed significant exportation of sediment along Bonham Creek and at Sally Branch, it is important to note that the results were influenced by the drought that occurred in 2007, which according to Fuchs (2008) was the second driest January-August in the last 100 years in Georgia. The NOAA National Climatic Data Center characterized the areas that encompassed the study site in an extreme drought category for the year of 2007. Much of the initial sediment movement likely coincided with recent completion of the road crossings, when soil stabilization and erosion control measures were still being implemented. A comparison of the mean sedimentation along the road-crossings that occurred in 2007 to the mean sedimentation in 2008 showed significant greater scouring occurring in 2007 at Bonham Creek (p=0.0004). This period showed greater scouring because of changes in stream-channel morphology coupled with modifications of the soil structure and lack of vegetation cover, which increased soil detachment. In 2008, soil loss decreased and sediment aggradation around the sediment pins increased slightly. The higher precipitation in 2008 is reflected in the greater variation between data points seen in Figure 6a. However regression analysis showed no relationship between the sediment pins measured sedimentation and precipitation on either stream.

Mean precipitation was not significantly different between 2007 and 2008 (Figure 10), but a t-test showed significant statistical difference (p=0.0460) between the year 2007 and the 30 year precipitation average for the area of Columbus, Georgia.

3.4.1.2 Streambank sloughing

Sediment pins placed horizontally into the streambank at both streams showed streambank erosion during the late portion of 2008. Bonham Creek streambank erosion averaged 1.1 ± 0.1 cm $month^{-1}$ and Sally Branch averaged at 1.4 ± 0.4 cm $month^{-1}$. These rates are much higher than the rates estimated by Jackson et al. (2005) of 0.21 to 0.46 cm yr^{-1} on the Murder Creek, GA, and within the range reported by Walter and Merritts (2008) of 5 to 20 cm yr^{-1} in the Pensylvania, and by Lawler et al. (1999) of 8.3 to 44 cm yr^{-1} in northern England. Nonetheless, it was noted during field data collection that most streambanks were steep and unstable. Streambank erosion is occurring in Bonham Creek and Sally Branch as a result of fluvial entrainment and mass wasting as described by Wynn (2006). According to Wynn (2006), fluvial entrainment corresponds to the detachment and removal of soil particles from the streambank caused by the hydraulic forces of the stream during flood events. Mass wasting represents the collapse of the streambank due to geomorphic instabilities. Such high rates of streambank sloughing support the idea of stream adaptation to the extensive sedimentation that occurred during the cotton-era. This adaptation involves a reconfiguration of the stream-morphology from braided shallow water and frequently flooded floodplain, to a deeply incised stream channel with a low terrace-like riparian forest, to a "V" shaped stream channel and sloped streambank.

The pattern of streambank erosion since the sediment pins were installed in July 2008 is depicted on Figure 11 along with daily precipitation data obtained from the NOAA's National Weather Service Forecast Office (http://www.weather.gov/climate/xmacis.php?wfo=ffc). As illustrated in Figure 11, no clear relationship between precipitation and streambank sloughing can be verified. A simple linear regression analysis confirmed the absence of a significant relationship.

3.4.3 Dendrogeomorphic approach

A total of 367 trees were analyzed with the dendrogeomorphic technique to estimate rates and patterns of sediment deposition or scouring on the floodplains of each stream. A total of 248 trees were examined on the floodplains of Bonham Creek, and 119 at Sally Branch. A wide variety of tree species found on the floodplains were used in this methodology, including: red maple (*Acer rubrum* L.), American hornbeam (*Carpinus caroliniana* W.), swamp cyrilla (*Cyrilla racemiflora* L.), American holly (*Ilex opaca* A.), large gallbery (*Ilex coriacea* C.), sweetgum (*Liquidambar styraciflua* L.), tulip poplar (*Liriodendron tulipifera* L.), sweetbay magnolia (*Magnolia virginiana* L.), wax murtle (*Morella cerifera* L.), black cherry (*Prunus serotina* E.), swamp tupelo (*Nyssa aquatic* L.), blackgum (*Nyssa sylvatica* M.), shortleaf pine (*Pinus echinata* M.*), and* water oak (*Quercus nigra* L.). Based on our field observations, the predominant species found in the floodplains of both streams, and consequently most used in the analyses, was red maple.

The results obtained from the dendrogeomorphic analysis showed stability with very little sediment redistribution on the floodplains of Bonham Creek and Sally Branch for the past 24 years. The estimated mean sediment redistribution/scouring rate on the floodplains of Bonham Creek was 0.46 ± 0.13 cm yr^{-1}, and the average age of examined trees was 26 years. Sally Branch's floodplain showed 0.34 ± 0.37cm yr^{-1} of sediment being reorganized in the floodplains and the average tree age was 21 years. The relative stability in the floodplains was associated with the lack of significant land cover modifications and/or intensive land management during the last 25 years associated with minor relief from microsite characteristics creating localized flows. The significant amount of legacy sediment deposited atop the original floodplain (see chapter 2) led to the disconnection between the streams and their floodplains; thus, decreasing the likelihood of overbank flooding and ceasing the subsidy of sediments from the streams to the floodplains, allowing redistribution of sediments already present in the floodplains.

A Student's t-test showed no significant difference between streams in overall sediment redistribution. Although scouring/redistribution is occurring on Bonham Creek and Sally Branch floodplains, no inference as to the amount of sediment being exported into the streams can be made, because this material may be redistributing on the floodplains instead of making its way into the creeks. In addition, this investigation did not gather data regarding suspended sediments, therefore it is unknown how much sediment is actually being carried by the streams.

Older trees from Bonham Creek may have influenced the final redistribution estimates. While performing the field portion of this study on the floodplains of both streams, it was noted that most of the older and mature trees were showing exposed root-collars more often when compared to the young ones. Bazemore et al. (1991) reported a similar relationship between tree age and root-collar burial by using the dendrogeomorphic approach in streams in West Tennessee. However he authors considered the relationship weak at most study sites due to variability in stream proximity and elevation among the sampling points. This may also be partially explained by the effects of compaction of the sediment over time, causing the soil to sink as time goes by exposing the root-collar of the trees. By utilizing the bulk density of the sediments in the floodplains (see chapter 2) and comparing (ANOVA) them between depth classes (0-10 cm, 10-20cm, and 20-30 cm), we found that the underlying layers of sediment were more compacted than the layers immediately above ($p=0.0042$, $r^2=0.1668$) (Table 3). This supports Hupp and Bazemore (1993) theory that compaction of newer layers of sediment may alter long-term sedimentation rates in floodplain forests.

Analysis of the sampled trees showed no difference in age between each side of the floodplain in which the sampling was performed for both streams. So, no statistical difference of age-class was found when comparing the different sampled sections on either stream. Therefore, we can assume that the sampled trees were relatively homogeneous and evenly distributed along the floodplains. No difference in mean sedimentation rates were found among sections of Bonham Creek and Sally Branch. However it is important to point out that the lower section in Sally Branch was the only section of the floodplain that showed mean sediment input in the last 25 years (Table 5), emphasizing that the sediment may be reorganizing on the floodplains. Both of these analyses ultimately demonstrate the relative stability of the streams with minimal redistribution of sediments on sections of their floodplains.

Analysis verifying the spatial patterns of sedimentation/scouring rates in terms of distance from the stream were performed using the dendrogeomorphic data. Since the data was collected on plots situated in transect gridlines that were placed perpendicular to the stream, determination of the distance of each plot from the stream was possible. As suggested by Walling and He (1998), sedimentation would be greater closer to the stream. However, analysis comparing the sedimentation among the plots based on their distance from the stream-channel (ANOVA with Tukey's HSD) showed no significant difference in mean sedimentation in terms of proximity to the stream on either creek.

3.5 SUMMARY AND CONCLUSIONS

This paper addressed current erosion and sedimentation patterns in two streams within the Upper Coastal Plain physiographic region at Fort Benning, Georgia. Sediment contribution from the unpaved graveled roads during a two-year monitoring period showed that significant amounts of sediment are being exported into the streams through road-crossings, even though the results were affected by the precipitation patterns of 2007, which was considered an extreme drought year. Road-crossings along Bonham Creek showed average sediment exportation values of 1.9 cm, while those on Sally Branch exported 1.2 cm over a 2-year period, supporting the hypothesis that current disturbances would generate significant erosion/sedimentation in the streams. However, precipitation changes resulted in significant differences in sediment exportation between 2007 and 2008, where 2007 had much lower mean sedimentation at Bonham Creek than 2008. Monitoring of the streambank also showed significant erosion occurring. The streambanks of both systems sloughed at an average rate of 1.24 cm month^{-1} during 2008. The sediment contribution from the floodplains, from the stream-crossings, and streambank sloughing, are likely contributing to the high suspended sediments reported in those systems by Houser et al (2006) and Sharif and Balbach (2008).

This paper concluded that the high erosion rates associated with streambank sloughing reflected changes in the stream morphology caused by the extreme high sedimentation that occurred during early settlement. Poor agricultural practices during the late 19th and early 20th centuries likely caused significant erosion and therefore, high sedimentation in the bottomlands. The resulting high banks and deeply incised stream channels likely caused streambank instability and failure.

The investigation also showed that the floodplains of both streams are in current stable conditions in terms of notable erosion and/or sedimentation, but they are undergoing sediment redistribution. The dendrogeomorphic technique showed a net floodplain scouring/redistribution rate of 0.46 cm yr^{-1} for Bonham Creek and 0.34 cm yr^{-1} for Sally Branch over the past 25 years. The Hupp and Bazemore (1993) hypothesis of compaction of lower layers of floodplain sediment by the weight of the upper layers altering long-term sedimentation rates may be occurring on the floodplains of Bonham Creek. On the floodplains of both streams, no trend relating sediment redistribution to the proximity of the stream was found, nor to stream section.

Stable conditions of the floodplains were associated with the lack of major changes in land cover during the last 25 years, and with the disconnection between the streams and the floodplains due to excessive sediment deposition on the floodplains during the cotton era. Stream overbank flooding is currently rare. During the two years of this project no overbank flood event happened. This highlights the importance of fully understanding the original geomorphology of stream systems and how past alterations may lead to current changes in the patterns and processes that are occurring.

