# GRAVEL SEDIMENT SOURCES AND BAR DISTRIBUTION WITHIN THE MAIN STEM OF UPPER BULL CREEK SOUTHWEST MISSOURI

A Masters Thesis
Presented to
The Graduate College of
Missouri State University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Natural and Applied Science

By
Kyle Kenneth Kosovich
December 2013

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## ABSTRACT

Public perception in the Ozarks is that gravel bar activity and related bank erosion problems have increased in Ozark streams during the past two decades. This thesis aims to investigate the historical trends in gravel bar deposition and remobilization in Bull Creek by: (1) Determining the spatial distribution and timing of gravel bars and channel disturbance zones; (2) Assessing spatial distribution and reach-scale dynamics of disturbance zones in the upper Bull Creek watershed; and (3) Evaluating the influence of past and present day sources of gravel supply including upland tributary inputs and the Chadwick Off-road Vehicle (ORV) area within Mark Twain National Forest. Historical aerial photographs in ArcGIS were analyzed to quantify bar area, channel planform, and gravel-filled tributary change over time. Key findings include: (1) Gravel bar activity is spatially persistent within disturbance reaches located at valley constrictions and valley bends along bedrock bluffs since 1941; (2) Active gravel bar area has decreased by almost half since 1979; (3) No relationship was found between ORV use and gravel bar activity in Bull Creek; (4) Present-day tributaries contain gravel bar areas that are similar to the 1940's and thus tributaries are probably supplying gravel to Bull Creek at relatively high rates in recent time; and (5) Gravel remobilization and transport rates may have increased recently due to the effect of increased flood magnitude and frequency during the past two decades as indicated by discharge gage records for the region. Complete recovery of disturbance zones in Ozark rivers is unlikely. However, knowing where disturbance reaches tend to form in Ozark rivers can help inform future management decisions.

**KEYWORDS:** spatial analysis, ozarks, gravel sediment, aerial photography, bull creek

This abstract is approved as to form and content

Dr. Robert Pavlowsky
Chairperson, Advisory Committee
Missouri State University

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# CHAPTER 1: INTRODUCTION

Human activities can influence river form and behavior to a greater degree than climate and geology factors at time-scales of interest to environmental managers (Wolman, 1978). Anthropogenic disturbances typically alter rates of sediment erosion, transport, and deposition in a river system and destabilize the equilibrium between water discharge and sediment supply (Graf, 1977). In general, anthropogenic disturbances compress the time-scale of geomorphic response that similar catastrophic natural events might have on a river system and increase the peak effect compared to natural disturbances (Simon and Rinaldi, 2006). Human activities have the capacity to alter the hydrologic and soil erosion characteristics of an entire watershed over a relatively short period of <50 years (Knox, 1977). Hence, changes in land use and management within a watershed can influence the spatial and temporal variability of geomorphic processes and channel form within river systems (Wolman, 1967; Knox, 1977).

Stream channels tend toward a steady state that fluctuate around an average condition of balanced sediment inputs and outputs and regularly display channel form that fluctuate around an average condition (Hack, 1960; Schumm and Lichy, 1965; Graf, 1977). However, changes in land use may alter the steady state of stream channels by increasing flood magnitude and frequency and upland sediment supply rates, which in turn produce geomorphic change (Knox, 1977; Boothe, 1990; Simon and Rinaldi, 2006; Kondolf et al., 2002). Land use changes such as riparian grazing, deforestation, agriculture, mining, roads, urbanization, and altered fire regimes are a few examples of direct and indirect land uses that affect the hydrologic response and geomorphology of mountain streams (Wohl, 2006). Decreases in the infiltration rate and resistance of the watershed surface can affect the sediment supply and transport rate within a river systems. For example, deforestation or the clearing of native vegetation for cropland results increases runoff and sediment yields to streams, and thus changes sediment dynamics, bed and bank stability, channel geometry, and aquatic and riparian habitat (Troendle and King, 1987; Nik, 1988; Luce and Black, 1999; Fransen et al., 2001; Wemple et al., 2001; Liébault et al., 2002). Riparian grazing and the reduction of riparian vegetation density can decrease bank stability and increase sediment delivery rates to channels, which in turn can result in channel aggradation and the development of a wide and shallow stream channel geometry (Kauffman and Krueger, 1984; Myers and Swanson, 1992; Kondolf, 1993; Trimble and Mendel, 1995; Magilligan and McDowell, 1997; Wohl, 2001).

Changes in the hydrologic network that increase the effective drainage density and flood frequency can also disturb channel morphology. In addition, transportation corridors like unpaved gravel roads can increase surface runoff and through-flow rates which increase mass movements, which in turn increase sediment yields and channel instability (Montgomery, 1994). Transportation corridors can also narrow flood plain area and constrict stream planform within narrowed valleys (Larsen and Parks, 1997; Lorch, 1998; Jones et al., 2000). Urbanization initially increases sediment yields to streams during the construction phase after which sediment yield is reduced with soil conservation practices (Paul and Myer, 2001). However, runoff rates from impervious surfaces produce larger flood peaks, which in turn result in bed and bank erosion, unstable channel planform geometry and degraded stream habitats (Wolman, 1967; Roberts, 1989; Trimble, 1997; Bledsoe and Watson, 2001; Chin and Gregory, 2001).

## Geomorphology and Disturbance of Ozark Channels

Human disturbance can increase the natural time-scale of change and impact the geomorphic stability. However, little is known about the connections between human activities and the variability of fluvial processes and forms in the Ozark Highland region. A better understanding of how land use impacts Ozark streams is needed (Splinter et al., 2011). This study examines the spatial distribution of historical channel changes in a small rural watershed in the Ozark Highlands of Missouri to evaluate the roles of human and natural factors in controlling gravel bar distribution since 1941. Previous work has focused on understanding the large-scale patterns of gravel sediment supply and relative bar occurrences due to historical land change (Jacobson, 1995; Jacobson and Gran, 1999; Jacobson, 2004). In addition, downstream changes in channel form have been examined in the Ozarks of Oklahoma (Splinter et al, 2010). Martin and Pavlowsky 2011 classified the types and spatial patterns in historical and recent disturbance reaches in an Ozark river. The present study will be the first to document reach-scale channel change since 1941 to evaluate specific questions about sources of excess gravel to the channel and the timing of channel disturbances.

The Ozark Highlands Physiographic Province is a rugged, dissected plateau region largely made up of Paleozoic limestone and dolomite with inter-bedded chert, sandstone and shale. Ozark rivers are characterized with gravel and bedrock channels that often flow along rock bluffs at the apex of meanders incised within the plateau (Sauer, 1920). Winding valley meanders may have high sinuosity yet stream channels have relatively low sinuosity and alternate between long straight and sinuous reaches that are termed stable and disturbance reaches (Jacobson and Pugh, 1995).

Human-induced land disturbance in the Ozarks includes substantial farming, grazing, and logging beginning in the mid-1800's. It is believed that the period of peak vegetation and soil disturbance occurred during the "timber boom" from 1880 to 1920 causing extensive gullying of headwater valleys and upland slopes (Jacobson and Pugh, 1997). This turn of the century land use impact may be responsible for the shallow and wide condition of some stream channels today (Saucier, 1987; Jacobson and Primm 1997). Ozarks residents recall losses of riparian farmland, shallow fishing/swimming holes, decreased fish habitat, and larger and taller gravel bars in streams in the early 1900's (Jacobson and Primm 1997). Yet, the role played by these past land disturbances in supplying excess gravel loads to present day Ozarks rivers on present geomorphology has only received limited attention by geomorphologists (Jacobson, 1995; Martin and Pavlowsky, 2011).

Channel instability and wide spread gravel bar deposition in Ozark rivers is still a major concern for environmental managers and landowners today. Conservation practices and reforestation has generally improved watershed conditions (Owen and Pavlowsky, 2011; Jacobson and Pugh, 1997). However high rates of gravel bar deposition and related bank erosion continue to be a problem (Martin and Pavlowksy, 2011). The increased sediment loads to the channels cause disturbances in channel planform that alternate between stable and disturbed reaches and can vary in overall length in a longitudinal direction downstream (Jacobson and Gran 1999, Martin and Pavlowsky, 2011).

However, there has not yet been a clear link found between land use and the pattern of stable and unstable reaches in the Ozarks (Jacobson, 1995). Disturbance reaches in Ozark streams have been classified based on geomorphic form and erosional/depositional processes in extension, translation, mega-bar, or cutoff types (Martin and Pavlowsky, 2011). Significant disturbance reaches adjust planform depending on where confining valley walls allow it and, while no significant trends in disturbance patterns was found, the largest area of gravel bar aggradation in the channel (mega-bar) tended to occur within several kilometers of larger laterally eroding channel bends (Martin and Pavlowsky, 2011). This suggests a link between gravel remobilization, floodplain storage, and downstream channel aggradation and bar deposition.

For Ozark rivers, what isn't as well known is how specific patterns of channels relate to the gravel sediment inputs and downstream channel change at the reach-and segment scale. Jacobson and Primm (1997) hypothesized that a major source of gravel was headward extension of channel networks due to a loss of riparian vegetation and cultivated crop areas on slopes that may have increased flood peaks and eroded gravel from first and second order valleys during a peak land disturbance between 1880 to 1920. Jacobson and Pugh (1997) hypothesized that it would take over 100 years for complete geomorphic recovery of the Little Piney Creek. Martin and Pavlowsky (2011) suggest that active bar zones are in balance with present sediment loads at the segment and watershed-scale. Studies investigating recent land disturbances that would affect gravel supply and channels patterns, on a more recent time scale, are as of yet unavailable for the Ozark streams.

In general, trail systems and unpaved all-terrain vehicle (ATV) road use negatively impact stream systems (Table 1). Increased road and trail densities fundamentally alter hydrologic and erosional processes in a drainage basin by increasing flood debris flows, modifying disturbance patches, and slowing the rates of recovery within disturbances areas (Jones et al., 2000; Montgomery, 1994). In some places, Ozark watersheds have recently been disturbed by off road vehicle use (Carden-Jensen, 1998). Recent land use impacts such as ATV trails have fueled landowner speculation that trails have introduced excess sediment into Bull Creek and degraded stream integrity (Carden-Jessen, 1998). The source of gravel to Bull Creek and the geomorphic effects of gravel bar deposition are unknown.

Table 1. ATV Trail Disturbance

| Location/Climate/ Soil Type | Environmental Result | Reference |
|---|---|---|
| | Erosion Rate | |
| Central California Gravelly sandy loam | 300-500 kg/m$^2$/yr | Webb et al., 1978 |
| San Francisco Bay/ Semi-Arid | 62 kg/m$^2$/yr | Wilshire et al., 1978 |
| Hungary Valley Calif/Semi-arid | 173kg/m$^2$/yr | Griggs and Walsh, 1981 |
| Forested Hillslope, Southeastern Ohio | 209 kg/m$^2$/yr | Sack, 2003 |
| | Land Impact | |
| Cape Cod National Seashore | Erosion, de-vegetation, wildlife disruption, emissions | Bleich, 1988 |
| Arid Regions | Increased wind water erosion, compaction, increased runoff | Dregne, 1983 |
| Montana | Alter drainage patterns, negative hydraulic functions | Joslin, 1999 |
| Southeastern Ohio, humid eastern region | Demonstrates erosion& compaction | Da Luz, 1999 |
| Forest Service Land | Sediment threatens stream ecol. | Wilkinson, 1999 |

## Purpose and Objectives

Bull Creek is a biological reference stream for the White River ecological drainage unit (Sarver et. al., 2002). Though Bull Creek is considered a good example of biological integrity and ecologically healthy, Woods Fork, a tributary of Bull Creek, was selected as an aquatic Conservation Opportunity (COA) area because it was predicted to contain five species of conservation concern: southern brook lamprey (Ichthyomyzon gagei), Williams’ crayfish (Orconectes williamsi), and three mussel species, Ouachita kidneyshell (Ptychobranchus occidentalis), Neosho mucket (Lampsilis rafinesqueana), and purple lilliput (Toxolasma lividus) (Nigh, 2005). When the Woods Fork COA biologic community was assessed by Culler (2010), the Index of Biotic Integrity (IBI) was classified as “highly impaired’ due to loose shifting gravel. Moreover, Beckman et al. (2002) classified the IBI in Bull Creek as whole being “moderately-impaired”. The IBI can allow scientists to measure condition, diagnose the type of stressors damaging aquatic biota, define management approaches to protect and restore biological condition, and evaluate performance of protection and restoration activities (EPA, 2012). Rapid Assessment of Missouri Streams Program (RAM) implemented by Missouri Department of Conservation (MDC), rated the IBI of Bull Creek as “not impaired” yet listed another tributary, Peckout Hollow, as “highly impaired” (Culler, 2010). Peckout Hollow contains the Chadwick ATV land use area in the Mark Twain National Forest and may provide a detrimental effect on the biologic integrity of Bull Creek, yet no geomorphic analysis of Bull Creek has been completed to evaluate impacts from gravel sediment that have been indicated elsewhere in the Ozarks. Moreover, local residents are concerned over recent gravel bar deposits and channel erosion that has occurred over the past 20 years.

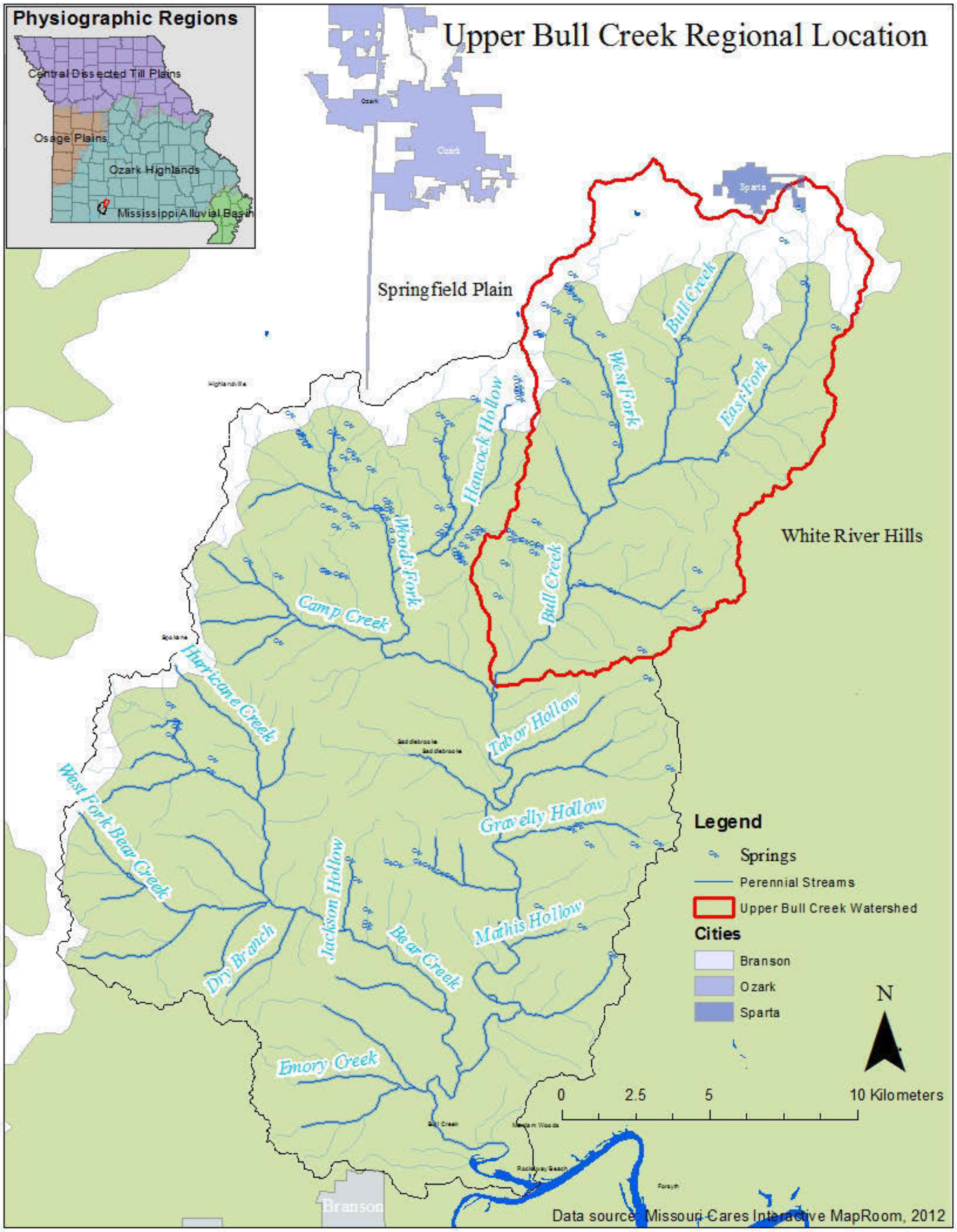
The purpose of this thesis is to address the questions of where and when gravel bar deposition has occurred in upper Bull Creek and determine the causes and sources of excess gravel sediment to the main stem. This thesis research will add to the knowledge base for geomorphic processes and disturbance in Ozark rivers and facilitate a better understanding of stream dynamics in this region. With better knowledge of Ozarks stream systems, management of freshwater resources will be improved by understanding how, when and where streams respond in a geomorphic manner to excess gravel loads derived from human induced land disturbances or natural sources. The specific objectives of this thesis are: (1) Determine the spatial distribution and timing of gravel bars and channel disturbance zones since 1941 based on the analysis of historical aerial photography; (2) Assess spatial distribution and the reach-scale dynamics of disturbance zones in the watershed and the geologic and land use factors that may cause them; and (3) Evaluate the present condition of Bull Creek in terms of past and present day differences in gravel supply and stream disturbance in relation to the Chadwick ATV area and other land use practices.

# CHAPTER 2: STUDY AREA

The Bull Creek watershed is located within the Ozarks Highlands physiographic region of Missouri and drains south from the Springfield Plain through the White River hills physiographic subsections, defined by Cozzens, (1939), and finally into the Taneycomo reservoir (Figure 1). The Bull Creek watershed is located south of the town of Sparta and drains 494 $km^2$ extending south where it flows into Tanycomo at Rockaway Beach 12 km above Powersite Dam. The focus of this study is on the upper Bull Creek sub watershed that drains 147 $km^2$ of largely rural land area. The headwaters of the study area watershed originate south of Sparta where Bull, East, and West Forks converge 9 km upstream from the Woods Fork just north of Saddlebrook, Missouri. These main 3rd order tributaries contribute to the 4th order, main stem of Bull Creek (Strahler ordering system) (Figure 2). Peckout Hollow joins Bull Creek half way between Woods and Bull Fork at 4.5 km.

## Topography and Geology

Bull Creek is known for its relatively steep topography. Early explorer Henry Schoolcraft described it as, “a hilly, sterile region, and which, from the similarity in the natural physiognomy of the hills, trees, soil, and brush is considered a dangerous place to get lost in” (Schoolcraft, 1821). The upper watershed ranges in elevation from 1443 m to 881 m at the confluence with Woods Fork (Figure 2). The watershed is underlain by Ordivician age sedimentary rock formations. Key rock formations include the oldest Cotter dolomite, a parent material of chert gravel and cobbles, while younger upper Reed Springs and Elsey formations contain interbedded chert at 40-60 percent (Dodd, 1985).



Data source: Missouri Cares Interactive MapRoom, 2012

Figure 1. Regional location of upper Bull Creek watershed.

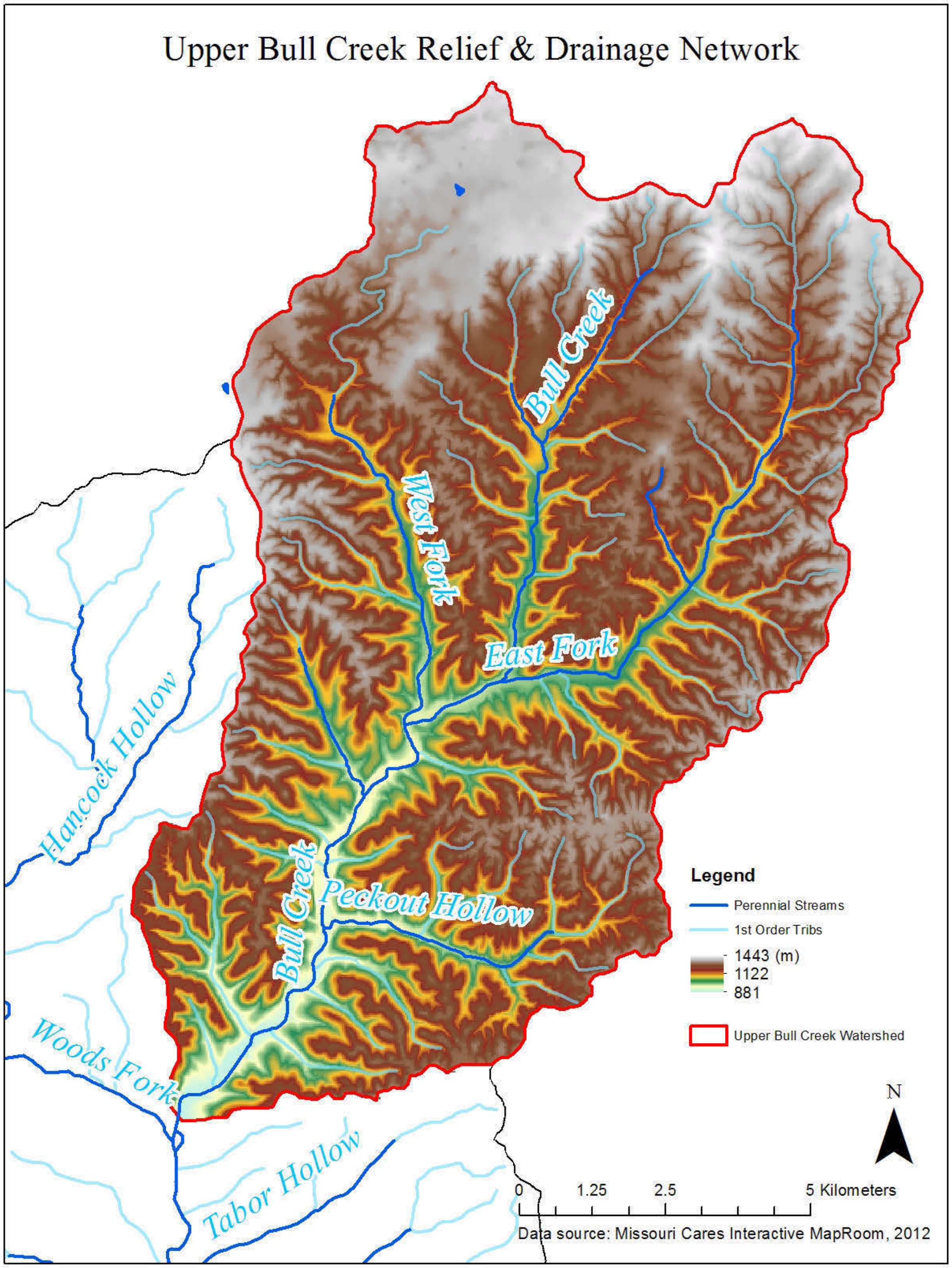


Figure 2. Topography of Bull Creek

## Soils

The USDA Soil Survey of Christian County describes soils of upper Bull Creek as originating from colluvium and residuum of cherty limestone, cherty dolomite and interbedded shale (Dodd, 1985). Run off rates for upland soils are moderate to very high, whereas soils formed on valley floors have greater permeability with less runoff potential (Table 2). Upland soils typically contain 20% to 60% chert gravel fragments with 10% to 35% of the chert fragments greater than three inches in diameter (cobble size) (Dodd, 1985). Therefore, soil erosion and upland gullying in areas by headward erosion of streams would be expected to supply relatively high loads of chert gravel sediment to the tributaries and main stem of Bull Creek.

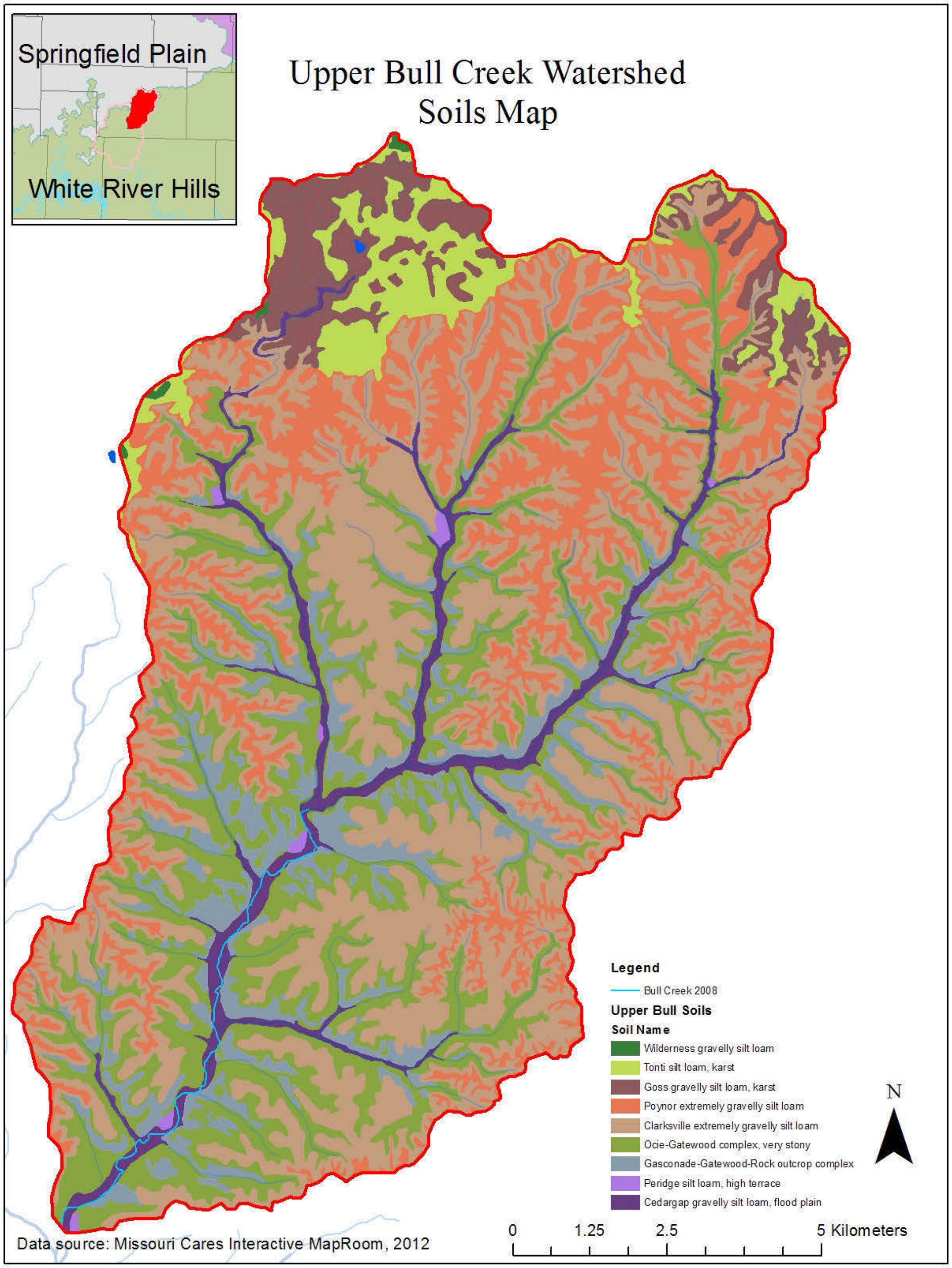
The distributions of soil series within the watershed generally follow topographic trends. Flat and gently rolling uplands of the watershed are underlain by the karst soils Wilderness, Tonti, and Goss silt loam series and contain cobbles and 15 to 80 percent chert fragments (Dodd, 1985). The majority karst features, including springs, caves, and loosing sections of stream are within the West Fork and Bull Fork drainages. Headwaters soils are mostly composed of the Poynor and Clarksvile series containing chert fragments from 40 to 75 percent (Dodd, 1985; Figure 3). Hillslope soils are composed of the Oci-Gatewood and Gasconade-Gatewood complex soils. These soils have steep slopes, rocky outcrops and, and are also very stony towards the surface with 10 to 60 percent gravel (Dodd, 1985; Figure 3). Valley floor soils consist of Peridge silt loam and Cedargap gravelly silt loam, composing high terraces and valley floor, respectively. Peridge soils are found on higher benches and older alluvial terraces with less than 8 percent slopes have very little gravel content, and are rarely to never flooded under present conditions

(Dodd, 1985). The Cedargap soils occur within the present floodplain and have slopes 0 to 5 percent and contain high gravel contents up to 65 percent with 10 percent being cobbles larger than 3 inches. These soils are typically flooded at least every 2 years. Therefore channel instability and bank erosion would remobilize material within the Cedargap series and to a lesser extent the Peridge series where the channel cuts into valley margin material.