Lastly, the findings of the present study emphasize the importance of additional study of stream morphology and ecology in the Southeastern U.S. New methodologies and more comprehensive approaches are needed in this field. This study emphasizes the need for further research in the areas that link stream morphology, ecology, and hydrology.

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Table 1: Mean (±SE) depth of sediment deposited (+) or scoured (-) for sediment pin monitoring of 2007 and 2008 at each stream-crossing.

Stream	**Reach**	**Number of Pins**	**Mean Sedimentation -cm-**	**Standard Error**
Bonham	Lower	49	+0.95	0.83
	Mid Lower	51	-2.72	1.10
	Mid Upper	70	-4.21	1.01
	Upper	52	-0.68	0.52
Sally	Lower	26	-3.42	1.57
	Middle*	32	-0.38	1.76
	Upper*	36	-0.41	2.10

*Indicate incomplete data sets

Table 2: Mean (±SE) mass of sediment (kg m^{-2}) deposited (+) or scoured (-) from the streambanks along the road-crossings of Bonham Creek.

Quadrant	**Lower**	**Mid-Lower**	**Mid-Upper**	**Upper**
	-kg m^{-2}-			
Downstream-East	+123.80	-124.36	-34.80	-22.84
Downstream-West	+35.08	-26.62	-16.61	-10.37
Upstream-East	-40.74	-50.59	-345.58	-23.48
Upstream-West	-25.91	-102.51	-73.42	+68.74
Total	**+92.22**	**-304.08**	**-470.42**	**+12.05**

Table 3: Mean (±SE) sediment bulk density (Mg m^{-1}) for each depth increment in the upper 30 cm of the soil of the floodplains of Bonham Creek and Sally Branch.

Stream	**Depth-Class**	**N**	**Mean Bulk Density - Mg/m -**	**Standard Error**
Bonham	0-10	23	0.77	0.1
	10-20*	32	1.02	0.1
	20-30*	9	1.17	0.1
Sally	0-10	20	1.07	0.0
	10-20	11	1.17	0.1
	20-30	5	1.02	0.1

*Indicate statistical difference among depth increments

Table 4: Number of individual trees and mean (±SE) annual sedimentation rate (cm yr^{-1}) observed with the dendrogeomorphic analysis in each sampled section of Bonham Creek and Sally Branch.

Stream	Section	Number of Sampled Trees	Sedimentation Rate	Standard Error
Bonham	Lower	42	-0.13	0.43
	Middle	69	-0.36	0.22
	Upper	137	-0.59	0.17
Sally	Lower	60	0.22	0.40
	Upper	59	-0.78	0.57

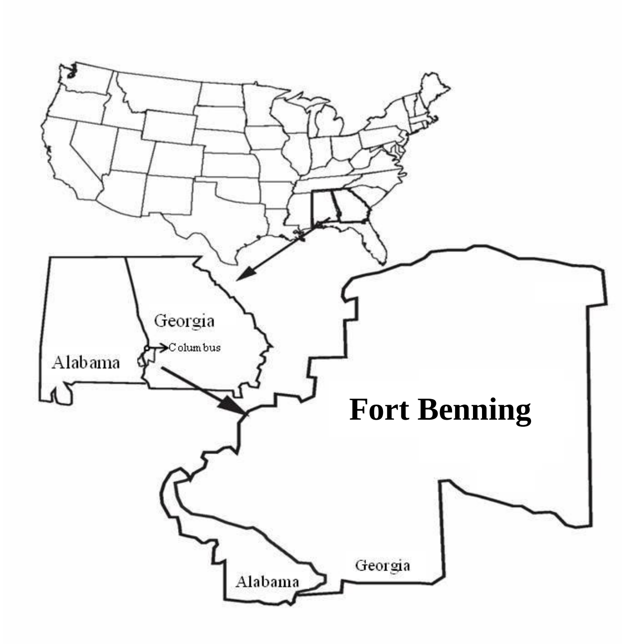


Figure 1: Geographic location of Fort Benning, GA.

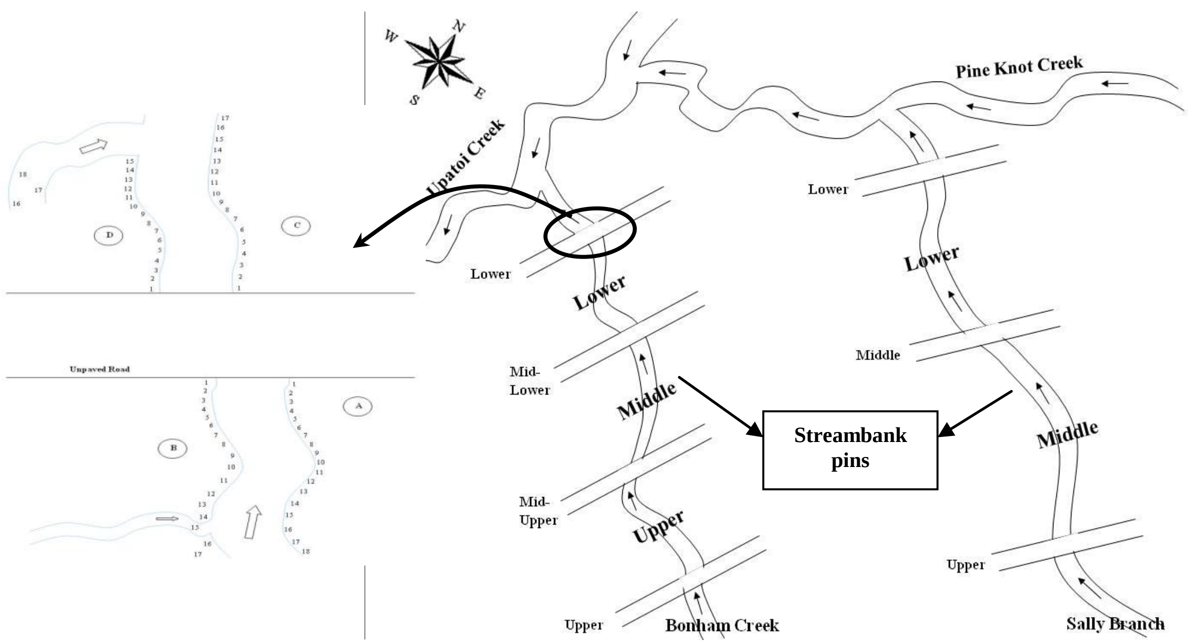


Figure 2: Schematic diagram of road-crossing locations (top), and placement of sediment pins (numbered) along a streambank (bottom). Sediment pin quadrants are noted as A-B-C-D.

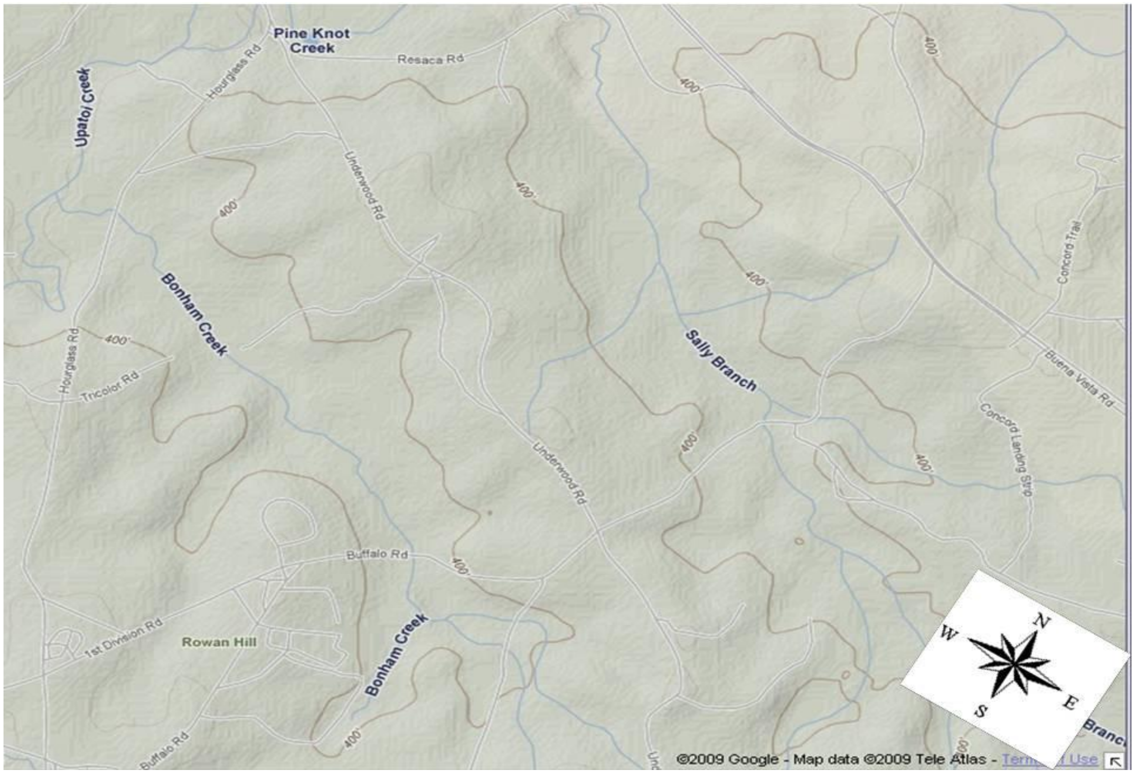


Figure 3: Terrain, roads and stream channels encompassed by the study area (Source: GoogleMaps.com).