Table 2. Soil Characteristics of upper Bull Creek Watershed

| Watershed Location | Soil Series | % Chert Fragments Upper-Mid-Lower horizons | % Chert Frag. >3in | Percent Slope | Surface Runoff Index | Depth to Bedrock (m) |
|---|---|---|---|---|---|---|
| Uplands | 1)Wilderness, gravelly silt loam | 20-55-80% | 10-40% | 2-9% | High to very high | >2.2 |
| | 2) Tonti, silt loam, karst | 15-30-50% | 5-35% | 1-12% | Medium to high | >2.2 |
| | 3) Goss, gravelly silt loam, karst | 15-60-25% | 5-35% | 1-70% | Low to high | >1.5 |
| Headwaters | 1) Poynor, extremely gravelly | 40-75-60% | 5-30% | 1-60% | Low to high | >2.2 |
| | 2) Clarksville extremely gravely silt loam | 40-60-75% | 5-20% | 1-70% | Medium to very high | >2.2 |
| HillSlopes | 1) Oce-Gatewood, very stony | 60-10-30% | 10-30% | 9-65% | Medium to very high | 0.3-1.2 |
| | 2) Gasconade Gatewood, rock outcrop | 60-10-35 | 10-30% | 9-65% | Medium to very high | <1 |
| Valley Floor | 1) Peridge, silt loam | 5-5-1% | 0% | 2-5% | Low to high | >3 |
| | 2) Cedargap, gravelly silt loam | 5-85-60% | 10% | 0-3% | Negligible to low | >1.5 |

Source: Soil Survey of Christian County, Missouri. USDA (Dodd, 1985).


Upper Bull Creek Watershed
Soils Map

Data source: Missouri Cares Interactive MapRoom, 2012

Figure 3. Upper Bull Creek Soils

## Precipitation

While presently in a wet period, the state of Missouri has a highly variable climate with varying lengths of wet and dry periods (Figure 4). Ozark, Missouri has a 65-year record with a mean annual precipitation of 100 cm a year (Figure 5). The maximum annual precipitation recorded is 154 cm in 1993 whereas the minimum record was approximately 44 cm in 1948. (University of Missouri Climate Center, 2012). Within the Bull Creek 17-year discharge record, the recent high peak in 2008 state and local precipitation data can be observed also within the Bull Creek mean annual and maximum annual discharge (Figure 6).

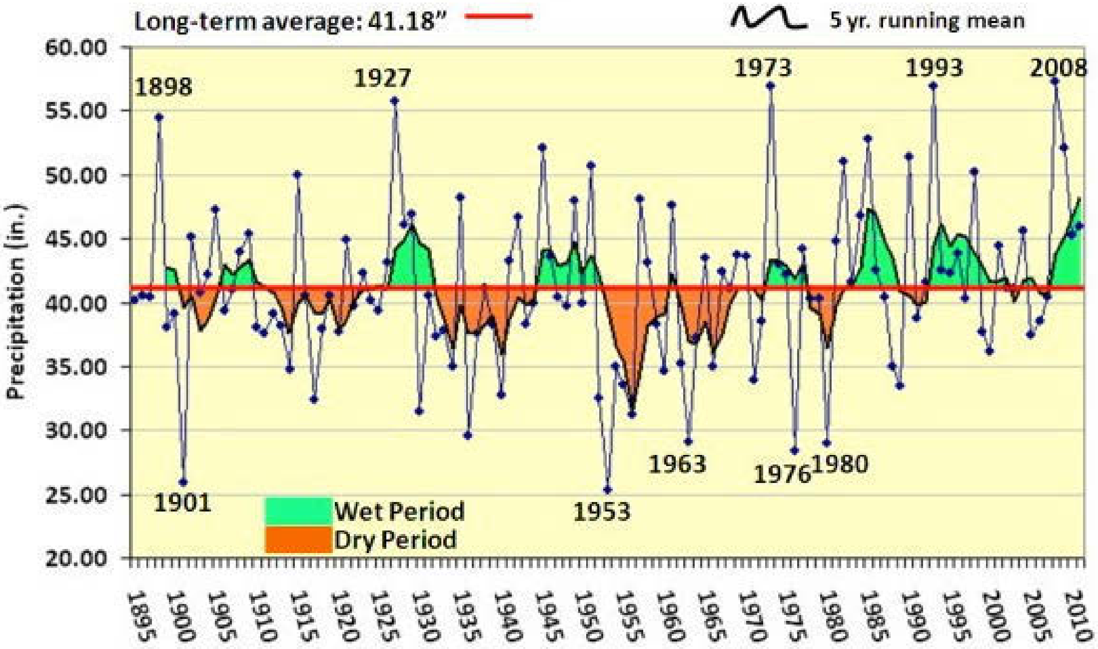


Figure 4. Missouri Annual Average Precipitation (1895-2011). Source: University of Missouri Climate Center, 2011

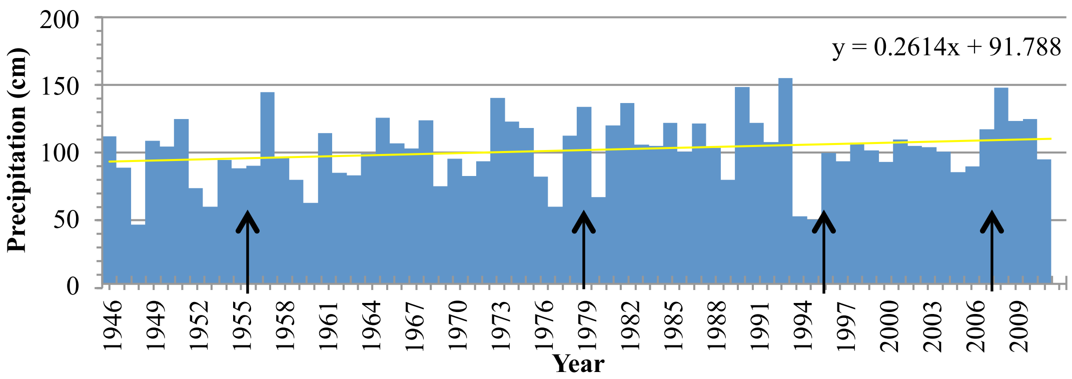
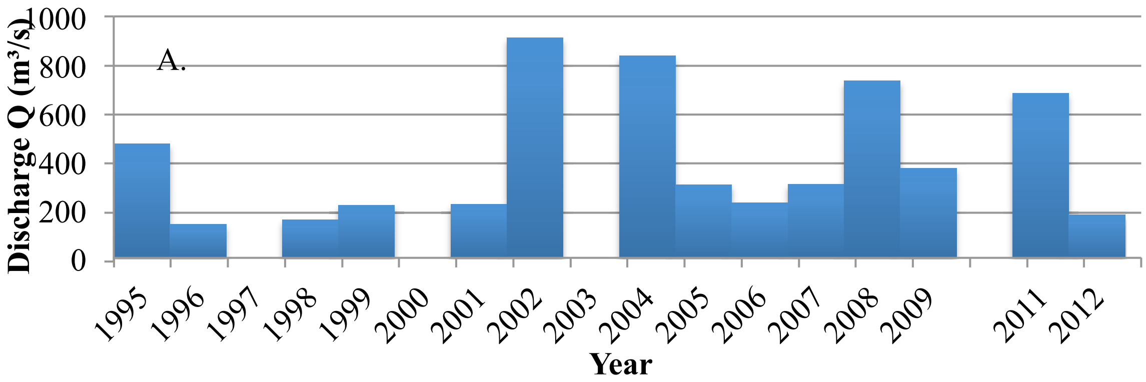


Figure 5. Annual precipitation record Ozark, Missouri (1946-2012). Arrows = Date of aerial photographs in this study. Data Source: Western Regional Climate Center, 2012



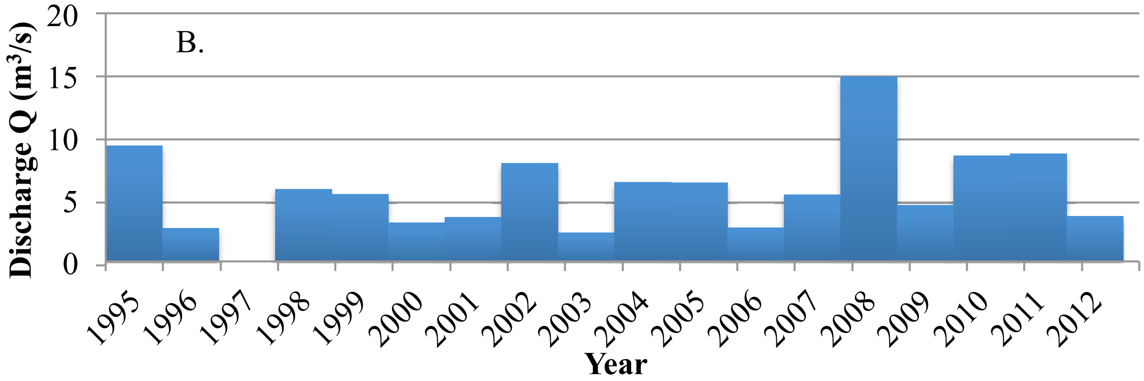


Figure 6. Bull Creek Discharge (1994-2008) at gage 07053810 Walnut Shade, Mo. A. Max Annual Flood. B- Mean Annual Discharge (USGS Water Watch, 2011).

## Land Use

Land cover in 2005 in the upper Bull Creek watershed was 68% forest, 30% grassland, only 1% of land use is urban impervious, and 1% water (Figure 6). Little growth or land use change has occurred since 2005. Pasture and grazing lands are generally located on the headwater uplands of the three main tributaries. US government land ownership by Mark Twain National Forest (MTNF) is 31 km² or ~20% of the watershed. The Chadwick ATV Area is located within the national forest in the study area with 128 kilometers of ATV and motorcycle trails (Forest Service, 2012).

## Main Stem Study Reach

Within the upper Bull Creek watershed the main focus of this research will be on the 9 km segment of stream channel and floodplain located between the Woods Fork confluence at the south and below the confluence of the East Fork of Bull Creek. This reach will be referred to as the “main stem” in this study (Figure 7). Peckout Hollow is the main tributary draining the MTNF ATV Area and enters the main stem segment in the middle of the study area. This conveniently allows the division of the main stem into above “upper” and below “lower” Peckout Hollow segments in order to evaluate potential ATV influence on channel morphology. Though there are small tributaries that enter the upper segment, Peckout Hollow is the largest tributary entering the main stem from the ATV Area and has been identified with excessive gravel and poor biotic integrity (Carden-Jessen, 1998; Culler, 2010).

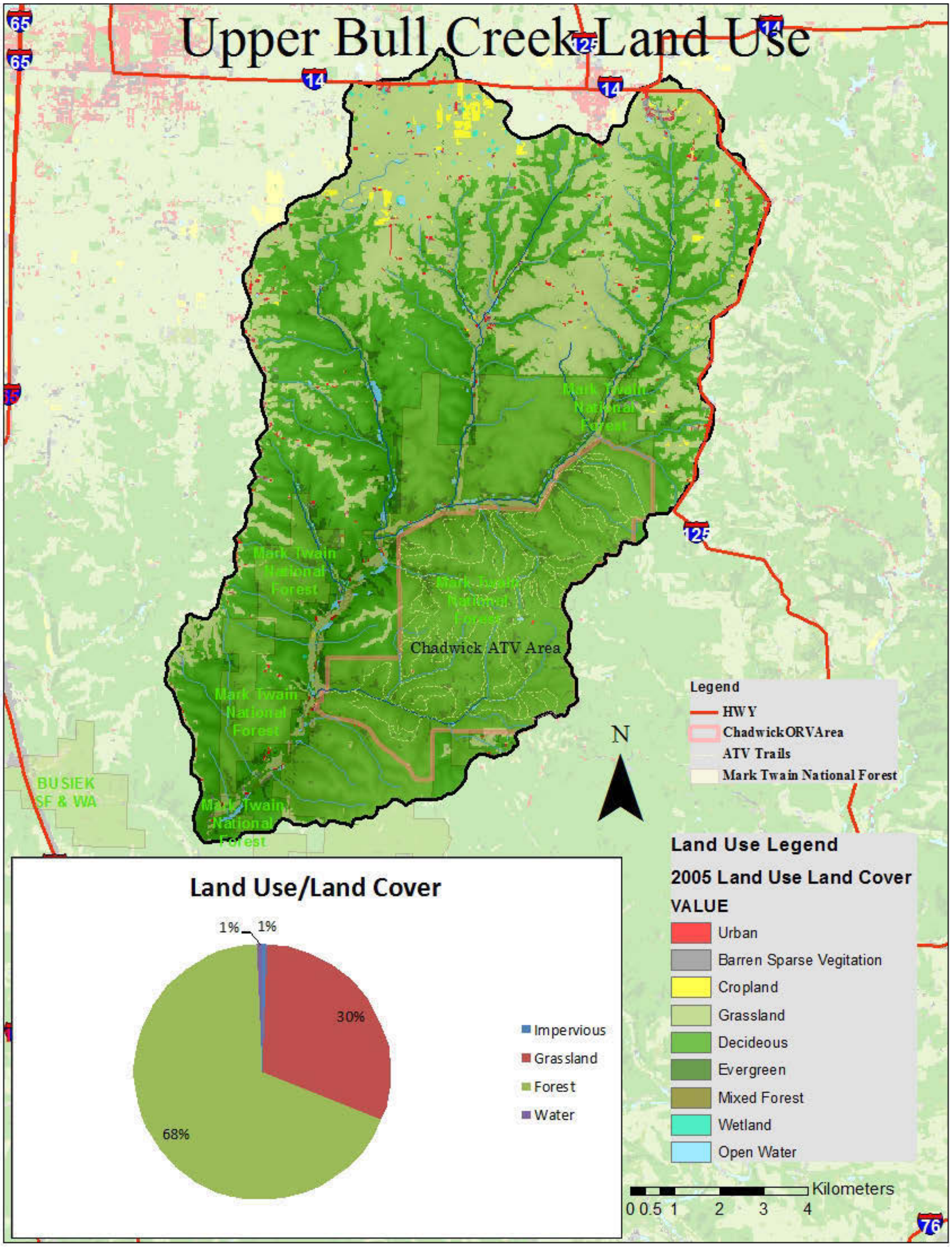


Figure 7. Land use/land cover for upper Bull Creek watershed (University of Missouri CARES Interactive Map Room).

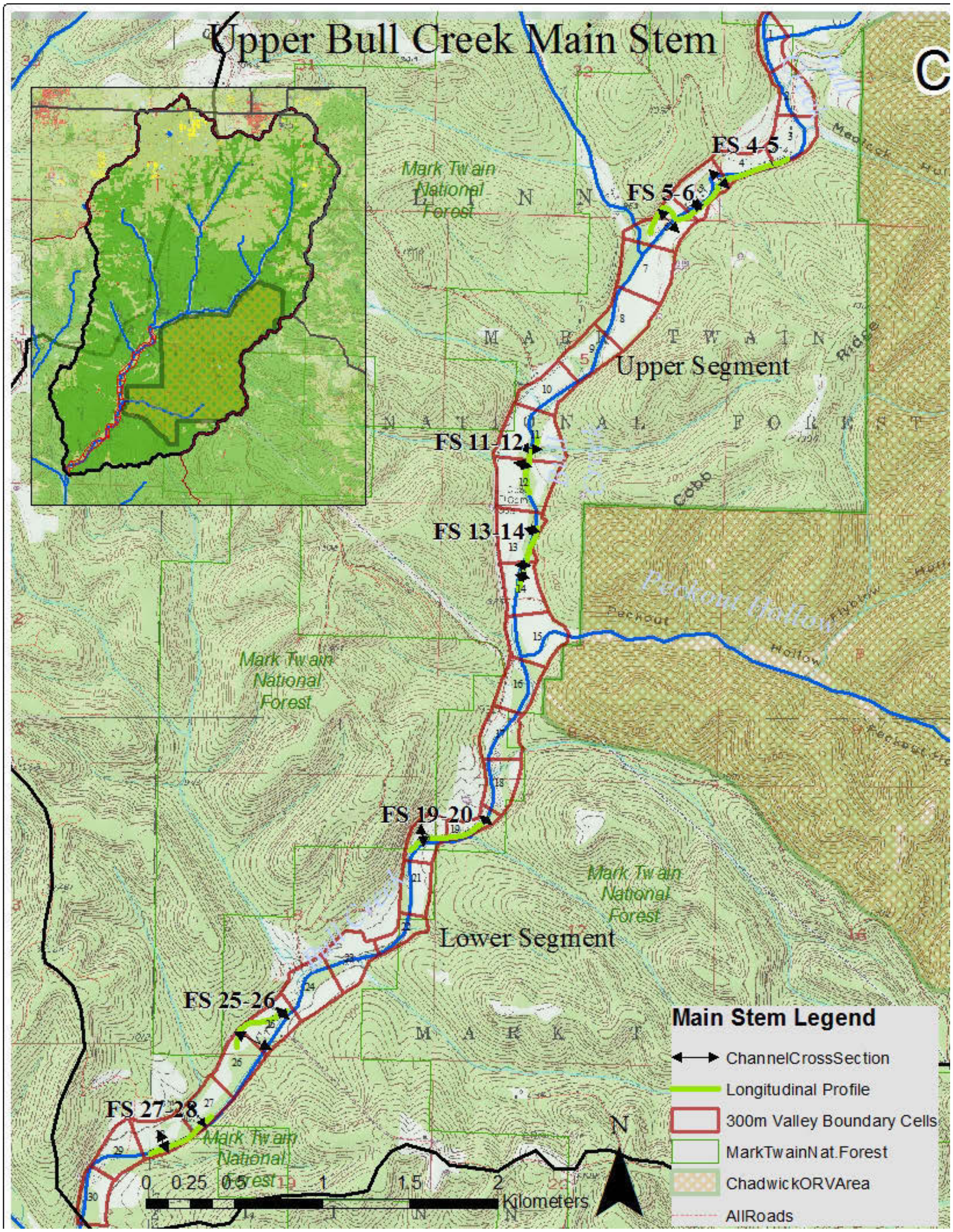


Figure 8. Main stem study site locations. Divided into upper and lower segments at Peckout Hollow. Segments divided into 300 meter cells with 7 field sites selected.

# CHAPTER 3: METHODS

Arc GIS analysis of historical aerial photography was utilized to monitor bar and channel change since 1941within the main stem of upper Bull Creek. Digitized aerial photographs were used to create data sets that quantify bar area, channel plan form, and gravel-filled tributary change over time. Ground-truthing of tributary channel and gravel bar occurrences was compared with the aerial photograph record. In addition, fieldwork to determine channel morphology and substrate condition was compared to understand planform change observed in the historical photograph record.

## Historical Aerial Photograph Record

Gravel bar and channel location data were obtained by digitizing features within aerial photographs from the years 1941, 1955, 1979, 1996 and 2008. Photographs were acquired from the Missouri State University Meyer Library and downloaded from Missouri Spatial Data Information Service (MSDIS) and Google Earth. Hard copy aerial photographs from 1941, 1955, and 1979 were checked out from the MSU library and scanned at 600 dpi to maintain the best resolution (Martin and Pavlowsky, 2011). Images were scanned into a .jpeg format and georeferenced with ArcGIS®'s georeferencing utility with six to eight ground control points (GCPs) (Huges et al., 2006). Photographs from 1996 were downloaded from Google Earth in a .jpeg format at an eye elevation between 4000-5000 feet and exported at 1044 x 869 pixels.

All aerial photographs were georeferenced and rectified to the base 2008 image that was acquired from MSDIS (Table 3). Ground control points were located in each aerial photograph and were geospatially rectified. Accurate points such as roads and building were used when available, yet in early photographs the watershed was very rural and few suitable GCP's could be found during georeferencing process, in which case the use of tree lines, ponds, and vegetation clearings were used as GCP's. Points were located as near to the digitization features as possible and error within the image rectification was determined by a point-to-point method (Table 3) (Urban and Rhoads, 2003; Hughes et al., 2006)

Vegetation, photo quality/resolution, and water levels all can alter the observed gravel bar area, channel digitization, and tributary gravel recognition in aerial photos. Early photos from 1941 and 1955 were taken during "leaf on" conditions, while the remaining photos were all taken in winter or "leaf off" conditions (Table 2). Photograph quality was rated qualitatively from best to fair, with the best being the base image of 2008. This photograph was in color and had a 2 ft. resolution with bar and channel features very easily distinguished and traced at 1:1000 scale. The good condition photographs consisted of the 1941 and 1955 sets. These photographs had features that were easily distinguished yet needed a slightly smaller scale (1:1500) for recognizing features. The fair quality photographs for years 1979 and 1996 were more pixelated. This made distinguishing features more difficult, thus zooming out and using a smaller scale at 1:2000 for digitization was used (Table 3).

Table 3. Historical Aerial Photograph Attributes

| Date of Aerial Photo | Number of Photos | Point-to Point Mean Rectification Error | Tree Leaf Cover | Photo Resolution or Scale | Photo Quality | Source |
|---|---|---|---|---|---|---|
| 7/6/1941 | 3 | 12 m | On | 1:20,000 | Good | Library |
| 9/1/1955 | 2 | 10 m | On | 1:20,000 | Good | Library |
| 12/2/1979 | 1 | 12 m | Off | 1:40,000 | Fair | Library |
| 3/31/1996 | 8 | 6 m | Off | 1044x869 | Fair | Google |
| 2/17/2008 | 1 | Base image | Off | 2 ft | Best | MSDIS |

**Feature Digitization**

Historical aerial photography analysis with GIS is a valuable tool to monitor spatiotemporal patterns in river systems (Eidse, 2005; Marcus et al. 2003; Jacobson and Pugh, 1995; Legleiter, 1999). Digitization is the process of converting hardcopy images and/or features into digital format to be viewed and analyzed with GIS. In this project the features within each year of aerial photographs included: (1) gravel bar shape and area, (2) stream channel centerline, (3) tributary gravel occurrence, and (4) riparian vegetation area. Tracing these features enables the comparison of polygon areas and line length/position to analyze the differences between different years of gravel bar area and channel movement in historical aerial photographs.

**Channel Centerline**. Due to the narrow channel of Bull Creek, the channel centerline was digitized as a single centerline approximated by hand. Martin and Pavlowsky (2011) utilized wetted channel perimeter and collapsed the two bank lines forming one final channel centerline to track planform changes over time. Yet in this project, stream discharge displayed in photographs as wetted channel nearly the width of the digitizing line width. The channel was observed as the darker line between the lighter gravel bars and along bluffs. In the older photographs the channel was difficult to see due to tree cover, shadows, or poor image resolution. Where the channel was difficult to discern, the last location and the next location seen in the photograph was used to connect a final channel line. The estimation of channel location was used on about 10% of total channel length. The wetted channel sometimes also appeared to "lose" all flow into gravel deposits within the channel (Figure 9). For further analysis in locations of channel planform movement over time, the channel centerlines were combined into a historic active channel belt (HCB) polygon or the area between all historical channel locations.

**Gravel Bars.** Within Ozarks streams, gravel consists largely of bed material composed of light-colored chert fragments originating from weathered parent limestone rock and released to the stream by residual soil erosion. In aerial photographs, gravel bar surfaces typically had very high reflectance and were easily identified in contrast to the dark riparian vegetation. Gravel bars without vegetation or only very sparse small trees were digitized as single polygons. Gravel bars that had numerous larger trees but still displayed gravel in between were traced as multiple polygons with trees being excluded from the bar area to avoid classification of floodplains as channel bars. Thus stabilized and re-vegetated bar surfaces were not included as "bar area".

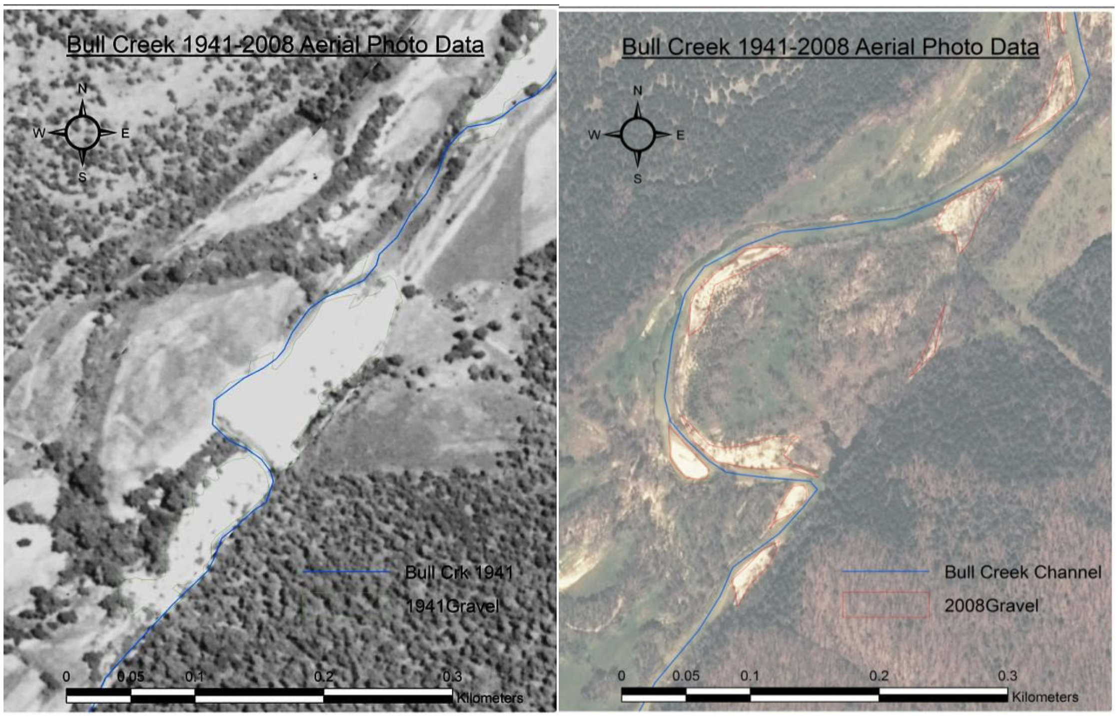


Figure 9. Aerial Photos (1941-2008) digitized gravel bars and channel shown

**Tributary Gravel**. Occurrences of gravel within the tributaries of Bull Creek were digitized as a single line indicating presence in small tributaries or a polygon indicating area in larger tributaries. This was conducted by tracing tributary gravel area where channels displayed wide bright graveled channels between forest cover and lines within the very narrow channels within the woods and fields (Figure 10). Tributary channel gravel was digitized for only 1941 and 2008 aerial photographs.

Tributary gravel identification was sometimes limited due to aerial photography quality and vegetation cover levels and therefore ground truthing was needed to confirm that GIS tributary assessment was accurate. Tributaries with positive aerial photograph gravel signatures and tributaries without visible gravel identification were visited to verify the aerial photograph assessment and confirmed accurate identification.