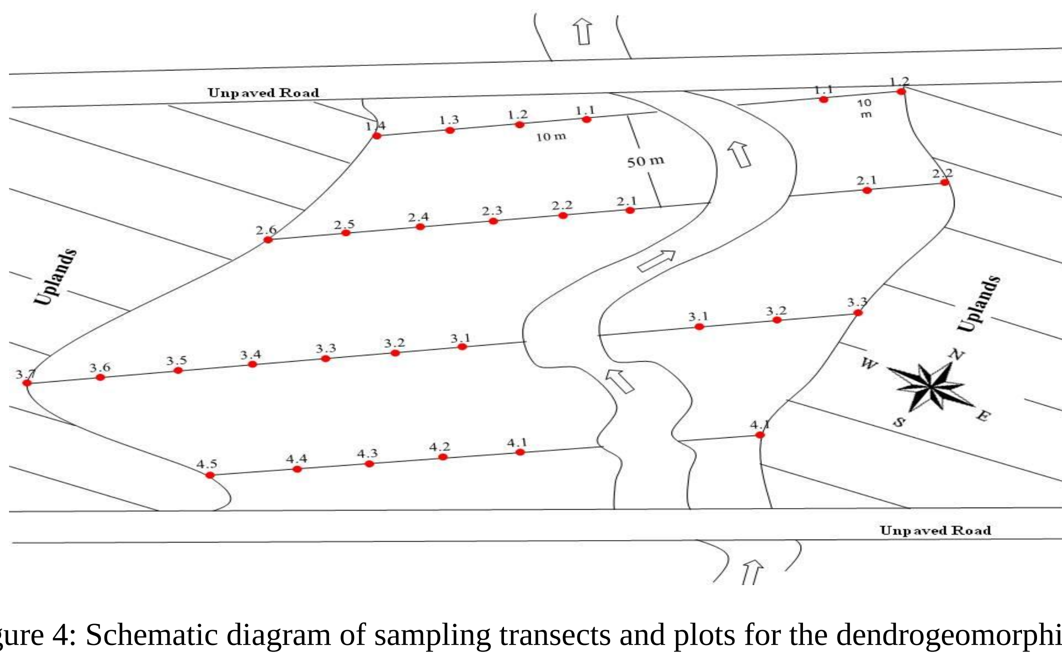


Figure 4: Schematic diagram of sampling transects and plots for the dendrogeomorphic approach on Bonham Creek and Sally Branch.

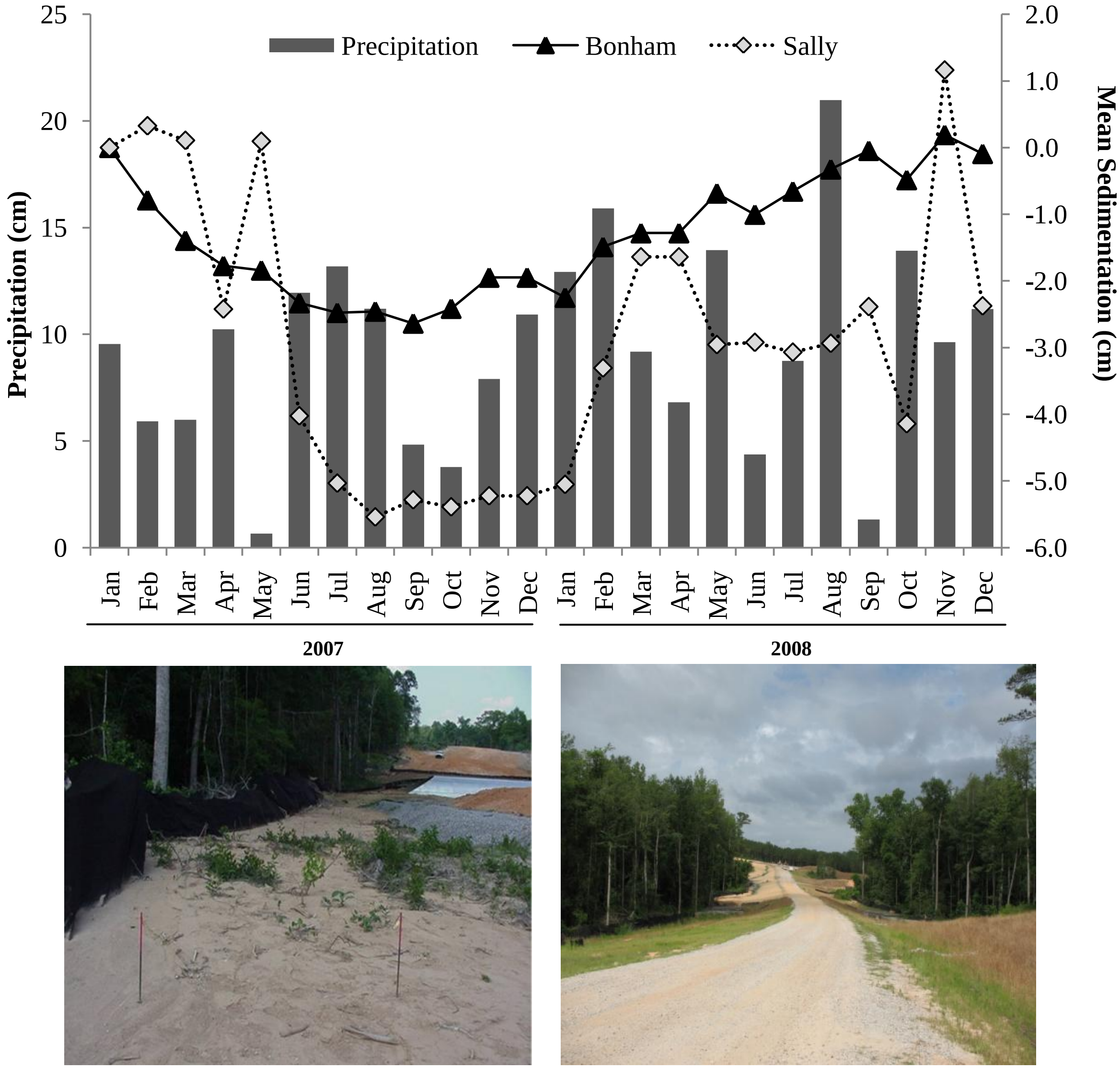


Figure 5: Time series of sediment movement in Bonham Creek and Sally Branch depicting the amount of sediment movement after the construction of the road-crossings in 2007 (bottom left), and a year later after the establishment of BMP's in 2008 (bottom right). Precipitation data gathered at the NOAA's National Weather Service Forecast Office (http://www.weather.gov/climate/xmacis.php?wfo=ffc) is also graphed throughout the monitoring period along with sediment data.

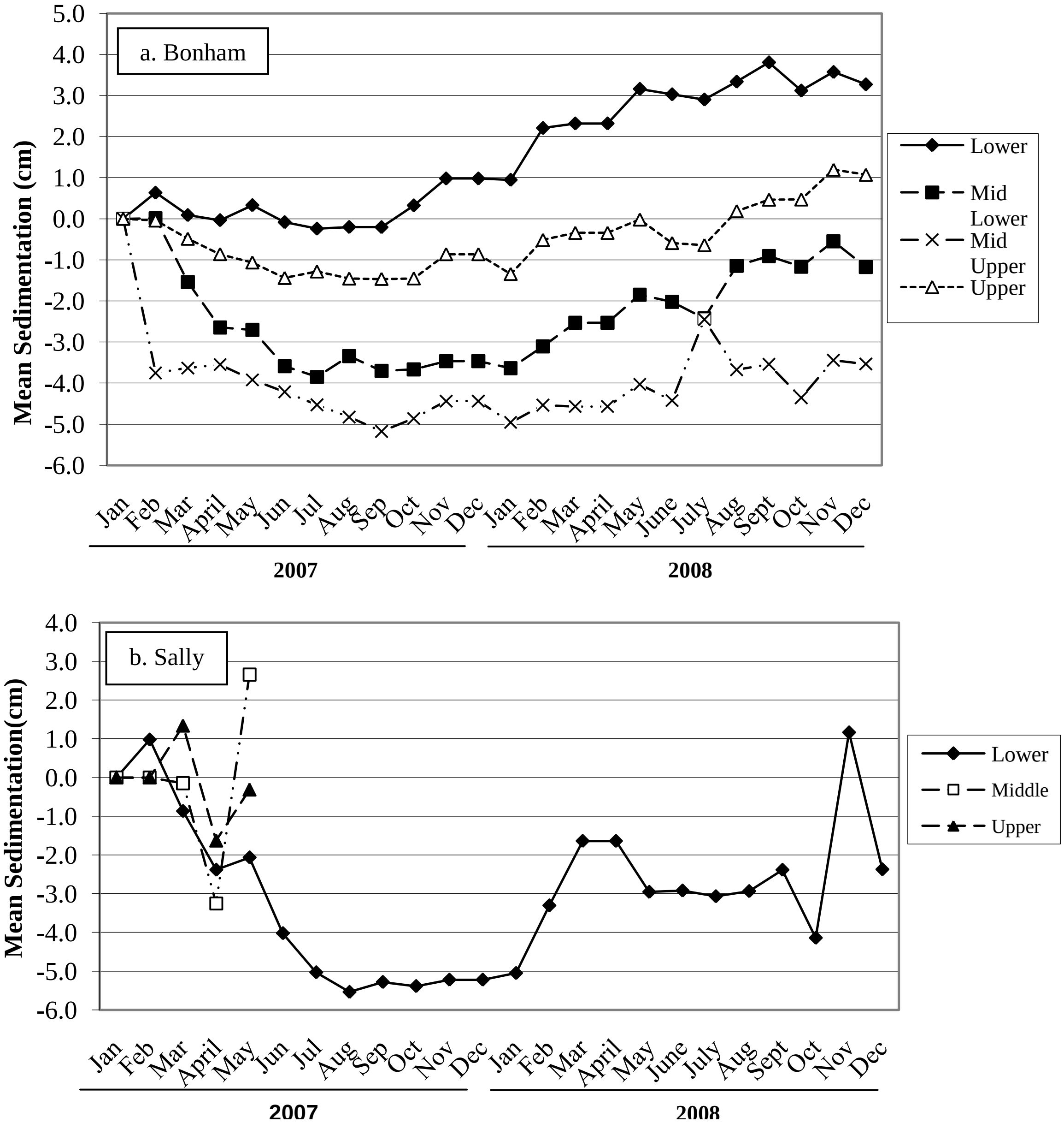


Figure 6: Evolution of mean sedimentation/scour (cm) observed with the sediment pin measurements in each stream-crossing at (a) Bonham Creek and (b) Sally Branch, during 2007 and 2008. Values are based on mean quadrant data for each crossing.