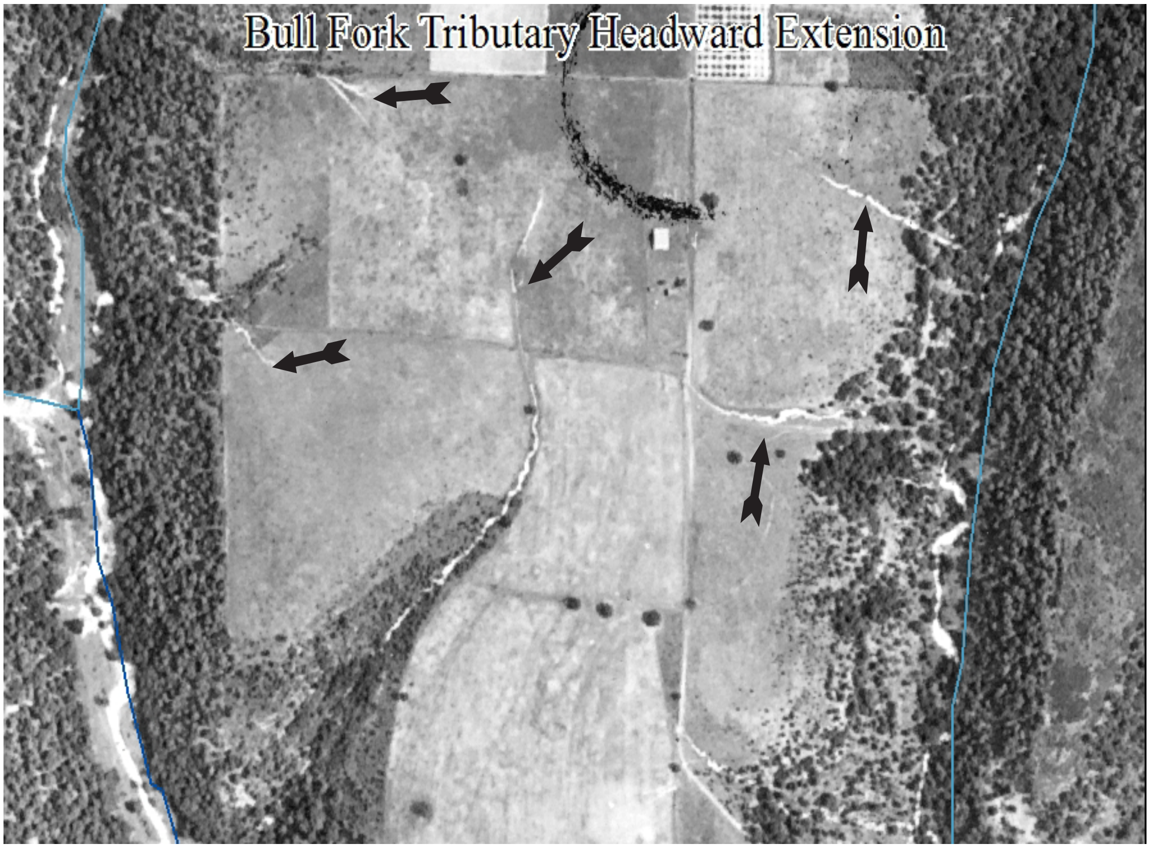


Figure 10. Tributary extensions. Appear as light-colored gravel tributaries in upland fields of Bull Fork.

**Tree-Covered Riparian Area.** Tree-covered riparian areas were digitized within each valley cell. Riparian area was identified as the darkest areas within the aerial photographs and did not include the lighter grassland cover. All riparian areas identified within valley cell boundaries were traced and created into polygon features. Small-vegetated areas or large individual trees within gravel bar areas were digitized into individual polygons for analysis. Digitized aerial photographs for 1941 (leaf on) and 2010 (leaf on) were included in the riparian analysis. Agriculture, residential, and urban lands without trees are not included in the polygons.

## Stream Discharge Correction

Photograph years had an increasing base flow discharge during fly over dates, with the highest in 2008 (Table 4). Higher discharge for a specific photograph could result in greater wetted-channel widths and smaller bar width measurements, even if actual bar width remained constant between the two years. To correct for the influence of varying channel discharge a width-to-area correction factor was used. The gravel bar area measurements for a given year were adjusted for by using a different discharge correction factor for each of the two study segments, with one upstream and one downstream of Peckout Hollow. This correction value was calculated by taking a wetted width measurement at each valley cell for each year. Then dividing the mean wetted width of 1941 main stem by each following year's mean wetted width, thus resulting in a yearly correction factor for the upper and lower segments. This method assumes that differences in wetted-width at the segment-scale are directly proportional to channel hydrology and discharge variability. The corrected wetted-width value was subtracted from the measured active channel width to determine the adjusted bar width.

Bull Creek does not have a discharge record to match the time span of aerial photographs used, so it was necessary to utilize other nearby stream gages as a reference to what discharge level Bull Creek was at during the time of each photograph (Table 4). The James River USGS stream gage at Galena, Missouri and Bryant Creek gage at Tecumseh, Missouri are the two gages nearest to Bull Creek with sufficient data records and therefore were used to understand local water levels and climate interactions within Bull Creek aerial photographs.

Table 4. Ozark Stream Hydrology and Bull Creek Correction Factors

A. Photography Day Discharge

| Gage (name-number) | Period of Record | Specific Q (liters/second/km$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | *10% | Mean Annual | *50 % | *90 % | Max Flood |
| James River at Galena 7052500 | 1921-current | 24.3 | 11.1 | 4.7 | 1.3 | 943 |
| James River at Springfield 07050700 | 1955-current | 22.1 | 10.6 | 3.2 | 0.5 | 1,827 |
| Bryant Creek at Tecumseh 0705800 | 1944-current | 19.4 | 10.0 | 5.1 | 2.7 | 1,362 |
| Beaver Creek at Bradleyville 07054080 | 1994-current | 21.3 | 10.3 | 3.6 | 1.1 | 1,337 |
| Bull Creek at Walnut Shade-07053810 | 1994-current | 25.6 | 12.8 | 3.4 | 0.3 | 1,485 |

***Flow Exceedence Variability**

B. Flow Exceedance Table

| Gage (name-number) | Drainage Area km$^2$ | Specific Q (liters/second/km$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | 1941 | 1955 | 1979 | 1996 | 2008 |
| James River at Galena 7052500 | 637 | 1.7 | 0.8 | 3.6 | 33 | 423.8 |
| James River at Springfield 07050700 | 2,556 | | | 2.1 | 9.9 | 176 |
| Bryant Creek at Tecumseh 0705800 | 1,476 | | 2.2 | 5.6 | 22.6 | 79.9 |
| Beaver Creek at Bradleyville 07054080 | 771 | | | | 30.2 | 261.5 |
| Bull Creek at Walnut Shade-07053810 | 494 | | | | 16 | 555.9 |

C. Correction Factor

| Wetted Width | 1941 | 1955 | 1979 | 1996 | 2008 |
|---|---|---|---|---|---|
| Main stem | 1 | 1.05 | 1.27 | 1.64 | 1.83 |
| Upper segment | 1 | 1.04 | 1.28 | 1.55 | 1.80 |
| Lower segment | 1 | 1.05 | 1.33 | 1.69 | 1.84 |

## Temporal and Spatial Analysis

**Valley Cell Delineation.** To classify the patterns of gravel bar deposition, channel planform changes and riparian area changes in each valley-cell quadrat analysis were evaluated. The main stem of Bull Creek was divided into 300 m valley-cells by collapsing the valley wall lines to a valley centerline. Valley wall lines originated from the alluvial soils map obtained through the University of Missouri CARES Map Room website. An objective fixed cell size is important to the quadrat count method of analyzing patterns in events (O'Sullivan and Unwin, 2009). Therefore, the valley wall centerline that was less sinuous than the channel centerline and therefore was used to form valley cell boundaries. Dividing the valley perpendicularly to the valley wall at 300 m intervals created valley cells. Valley cells were then numbered with ARC tool "identity" to allow the export the digitized gravel bar area present in each cell.

**Hot Spot Analysis (HSA)**. In order to quantify the specific pattern of historical planform changes, the spatial statistics tool kit in ArcGIS®10 was used in identifying statistically significant "hot /cold spots" of yearly gravel bar areas. In other words, an area along the main stem where gravel bars deposit consistently in the same location year after year are labeled as a "hot-spot", other locations where gravel bars deposit are more randomly dispersed are labeled "cold-spots". A low p-value and a high z-score indicate areas of large-area gravel bar clusters, and the high p-value and low z-score indicate areas of small-area gravel bars clustered. A z-score near zero indicates that there is no apparent spatial clustering while the higher or lower the z-score the more significant the clustering. In summary, this tool highlights the locations where gravel bars of similar size occur over time (ArcGIS10, 2013).

Ozark streams have been previously classified into disturbance and stable reaches by observing channel planform changes and gravel bar area (Jacobson, 1995; Jacobson and Primm, 1994; Martin and Pavlowsky, 2011). Point pattern analyses such as Hot Spot Analysis (HSA) in ArcGIS have not been used in classifying Ozark stream channels and therefore this is a new method in stream classification to be applied here. Point pattern analysis method such as HSA was chosen to describe the gravel bar area distribution patterns that would possibly locate disturbance and stable reaches along Bull Creek based on the clusters of gravel bar areas in the same location.

**Geospatial Measurement Error.** Geospatial errors can alter results of area and position. Error in area between 0%-10% can be associated with tilt and terrain and not scale of photographs or the size of polygons (Bolstad, 1992). Errors of less than ±5 m were found when using at least 8 GCP's near areas of interest (Huges, 2006). A point-to-point error (6 m - 12 m) was found within the upper Bull Creek aerial photographs. This can be attributed to old photographs with a lack of both quality and the total quantity of GCP's during the image rectification and digitizing processes. Image quality in the photographs was adequate in all years with 1979 being least quality and potentially the most difficult group of photographs in identifying features during digitization and location of GCP's.

Errors within gravel bar area digitized from aerial photographs can also be affected by water levels and from riparian vegetation during leaf-on photographs. Increased discharge during the photograph series could factor for decreased bar area in most recent years, yet this was adjusted for with a correction factor calculated with wetted width increases observed in aerial photographs. Additionally, only photographs from 1941 and 1955 were taken during leaf-on conditions, potentially decreasing bar area and gravel tributary length, yet they are nearly the highest years for total bar area within the time studied.

**Geomorphic Measurement Definitions.** During project mapping and fieldwork several geomorphic form variables were assessed to indicate the spatial and temporal variability of sediment inputs and channel disturbance in Bull Creek.

“Bedrock channels” are those that contained a dominant bottom substrate of bedrock and were designated as bedrock reaches in Bull Creek. These reaches are important to note due to the resistance of channel change offered by this resistant boundary material (Knighton, 1998). In this study bedrock reaches were identified by field site observations.

“Terraces” were remotely located Using USGS 7.5 minute topographic maps in ArcGIS10, terraces were located by tracing contour lines and verified during fieldwork observations. Terraces include both fill and strath terraces that indicate position of older floodplains, presently not affected by flooding. In stream valleys, the differences in terrace height and location can indicate erosional and depositional history (Knighton, 1998). In this study, terraces are important to identify due to the indication that terraces stabilize gravel channels at local reaches (Lisle, 1986).

“Bluffs” are locations where the channel contacts the steep or rocky outcrop of the valley wall were identified as bluffs on Bull Creek. A bluff was digitized circling the steepest USGS topographic slope bordering alluvial soils. These locations are important to locate to understand the effect of bedrock and bluff obstructions on channel form.

“Historic active channel belt” is the entire area in which the channel occupied from 1941 to 2008 is described as the historical active channel belt (HCB). Average HCB width equals the polygon area of clipped HCB divided by valley cell centerline length. Understanding the locations of the channel planform over time will help understand the location and magnitude of sediment storage and disturbance reach activity.

“Valley width” is the total width derived from the alluvial soils map from the University of Missouri CARES Map Room website. Valley width is measured by dividing a valley cell area by valley cell length (300 m). The minimum valley distance equals the distance between terraces. Valley width controls are known to influence stream channel planform and thus are important to measure in this study of Bull Creek (Jacobson and Grann, 1999; Martin and Pavlowsky, 2011; Martin, 2005; Fotherby, 2009).

“Forested riparian area” is the area within each previously defined valley cell that contained tree-covered land is identified as the riparian area. Only two aerial images were acquired (1941 and 2010) for analyzing riparian area.

## Field Assessment & Ground Truthing

Geomorphic field data collection at main stem field sites, included a longitudinal profile, channel cross section, and pebble counts (Appendix A-G). Longitudinal and cross-section profiles were conducted using: auto level, stadia rod, and 100 m measuring tape (Rosgen, 1996). Cross sections were recorded using Rosgen, (1996) methods, but placing cross sections at the maximum HCB widths for field truthing and at the upstream glide at the most narrow HCB width.  Pebble counts using a gravelometer were conducted on all gravel bars using channel grid method within the each site (Rosgen, 1996). Tributaries entering the main stem were also visited for ground truth of gravel sources derived from aerial photographs.

Longitudinal profile length was 10-14 channel widths or about one meander cycle. Points were collected every 3 meters or at breaks in slope to quantify channel form.

Channel cross sections, are used to compare HCB widths and ground truth HCB widths at field sites. Cross sections were placed at the narrowest HCB width riffle crest and lower cross sections were placed at the widest HCB width riffle crest of the field sites. Field sites were located by selecting valley cells with gravel bar hot and cold spots (Figure 8). A maximum channel disturbance cross section was taken at the glide-riffle transition and was used for ground truthing of GIS methods.

Pebble counts were conducted on gravel bars by blind sampling gravels and sizing them with a gravelometer. Riffle and glide samples were not collected due to cold water and wintery conditions. Pebble data was collected at bar head, bar middle, and bar tail. Bar max, largest blocks, and riffle crest max were also collected. Pebble count data was collected at 6 of 7 sites due to a landowner denying further access during the last scheduled field day.

Ground truth at tributaries was conducted by visiting accessible tributaries within the watershed. Each of the major three tributaries to the main stem was visited. At each site photographs and notes were taken to document mobile gravel presence or absence (Appendix G).

# CHAPTER 4: RESULTS & DISCUSSION

The goal of this thesis it to describe the spatial and temporal variations in gravel bars and unstable channel reaches in upper Bull Creek. First, the geomorphic characteristics of Bull Creek are described and quantified. Second, historical trends in gravel bar location and area are evaluated in terms of valley-scale geomorphic controls such as valley width, riparian forest cover, and tributary confluence points. Third, spatial-geomorphic analysis at the bar-scale is used to evaluate gravel bar distribution. Furthermore, final evaluation of gravel sources to the main-stem and the influence of ORV land use on upper Bull Creek are concluded.

## Valley-Scale Morphology

Before investigating the impacts of ORV influence and land use relationships on excess gravel loads in Bull Creek, it is important to understand the influence of valley-scale geomorphic controls such as valley width, bluff obstructions, and channel bends on gravel bar location and size along Bull Creek. Valley-scale control on gravel bars can obscure the impacts of land use and tributary sources of gravel (Panfil and Jacobson, 2001). Larger-scale landforms such as valley bends, valley width, and tributary junctions can affect gravel bar area and channel stability (Lisle, 1986; Jacobson and Gran 1999). Differing channel patterns create reaches with large historically active channel belts (HCB) and associated gravel bars (Pavlowsky and Martin, 2011).

The historical active channel belt (HCB) is defined as the total area between all channel positions across the valley floor since 1941 (Figure 11). The HCB pattern gives an indication of where valley morphology is conductive for channel stability (narrow belt) or disturbance reaches (wide belt). The range in the HCB width is 12 m to 73 m. Disturbance zones are spaced about every 600-800 m downstream (Figure 11 & 12B). These disturbance zones tend to form before and after contact with the valley wall, bedrock, and minimum valley widths.

Total valley width is the distance between valley wall hill slopes and is defined by the alluvial soil group. The minimum valley width is the distance between the valley wall and any terrace present restricting channel planform movement (Figure 11). Wide valley widths tend to have less gravel than narrow widths, while gravel width is higher in the narrower valley of the lower segment (Figure 12). Overall valley width is generally narrower in the lower segment (VC 16-30) and wider in the upper segment (VC 1-15).

Terraces include both fill and strath terraces that indicate position of older floodplains, presently not affected by flooding. Strath terraces are underlain by bedrock benches and parallel many of the bedrock channels and are generally located on the inside of long bends and across from tributary junctions (Figure 11 & 12A). Terraces constrict the overall active valley width and limit HCB widths and may promote local channel stability when in contact with the channel.

Bluffs are very steep or rocky outcrops at the valley wall. Bluffs are distributed relatively evenly along the study reach and may limit HCB widths when in contact with the channel at the valley bend. In-channel bedrock cells are more frequent in the upper segment equaling 6, in contrast to only 2 valley cells in the lower segment with bedrock. Valley cells 11-14 contain bedrock, the largest valley widths, and some of the lowest gravel bar widths (Figure 11&12).

Artificial structures such as low water crossings and bridges are known to create stream channel instability and thus potentially increase gravel bar area through accelerated bank erosion, channel widening, and bar deposition at or below crossing sites (Bouska et. al., 2010; Gilbert 2005). Crossings are typically located within bedrock reaches or along small bluffs where low flows are shallow and channel beds are stable, such as VC 2, 5, 14 and 17. Therefore, the low-water bridges and crossings within the study segment of Bull Creek do not generally correlate with higher bar areas and channel change at the cell-scale of 300 m.

Digitized gravel bars within each aerial photograph year were measured in area ($m^2$), corrected by photograph date discharge, totaled for each valley cell, and then divided by cell length (300 m) to equal the average gravel bar width (Figure 12A). Minimum gravel bar width is the smallest historical value for each valley cell, while maximum is the largest historical value for each. Gravel bar width is generally higher in the lower segment than the upper. The maximum gravel bar width (89 m) is at VC 20 and the minimum width (0 m) is located at VCs 27&28. In general, valley cells with the largest range in variability of gravel bar widths tend be located in the lower segment within narrow valley widths and valley bends (Figure 12A). Elevated gravel bar widths at valley bends may suggest a control on gravel bars through valley planform.

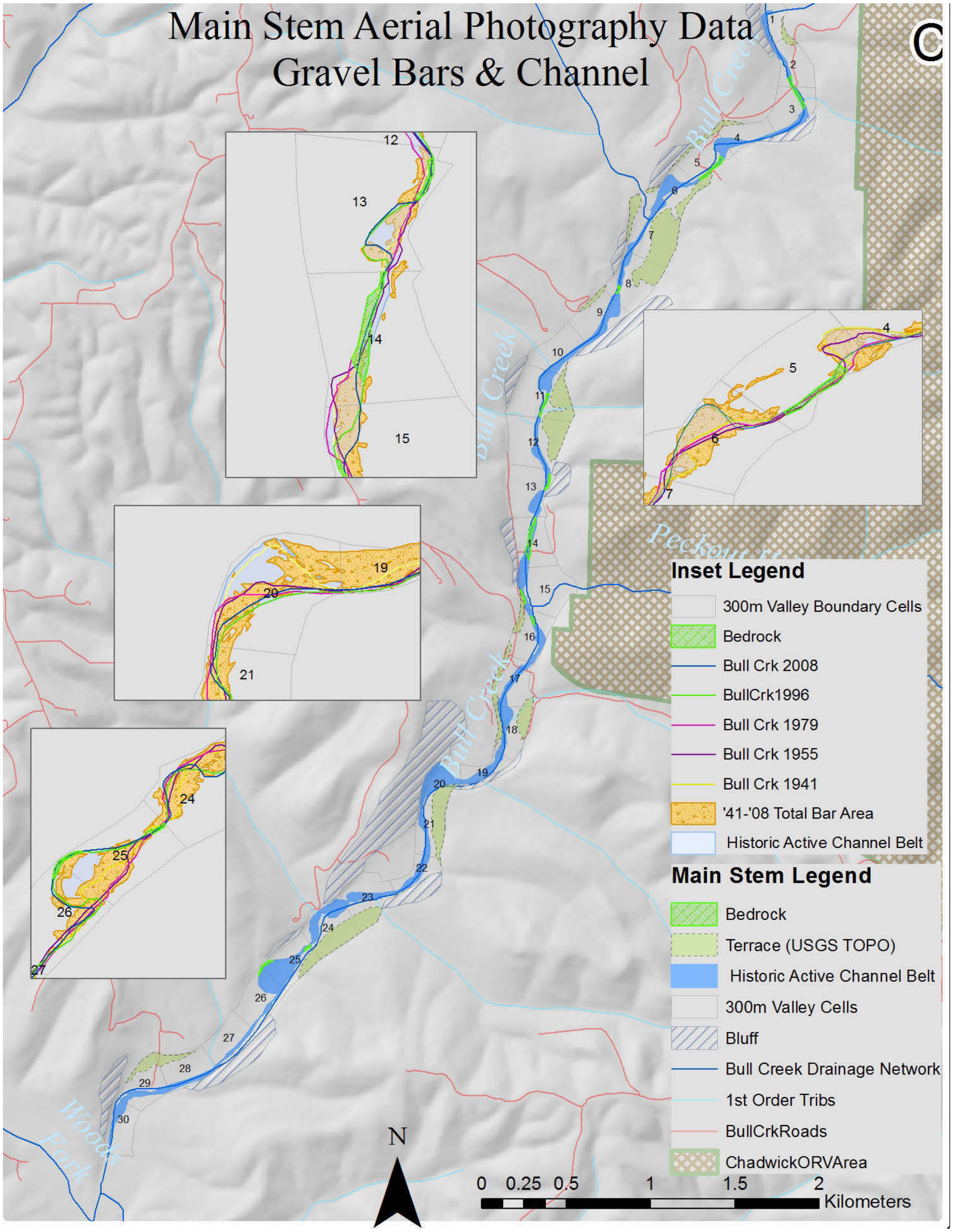


Figure 11. Gravel bar and channel location in relation to geomorphic features.

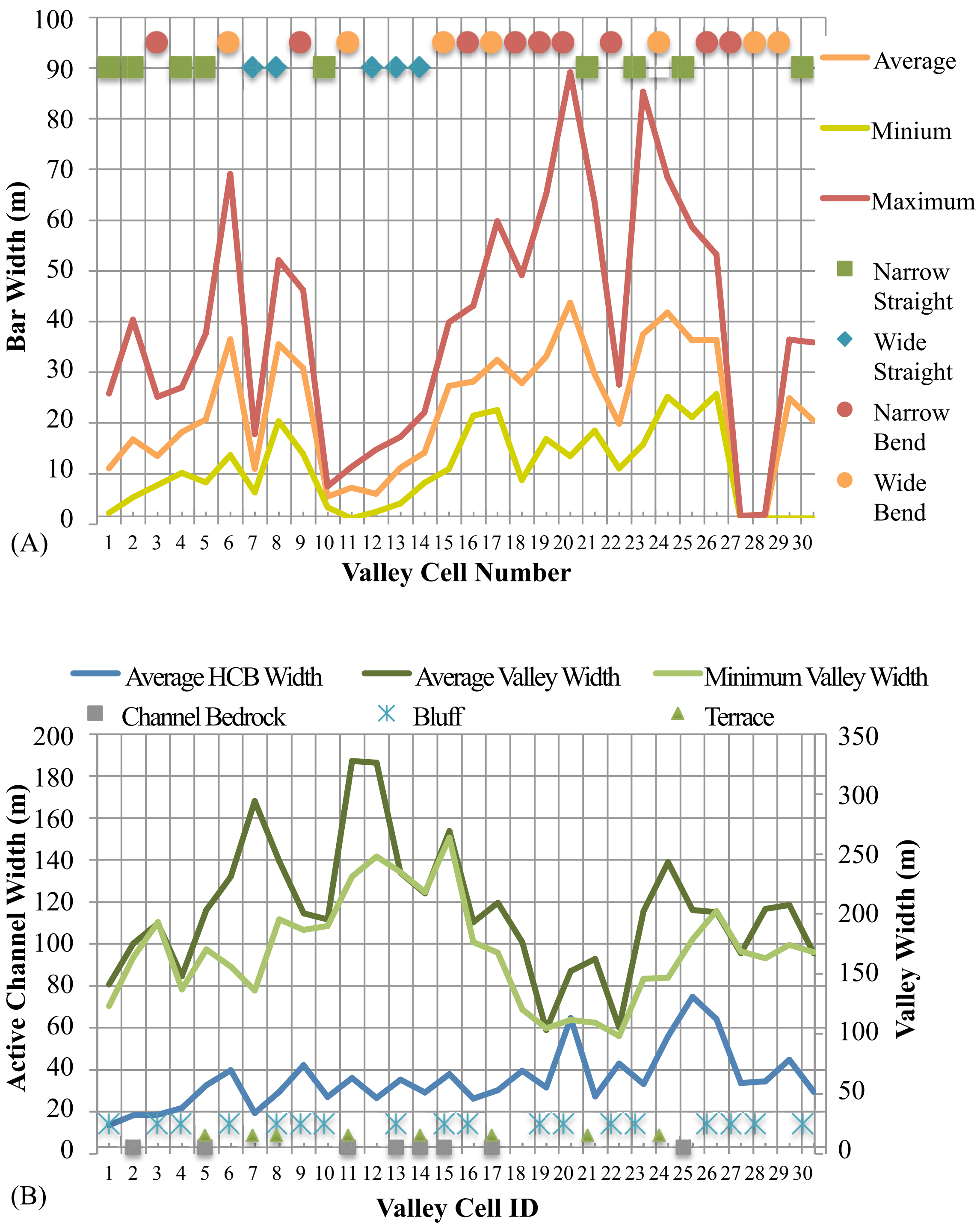


Figure 12. Downstream trends in geomorphic planform classification. (A) gravel bar widths per valley cell. (B) Historic active channel, average/minimum valley widths.

**Valley Planform Classification.** To further evaluate gravel bar and valley morphology interactions, gravel bar and HCB widths were totaled for each valley cell. Valley cells were classified into planform categories as either a wide valley (>200 m) straight or bend, or narrow valley (<200 m) straight or bend, based on minimum valley width between terraces. The widest valley cells have the widest HCB measurements, due to decreased confinement by terraces and bluffs. In general the lower segment has the larger HCB widths at wide valley straights and valley bends (Figure13). Furthermore the average gravel bar widths for each class of cell have increased recently in the upper segment (2008) compared to the lower segment in historical photographs (1941) (Figure 14). Valley bends contained more historical gravel while recent gravel bar widths in 2008 are relatively evenly distributed between bends and straight valley cells (Figure 14).