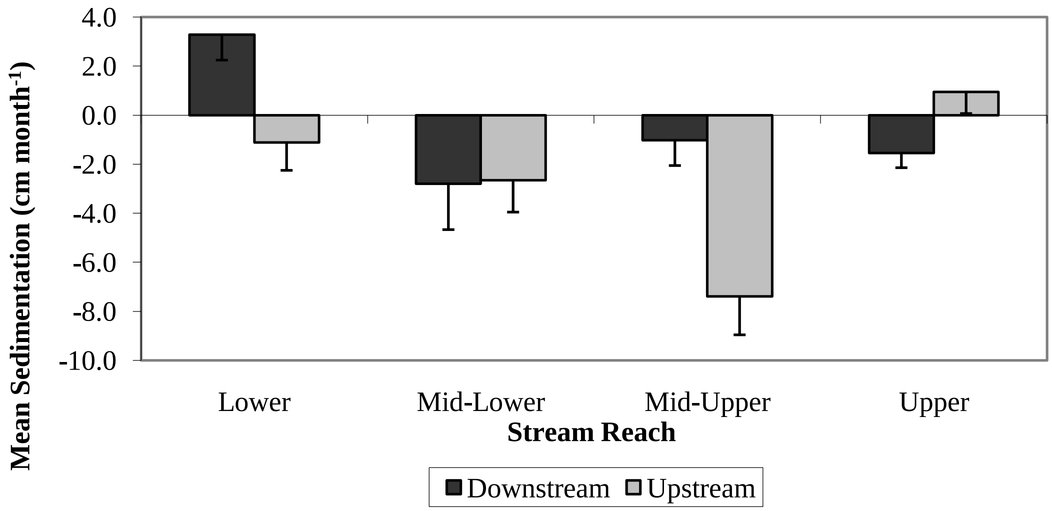


Figure 7: Mean (±SE) sedimentation (cm) and observed with the sediment pin measurements in each stream-crossing at Bonham Creek.

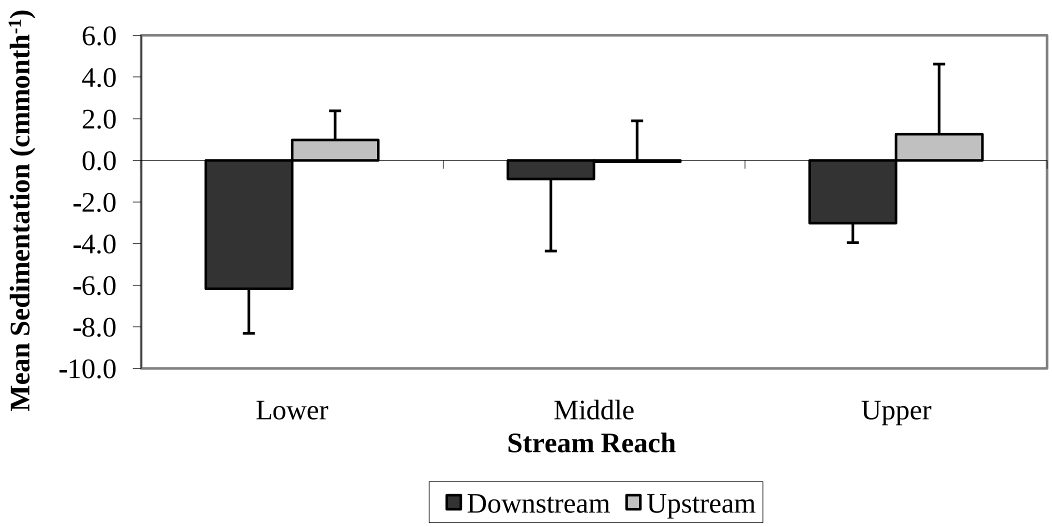


Figure 8: Mean (±SE) sedimentation (cm) observed with the sediment pin measurements in each stream-crossing at Sally Branch.

Figure 9: Rip-rap (rocks) erosion control measures that were placed where sediment pins were located along Sally Branch streambank.

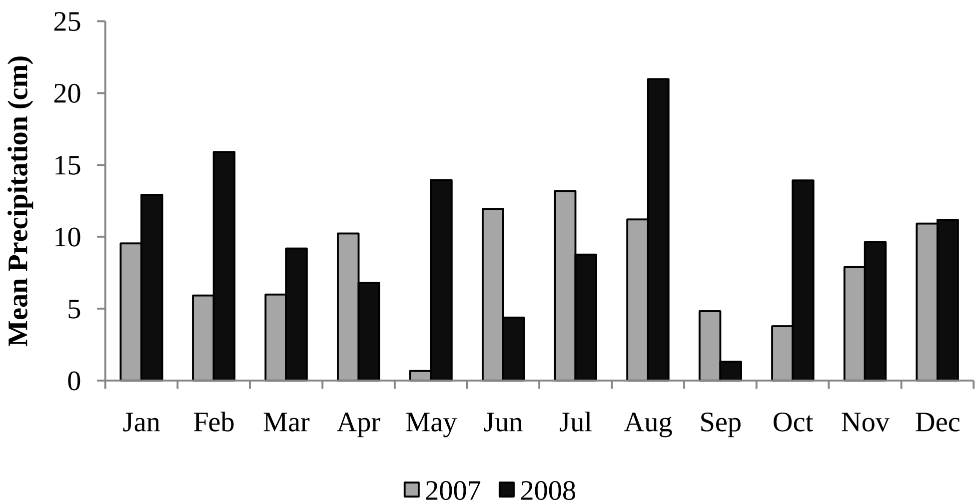


Figure 10: Monthly precipitation for the area of Columbus, Georgia. Data obtained with at the NOAA's website (http://www.weather.gov/climate/xmacis.php?wfo=ffc).

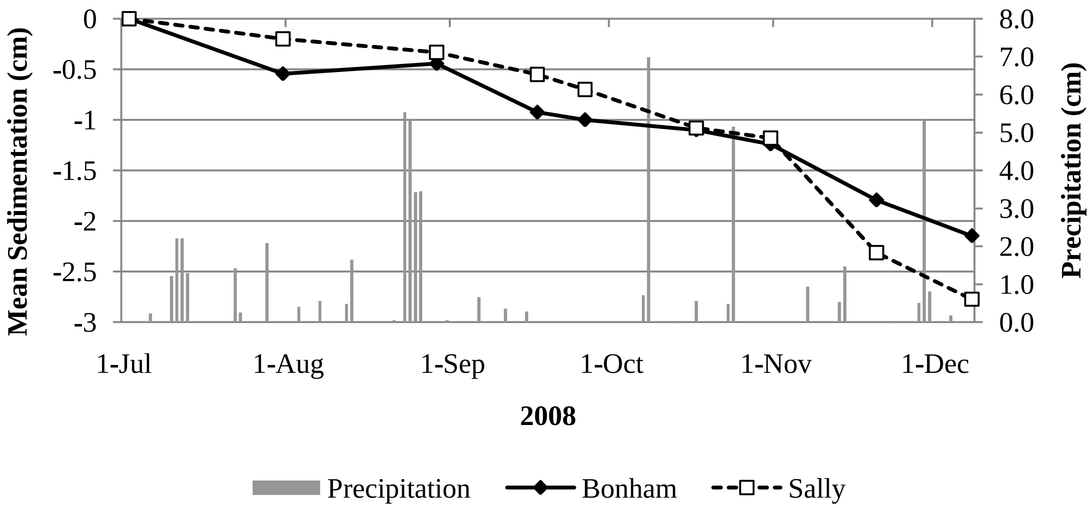


Figure 11: Evolution of mean sedimentation (cm) observed with the sediment pin placed into the streambank of Bonham Creek and Sally Branch along with daily precipitation.

4. CONCLUSIONS

This study addressed the role that anthropogenic disturbances caused by the early American-European settlers have played in defining the hydrology and geomorphology of two streams and associated floodplains in the Southeastern Coastal Plain physiographic region of the United States. Prior to the American-European settlement, the “U.S. South” was described as an astonishing landscape with vast forests, expansive meadows, daunting wetlands and abundant water resources. However, the lack of soil conservation practices in the settlers’ agriculture, such as lack of terracing, resulted in extensive soil erosion in the cultivated fields and consequently significant sedimentation in the valley-bottoms and streams.

The significant amount of sediment deposited in the floodplains identified in this study critically altered the ecology of the streams by causing modifications to their hydrology and geomorphology. The original floodplains on Bonham Creek are buried under 179 cm of alluvium that originated from the settlers’ lack of conservation practices. This depth of sediment represents an equivalent mass of 2,305 kg m^{-2}. Sally Branch showed similar results, where the original floodplains are buried under 178 cm of legacy sediment with equivalent mass of 2,371 kg m^{-2}. On both floodplains legacy sediments were evenly distributed throughout the floodplains. Due to the characteristics of the physiographic region of study, the legacy sediment was characterized as sandy loam or loamy sand; however, the particle size content varied among the sections and depths where it was sampled. Organic carbon concentration was also relatively low:

Concentrations in the legacy sediments on Bonham Creek's floodplain were 26,612 mg kg^{-1}, while those on Sally were 25,097 mg kg^{-1}. These organic carbon concentration indicate rapid sediment deposition on the floodplain not allowing enough time for organic matter to be incorporated in the alluvium. The concentrations corresponded to an organic carbon content of 59.64 kg m^{-2} on the legacy sediments of Bonham Creek's floodplain, and 56.79 kg m^{-2} on Sally Branch's.

Legacy sediment accumulation estimated by a computer-based model (WEPP) conflicted with the field-data. The results of sediment mass obtained with WEPP were considerably lower than the estimations based on the field-data. By relating mass of legacy sediment to depth of the deposition layer, we verified that the WEPP estimate of legacy sediment depth was shallower than the depths recorded in the field. We concluded that the discrepancy probably occurred due to the limitations of the model in simulating scenarios with lack of conservation measures, especially soil conservation techniques (lack of terracing), and due to the limitations of the model in accounting for concentrated flows such as gullies, which was likely the pathway through which most erosion was transported in the sandy soils present in the Coastal Plain physiographic region.

Sedimentation of the magnitude reported here likely raise the streambed and resulted in the swamping of the entire stream systems (streams and floodplains). With years passing, water-mediated erosion caused the down-cutting of this sediment resulting in a new, deeply incised stream-channel, now disconnected from its floodplain. These features do not represent the natural conditions of undisturbed Southeastern Coastal Plain streams.

The process of down-cutting the legacy sediment resulted in an average streambank-height and bankfull-width of 1.99 m and 4.54 m respectively on Bonham Creek, and 2.68 m and 8.42 m on Sally Branch. Water has carved the channel in Sally Branch significantly deeper and wider than in Bonham Creek and this allowed the historic floodplain surface/stream-channel to become visible in the lower reaches of the creek. Since Sally's watershed is greater in size and has a higher gradient, the amount of energy delivered by the streamwater was more effective than in Bonham in exporting the legacy sediment. Therefore, we concluded that the larger watersheds with steeper gradients had a greater potential for exporting the legacy sediments.

As a consequence of the high banks, there is very little possibility for occurrence of overbank floods, and therefore, it is likely that no overbank sedimentation has been occurring on the floodplains of the streams. Based on the dendrogeomorphic technique, the floodplains of both streams showed mid-term stability in terms of sediment aggradation and/or degradation. In fact, both streams are undergoing sediment redistribution/scouring in the floodplains for the past 25 years as identified by the dendrogeomorphic approach. Bonham Creek is reorganizing the sediments on its floodplains at a rate of 0.46 cm yr^{-1} for the past 26 years, while Sally Branch is redistributing 0.34 cm yr^{-1} over the past 21 years. Analysis of the results showed that redistribution of sediments was greater around older trees. We concluded that older trees have undergone a greater number of storm events which may have resulted in little sheet occurrence, reflecting greater sediment movement on its surroundings. The stability observed in the floodplains was attributed to the lack of significant land cover conversion and to the disconnection of the streams from their floodplains. Furthermore, the reported redistribution of sediments in the floodplains could be considered as a natural counter-balance of the system in response to human disturbances that led to excessive sediment deposition.

The mid-term (20 to 60 years) sedimentation patterns and deposition estimation techniques used in this study showed conflicting results. The Cesium-137 results showed net sediment accretion in both stream's floodplains since 1954 (average of 0.4 cm yr^{-1}), whereas the dendrogeomorphic results showed net sediment redistribution/scour for the last 25 years. The ^{137}Cesium fallout results were considered less representative of the ongoing sedimentation process within the basins due to the low sampling frequency, micro-site variation, and perhaps proximity to newly constructed roads.

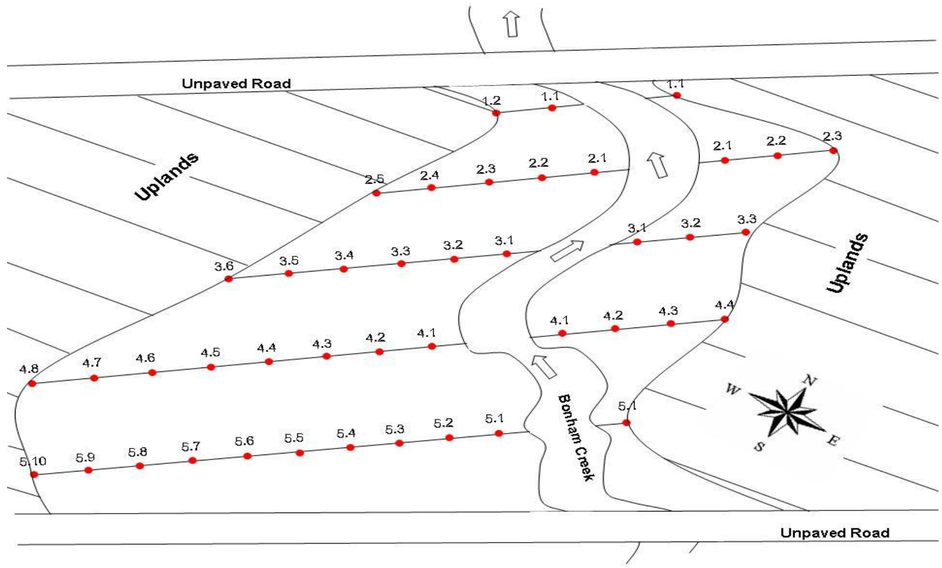
Current sediment movement in the watersheds according to the sediment pins method showed significant exportation from the streambanks and along road-crossings. On Bonham Creek and Sally Branch, cumulative sediment scouring along the road-crossings were 1.9 cm $month^{-1}$ and 1.2 cm $month^{-1}$ respectively. However the low rainfall in 2007, which was characterized by the National Climatic Data Center (2009) as extreme drought, definitely impacted the results. Mean cumulative sediment contribution from the roads was significantly lower in 2007 than in 2008. Nonetheless, the banks along the road-crossings exported an average of 670 kg m^{-2} of sediment over the two year monitoring period.

The streambanks of Bonham Creek and Sally Branch are eroding at a cumulative rate of 1.12 cm $month^{-1}$ and 1.35 cm $month^{-1}$ respectively. These high rates observed likely reflect alterations in the morphology of the streams caused by historic sediment deposition. The high streambanks and consequent deeply incised stream-channels resulted in streambank instability, and led to more pronounced streambank erosion and, in some instances, failure.

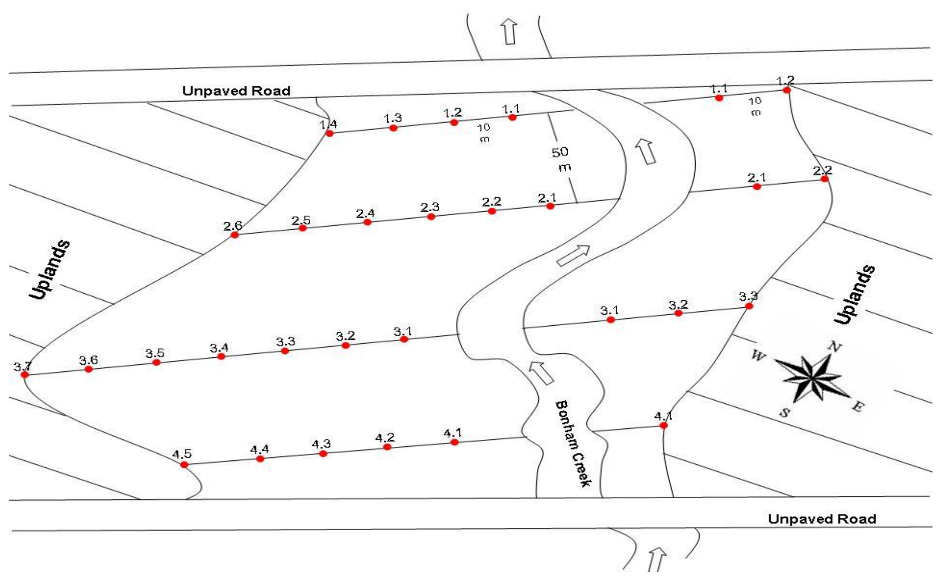
The findings of the present study emphasize the need for preserving, conserving, and restoring the remaining riparian ecosystems and ensuring their integrity and functionality for the continuation of the services they provide, such as sediment retention and improvement of water quality. The investigation also highlighted the importance of assessing and comprehending the original ecology, hydrology, and geomorphology of streams and floodplains systems in projects of construction, restoration, and/or management of these systems. The need for further multi- and inter-disciplinary research was emphasized in the areas linking the fields of stream ecology, morphology, hydrology, and landscape history in the Coastal Plain physiographic region of the Southern US.

Finally, this study reveals the importance of fully understanding the original conditions of a determined ecosystem and how disturbances that occurred in the past may determine the current status of ecological functions. Further, it reveals the intrinsic importance of maintaining the integrity of streams and their floodplains ecosystems, and their capacity for maintaining and even enhancing human welfare.

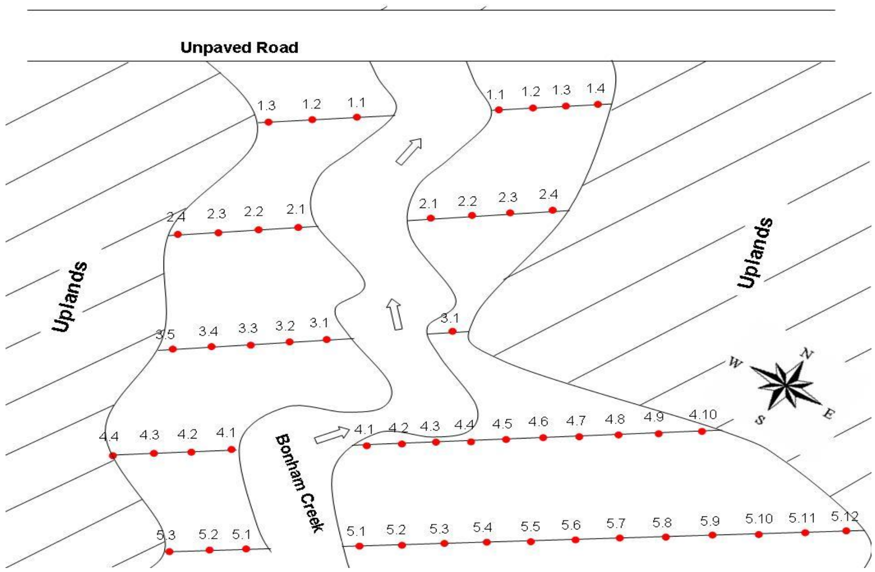
APPENDICES



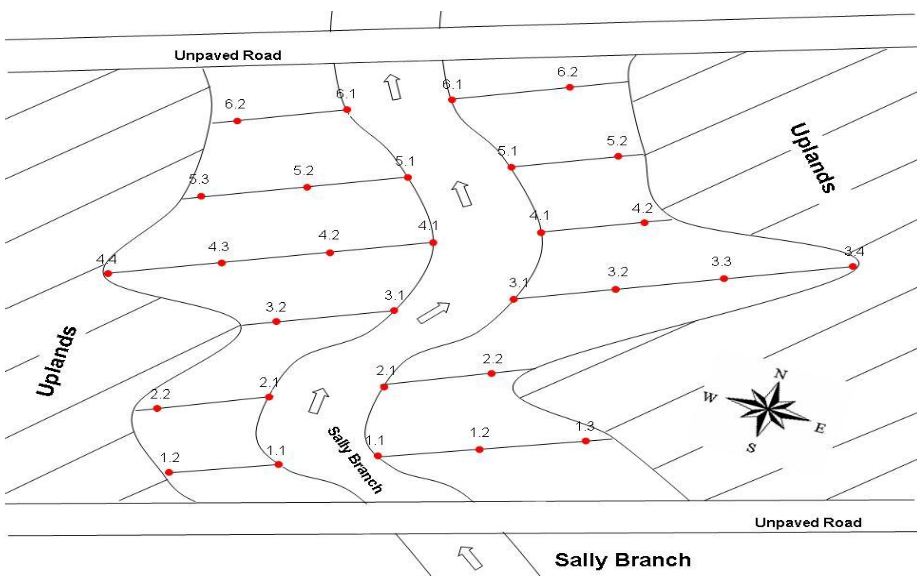
Appendix A: Schematic diagram of sampling transects and plots for soil core and dendrogeomorphic methodologies on the lower section of Bonham Creek.