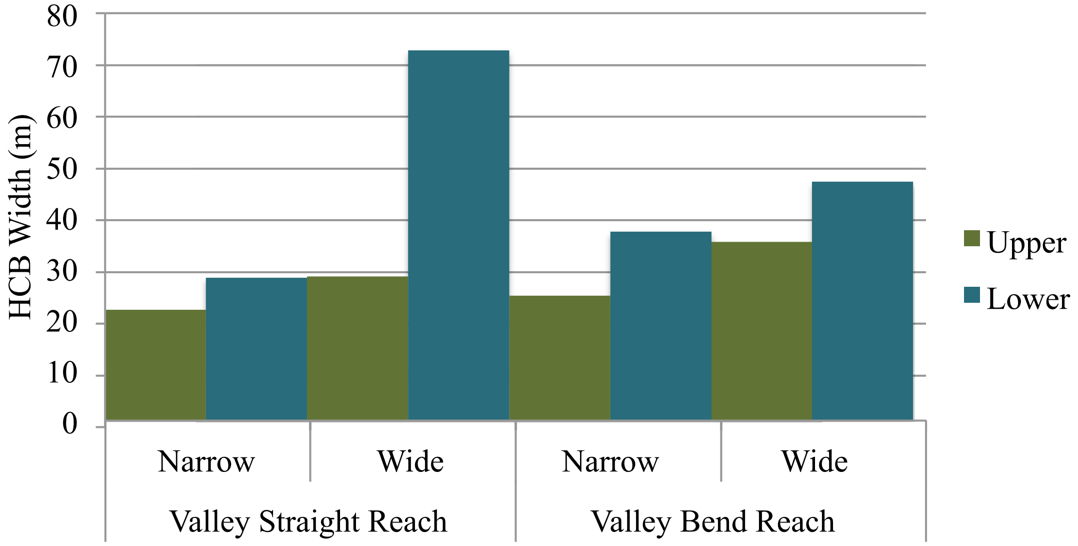
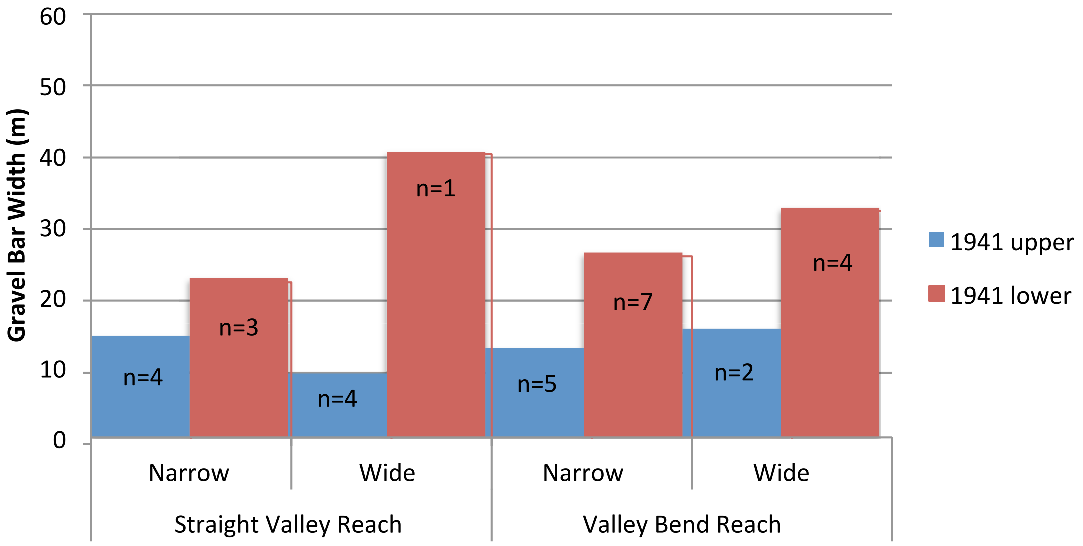
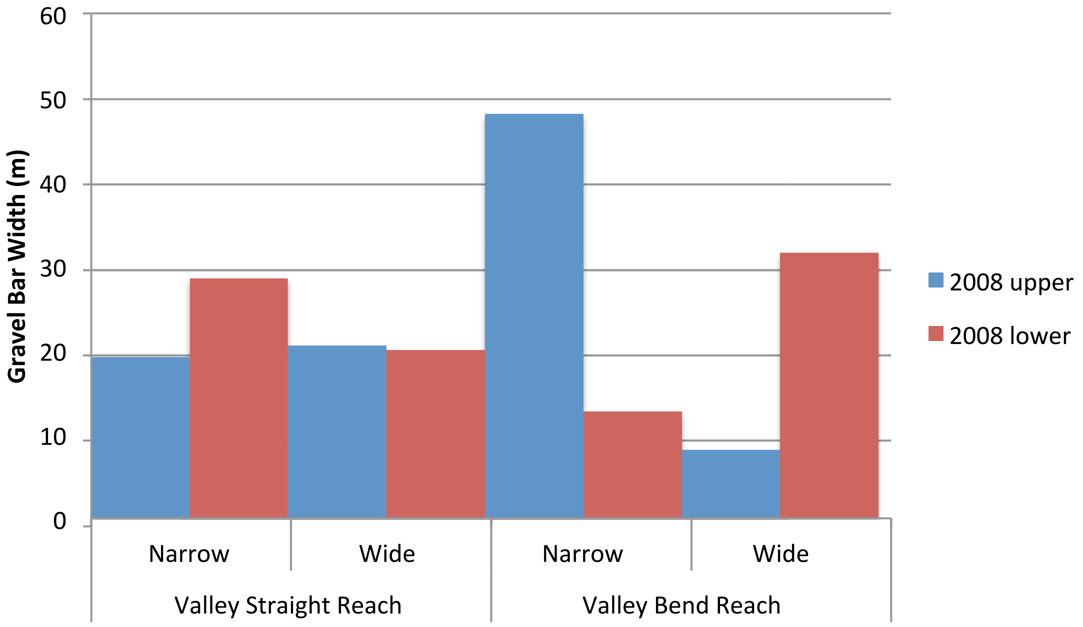


Figure 13. Sum of valley cell HCB widths of each geomorphic classification within upper and lower segments.



(A)



(B)

Figure 14. Total average gravel bar widths by valley classification for 1941 and 2008. (A) 1941 aerial photograph data (B) 2008 aerial photograph data

**Riparian Forest Area.** In general, the current riparian width has remained the same in the upper segment while increasing in all valley cells in the lower segment (Figure 15). The increase in riparian forest suggests a recovery of valley tree cover along upper Bull Creek. While riparian corridor is considered to be a valley-scale control by Montgomery and Buffington (1997), an increased riparian width does not decrease the HCB width in Bull Creek (Figure 16). The lack of correlation between forested riparian and channel erosion is consistent with other research in the Ozarks. Jacobson and Pugh (1995) found that on the Little Piney River, Missouri, both wooded and grassed riparian buffers had the relatively the same susceptibility to bank erosion. Therefore, HCB and gravel bar widths in Bull Creek are likely controlled more so by valley-scale morphology interactions than forested riparian area.

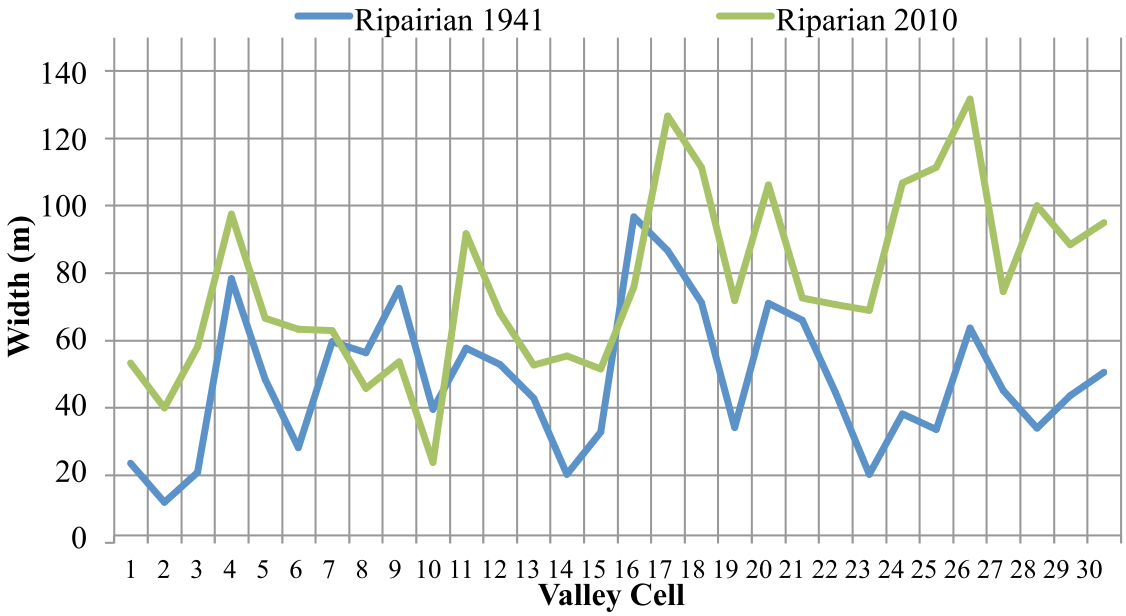


Figure 15: Downstream trends in riparian buffer during years 1941, and 2010 (leaf on photographs) and gravel bar recovery width by cell.

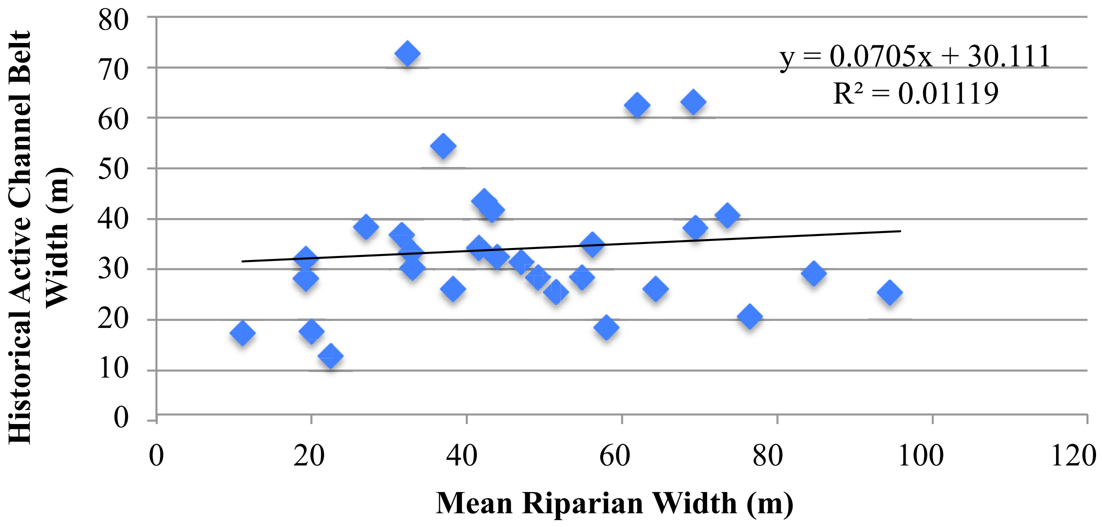


Figure 16. Historical mean riparian width relationship to the historical active channel.

**Summary.** Overall, the relationship between valley-scale morphology and HCB and gravel bar widths supports a correlation between morphology and disturbance reaches. For example, a narrow valley bend generally has larger gravel bar widths and HCB widths (Figure 12&14). Furthermore, wide HCB widths are found mostly at locations before and after the channel comes in contact with a bluff, bedrock, or constriction in valley width by a terrace (Figure 11). In contrast, maximum valley widths contain high HCB and gravel bars widths, but mostly wide valley cells display low gravel bar and HCB widths due to in-channel bedrock and terraces present that support channel stability (Figure 12). Similarly, on the Current River in Missouri, Jacobson and Gran (1999) found that some valley locations have gravel peaks related increased valley widths, but many gravel peaks corresponded to an intermediate valley width of about 250 m instead of the widest valley reaches. Moreover, Jacobson and Gran (1999) also concluded that valley-scale constraints described disturbance reaches in the Current River better than channel meander spacing. The spacing of wide HCB widths would be expected every 100-300 m or at every 11-16x's the channel width (Leopold, L. B., et. al, 1964). Spacing on wide HCB widths in Bull Creek was about 600-800 m (Figure 11). Thus, valley-scale constraints appear to better describe the wide HCB measurements and disturbance reaches on Bull Creek.

In general, planform classifications show that valley bends and straight valleys have wide HCB and gravel widths. In the lower segment during 1941, the largest average gravel bar widths are found within one straight valley cell, yet most gravel widths are in valley bend cells (Figure 14). Recently, 2008 gravel bar widths increase in the upper segment at valley bend cells. While wide valley cells have wide gravel bar widths, gravel bar width seems to correlate more so with valley bend cells. Therefore, at the cell-scale Bull Creek disturbance reaches are largely controlled by valley-scale morphology such as bluffs, in-channel bedrock, and valley width.

## Historical Variations in Gravel Bar Area

Overall, between all the years studied, 1979 is the year with the largest overall main stem gravel bar area (Figure 17). The aerial photograph for 1979 was during winter leaf-off conditions like 1996 and 2008 photographs (Table 3). Point-to-point error is the same as the 1941 photograph and similar to 1955. Also the time between a flood prior to the photograph date are similar in all photos and do not suggest that 1979 would have an elevated gravel bar area due to these factors.