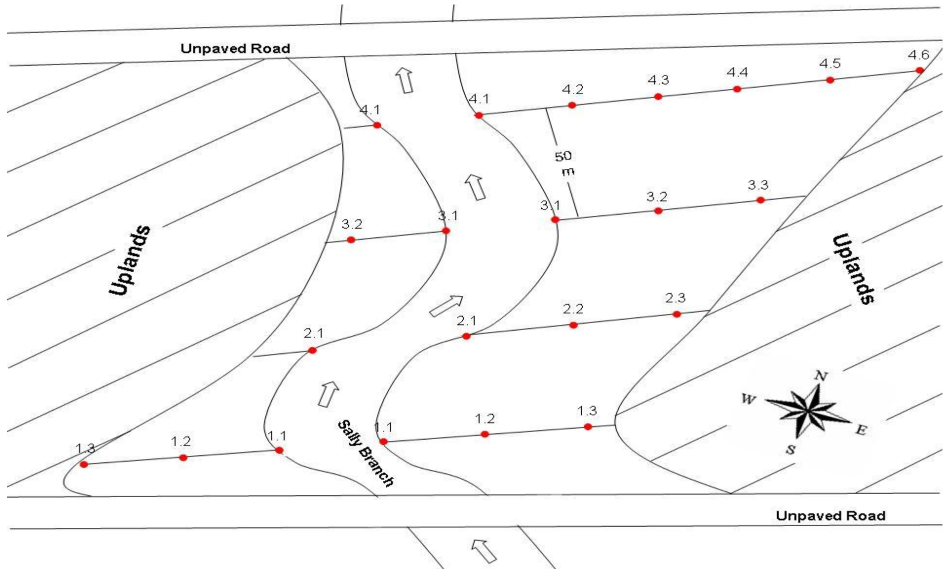
Appendix B: Schematic diagram of sampling transects and plots for soil core and dendrogeomorphic methodologies on the middle section of Bonham Creek.



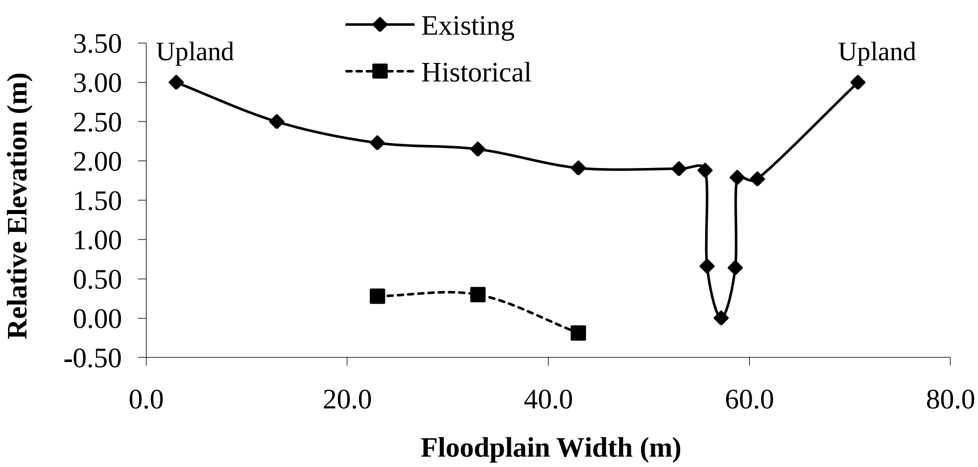
Appendix C: Schematic diagram of sampling transects and plots for soil core and dendrogeomorphic methodologies on the upper section of Bonham Creek.



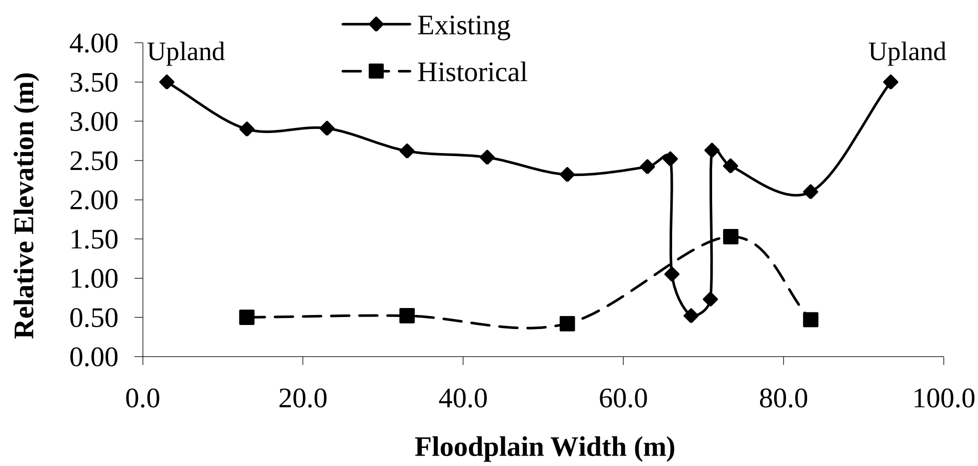
Appendix D: Schematic diagram of sampling transects and plots for soil core and dendrogeomorphic methodologies on the lower section of Sally Branch.



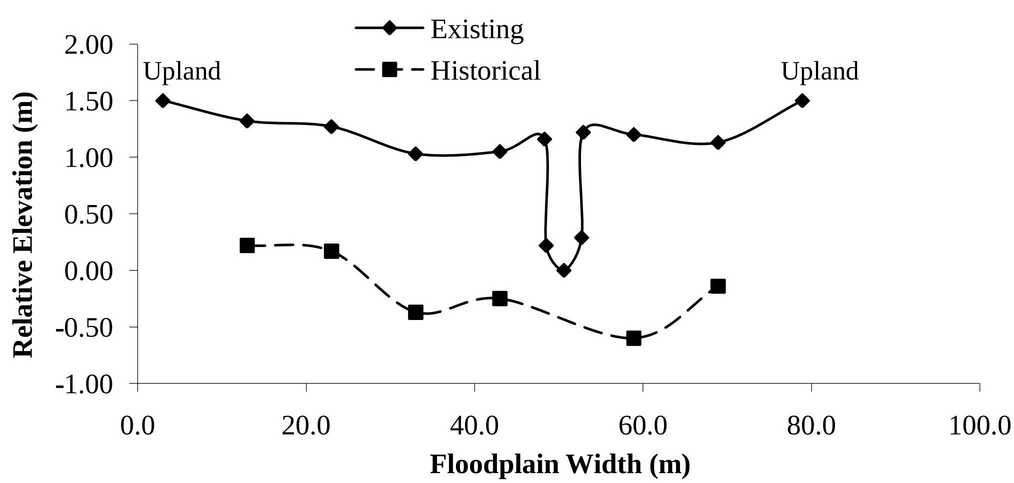
Appendix E: Schematic diagram of sampling transects and plots for soil core and dendrogeomorphic methodologies on the upper section of Sally Branch.



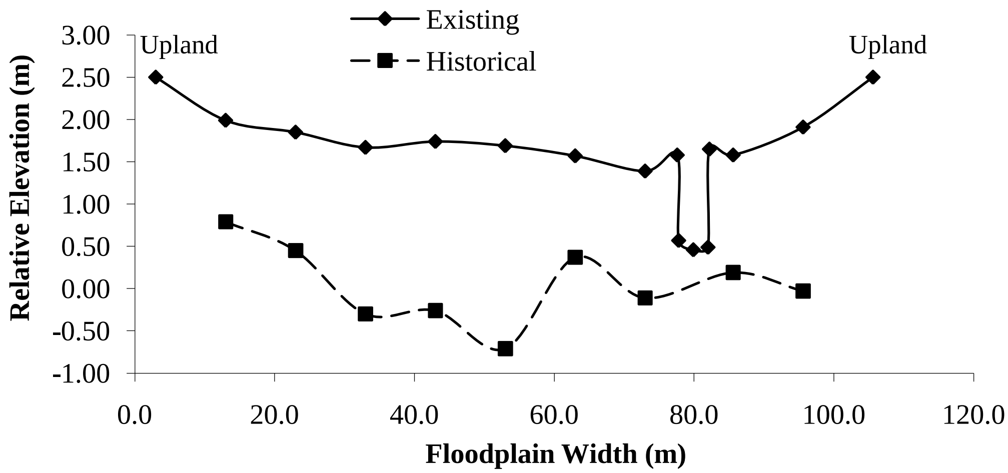
Appendix F: Cross sectional profile of transect 2 on the lower section of Bonham Creek along with the historical floodplain profile (dashed line).



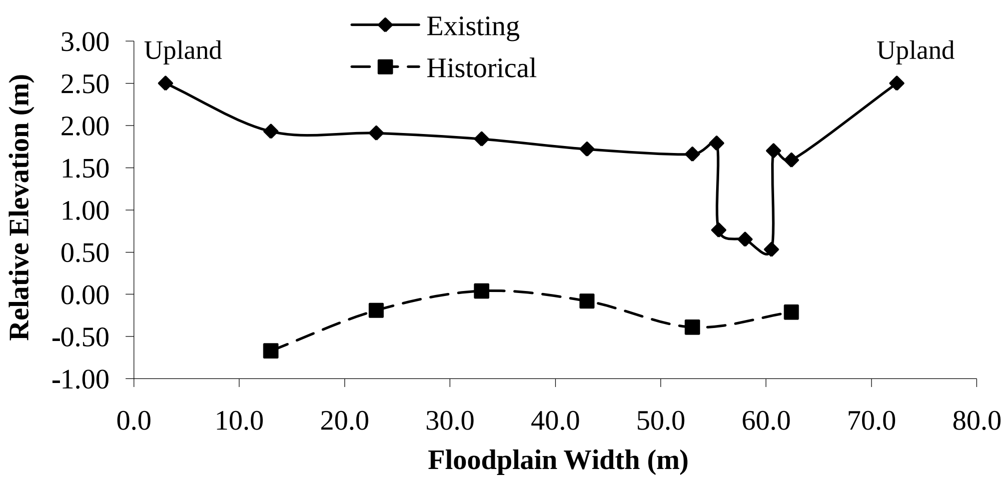
Appendix G: Cross sectional profile of transect 3 on the lower section of Bonham Creek along with the historical floodplain profile (dashed line).



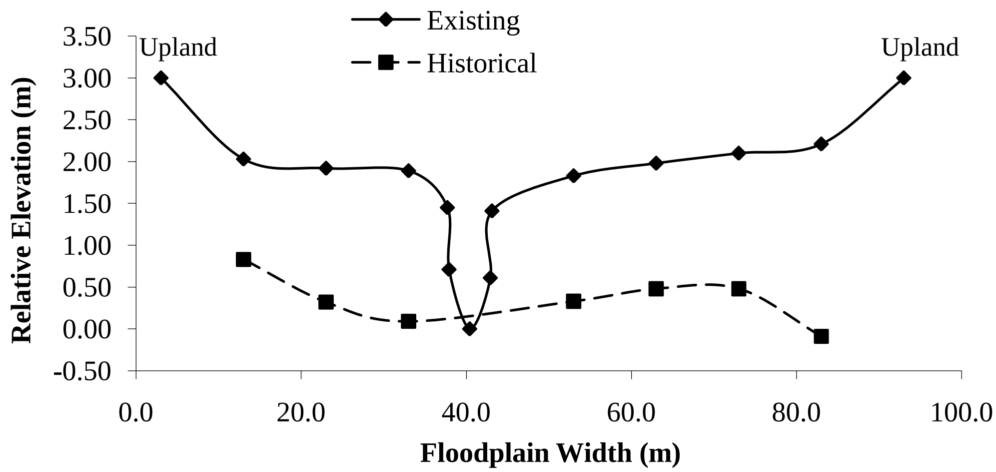
Appendix H: Cross sectional profile of transect 1 on the middle section of Bonham Creek along with the historical floodplain profile (dashed line).



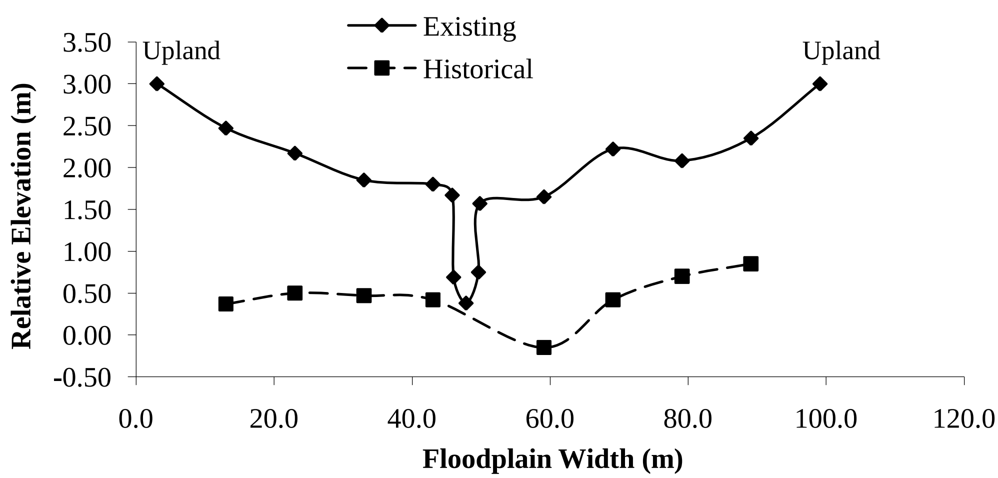
Appendix I: Cross sectional profile of transect 3 on the middle section of Bonham Creek along with the historical floodplain profile (dashed line).



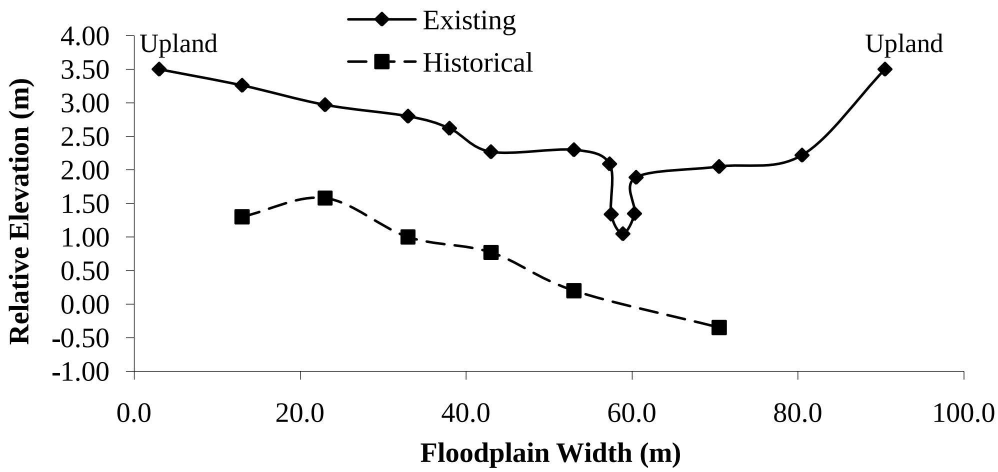
Appendix J: Cross sectional profile of transect 4 on the middle section of Bonham Creek along with the historical floodplain profile (dashed line).



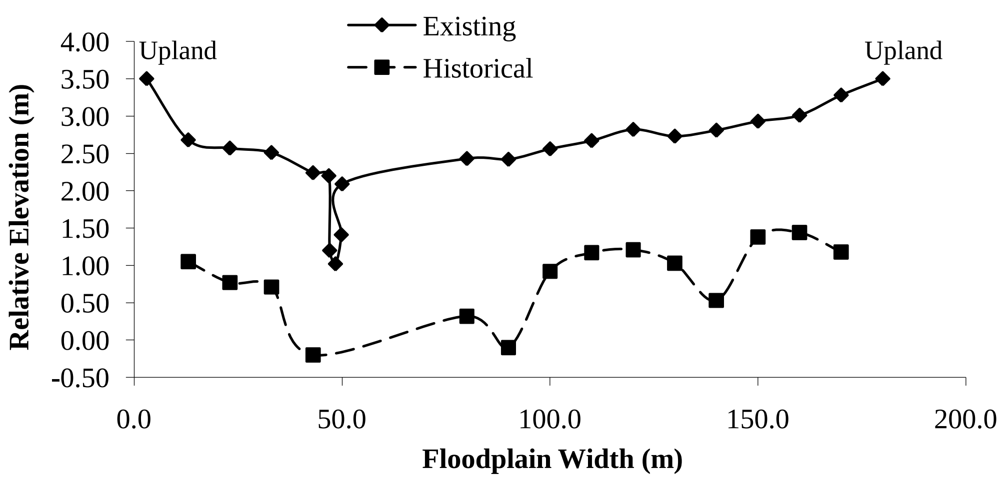
Appendix K: Cross sectional profile of transect 1 on the upper section of Bonham Creek along with the historical floodplain profile (dashed line).



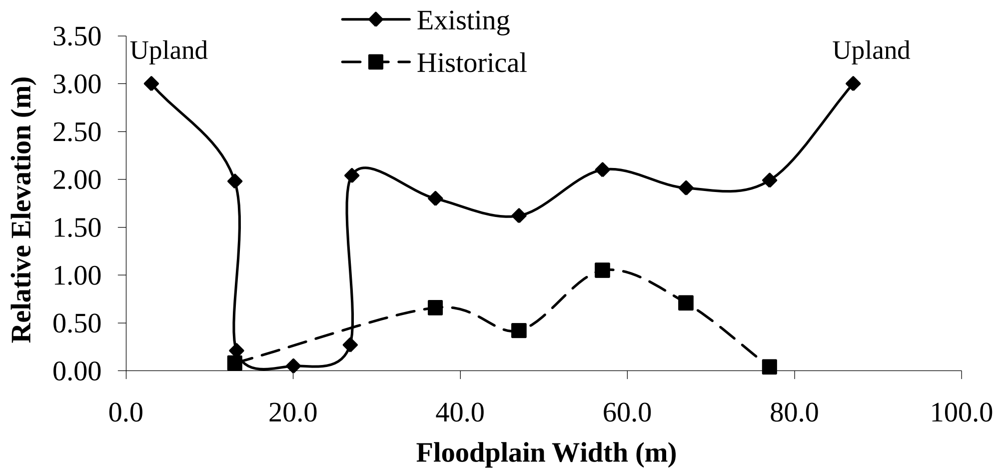
Appendix L: Cross sectional profile of transect 2 on the upper section of Bonham Creek along with the historical floodplain profile (dashed line).



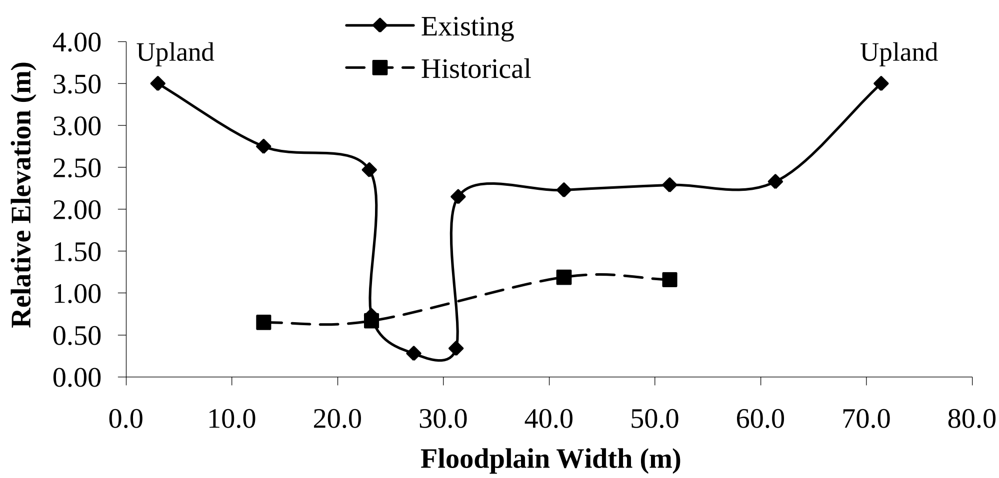
Appendix M: Cross sectional profile of transect 3 on the upper section of Bonham Creek along with the historical floodplain profile (dashed line).



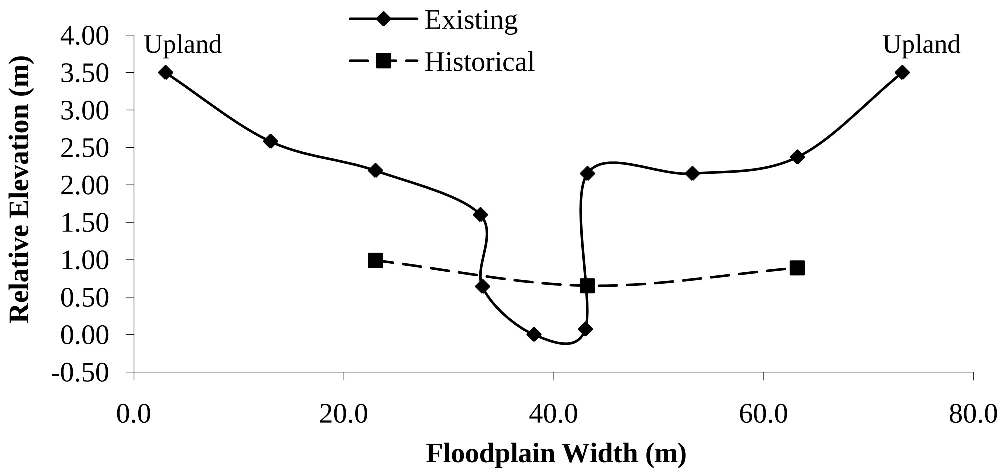
Appendix N: Cross sectional profile of transect 4 on the upper section of Bonham Creek along with the historical floodplain profile (dashed line).



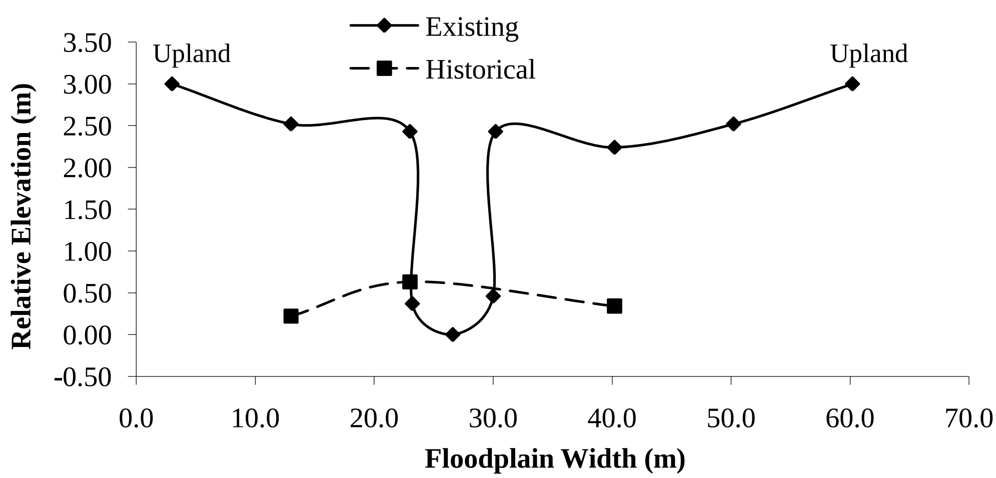
Appendix O: Cross sectional profile of transect 1 on the lower section of Sally Branch along with the historical floodplain profile (dashed line).



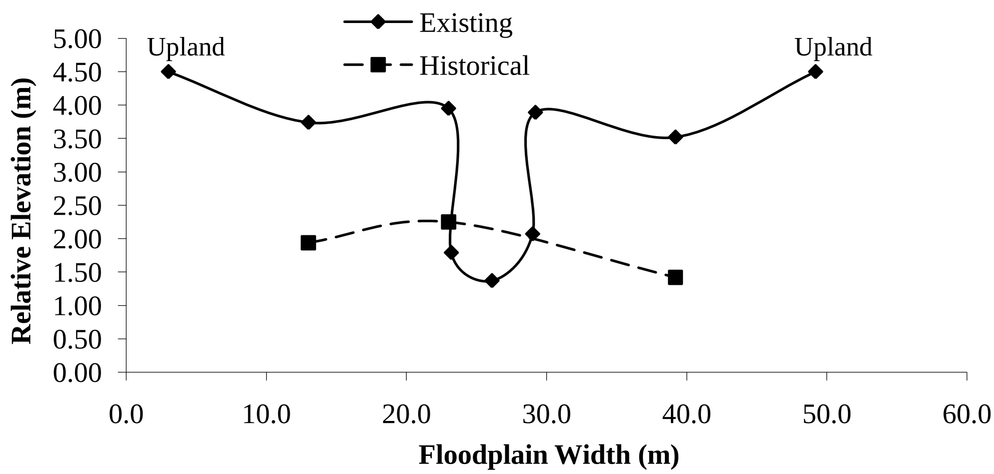
Appendix P: Cross sectional profile of transect 2 on the lower section of Sally Branch along with the historical floodplain profile (dashed line).



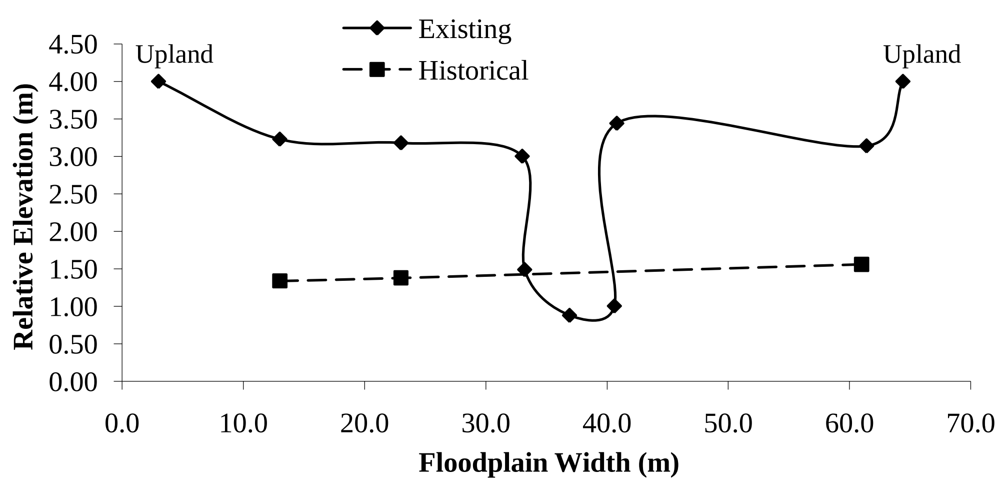
Appendix Q: Cross sectional profile of transect 4 on the lower section of Sally Branch along with the historical floodplain profile (dashed line).



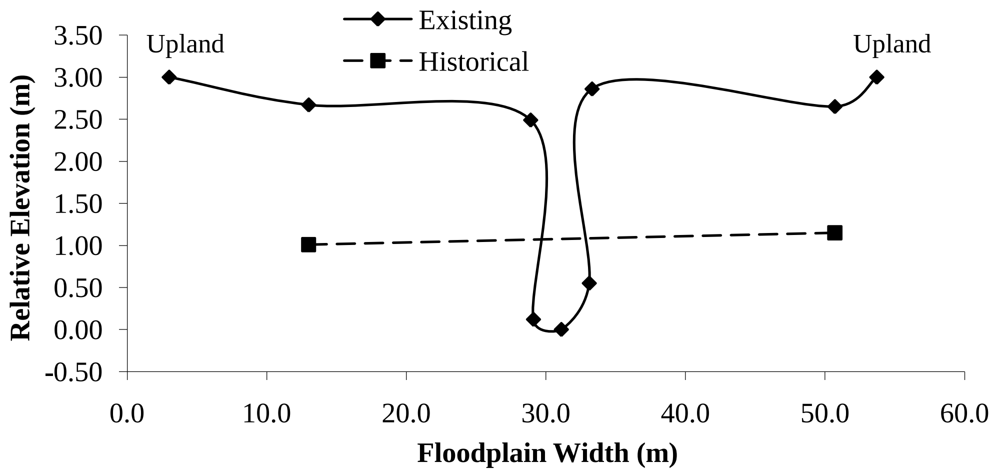
Appendix R: Cross sectional profile of transect 1 on the upper section of Sally Branch along with the historical floodplain profile (dashed line).



Appendix S: Cross sectional profile of transect 2 on the upper section of Sally Branch along with the historical floodplain profile (dashed line).



Appendix T: Cross sectional profile of transect 4 on the upper section of Sally Branch along with the historical floodplain profile (dashed line).



Appendix U: Cross sectional profile of transect 6 on the upper section of Sally Branch along with the historical floodplain profile (dashed line).