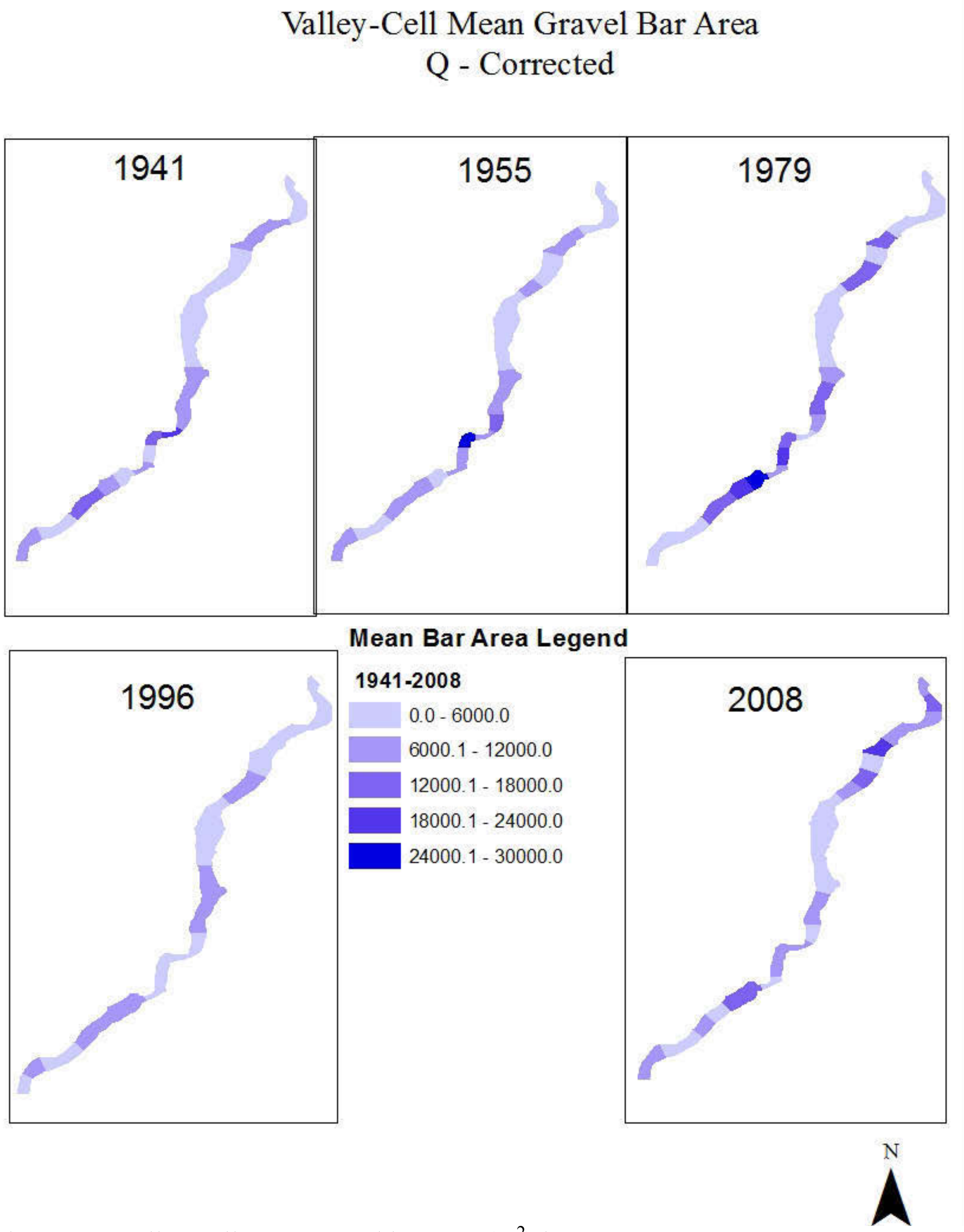


Figure 17: Valley-cell mean gravel bar area ($m^2$) by year.

Furthermore, gravel bar widths have increased recently in the upper segment and decreased from historical widths in the lower segment (Figure 18). The year of 1979 is contrary to Jacobson's (1995) findings on Ozarks' streams, which gravel sediment moved through larger watershed between 1920 and 1940. Under that hypothesis the peak in gravel bar area should be no later than 1941. Thus, gravel supply could have been elevated by other means of disturbance such as climate changes, land use changes, or combinations of these factors.

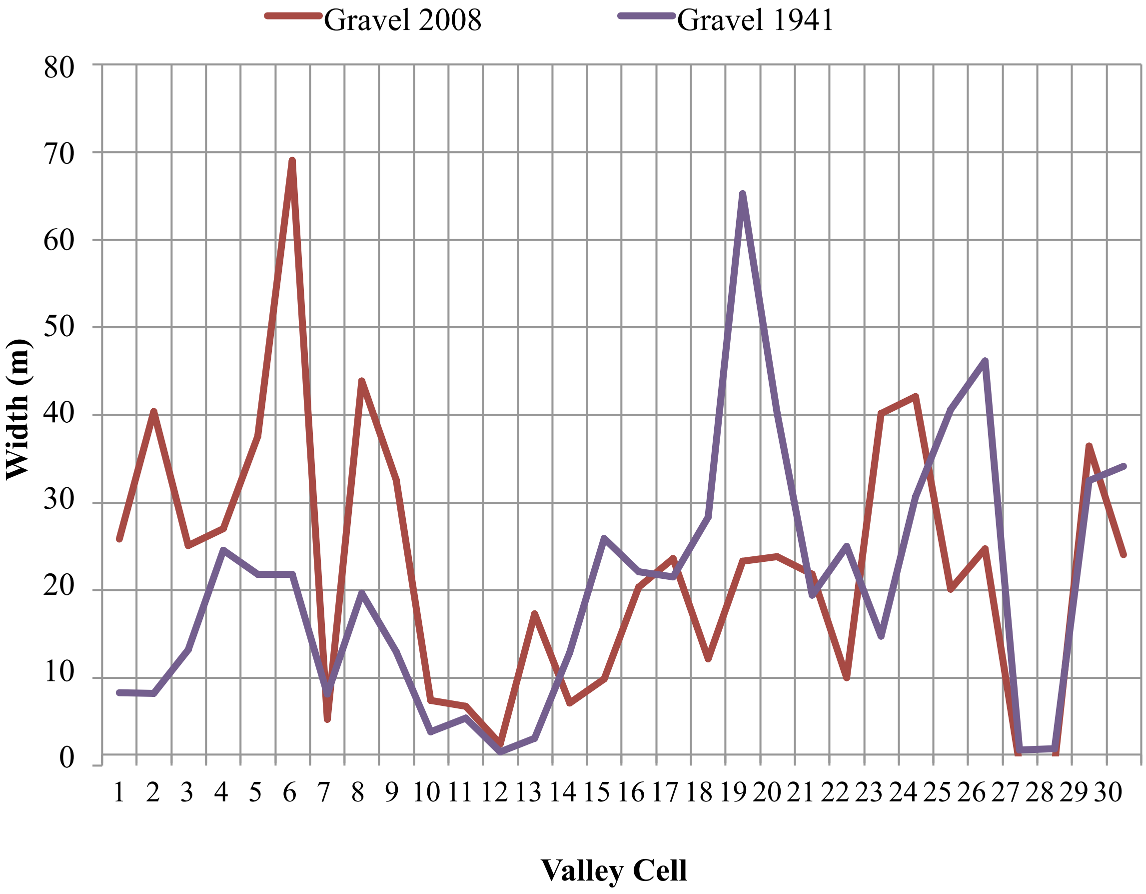


Figure 18. Downstream trends in gravel bar width for years 1941, and 2008.

**Spatial-Geomorphic Modeling of Gravel Bar Distribution.** Using GIS to identify temporal and spatial changes in HCB and gravel bar width has been used in previous studies investigating Ozark stream reaches (Jacobson and Gran 1999, Martin and Pavlowsky, 2011). In this study, “hot spot analysis” tool identifies gravel reaches with the greatest gravel bar area at bar-scale rather than previous valley-cell scale. By identifying spatial relationships within gravel bar polygon data it is possible to locate reaches of Bull Creek that have contained relatively large gravel bar deposition areas in all photographs. Hot spot tool analysis has not been previously utilized to identify disturbance reaches in streams.

The upper segment contains four different gravel bar hot spots, while the lower segment has six hot spots (Figure 19). The upper and lower segment hot spots are located at valley bends, with a bluff present, and either follow or precede a constriction in the valley by a terrace. Likewise, other hot-spots demonstrate similar valley-scale characteristics (Table 5). Hot-spot (1) - (2) contains 2 maximum widths in HCB and gravel bars during 2008, while they both are located before and after a constriction from a terrace and have tributary supply (Figure 12, 18 & 19). Hot-spots (6) – (7) display a 1941 peak in HCB and gravel bar widths (Figure 12). At this location the channel enters a valley bend and the minimum valley width changes abruptly (Figure 19). Jacobson and Gran (1999) concluded a weak association of gravel bar area with valley-scale geologic constraints such as channel meanders, tributary junctions, and intermediate valley widths (250m). Like Jacobson and Gran (1999), it seems geologic constraints alone are not entirely responsible for gravel bar hot spots in Bull Creek, but it appears that the largest disturbance reaches tend to form as the channel enters into and departs from a valley bends as well as when the channel enters and exits extreme valley widths.

Overall, valley-scale controls and the hot spot analysis are similar in describing the valley cells the exhibit the spatial distribution of large gravel bars (Figure 12 & 19). Cell-scale analysis is probably not the best method for evaluating the distribution or pattern of disturbance reaches, but it does yield good results, even if limited by cell boundary “averages”. The cell analysis allows collection of cell-level data for further analysis whereas hotspot analysis has more pattern recognition capabilities. With both methods, you get similar results but the GIS-Hotspot analysis is more true to the river form. Therefore, the hotspot analysis shows fairly clearly that the most persistent bars within major disturbance reaches occur at locations entering (in) and leaving (out) of a valley bend but not in the bend (Figure 19). Other secondary or contributing factors seem to be the location of a tributary confluence near the disturbance reach and in very narrow/constricted valleys. These locations are important to understand when investigating the timing of gravel bar deposits and sources of gravel bars.

Table 5. Valley characteristics at gravel bar hot-spots.

| Large/High Gravel Bar Hot-Spots | | |
|---|---|---|
| Hot Spot ID | Valley Cell Location | Valley-scale Characteristics |
| (1) - (2) | VC 6-9 | Bend in-out + tributary supply |
| (3) - (4) | VC 14-16 | Bend in-out + tributary supply |
| (5)- | VC 18 | Bend out + minor tributary supply |
| (6) - (7) | VC 19-21 | Bend in-out + narrow valley |
| (8) - (9) | VC 24-26 | Bend in-out + tributary supply |
| (10) - | VC 29 | Bend in + narrow valley |

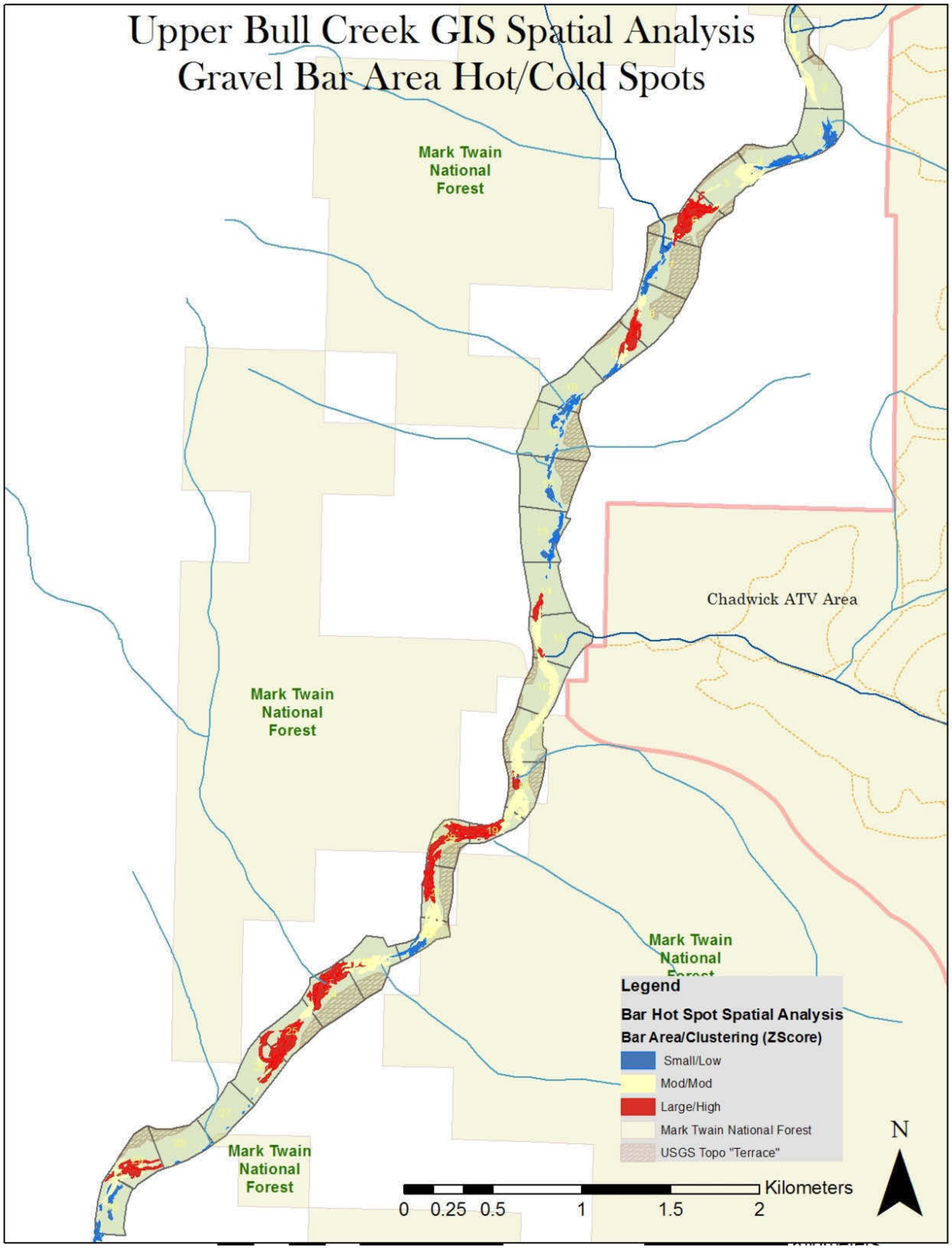


Figure 19. Hot spot analysis (HSA) of gravel bar data from a 70 year period of five aerial photographs.

## Gravel Supply to Bull Creek

Sources of gravel to the main stem include gravel stored in valley floor and colluvium deposition by pre-settlement climate shifts, gravel stored in the HCB and main stem tributaries is presently in transit from historical land use during early European settlement, and the current re-mobilization of sediment stored in disturbance reaches through channel instability (Jacobson and Pugh, 1995; Jacobson and Prim, 1994; Jacobson and Gran, 1999; Owen and Pavlowsky, 2011). To understand where gravel is coming from in the landscape, disturbance reaches were located and further investigation of tributary supply to the main stem of upper Bull Creek. Further aerial images were analyzed for historical land use derived sediment within upland tributaries.

Land use effect trends suggest upland recovery from initial land use practices during early settlement. Livestock no longer range free on the slopes, row crops are not grown in valley bottoms and many forests have nearly matured within the watershed. Although, present land uses of increased suburban buildings and increased road networks are known to increase runoff rates within watersheds (Montgomery, 1994).

Historical flood data show a recent overall increase in peak discharge in James River (Figure 20). Jacobson and Pugh (1995) concluded that channels previously disturbed by sediment would have a lower resiliency to climactic shifts from dry to wet periods of increased flood frequency and magnitude. Therefore, rapid shifts in flood frequency or magnitude will increase gravel transport from tributaries and disturbance in the main stem.

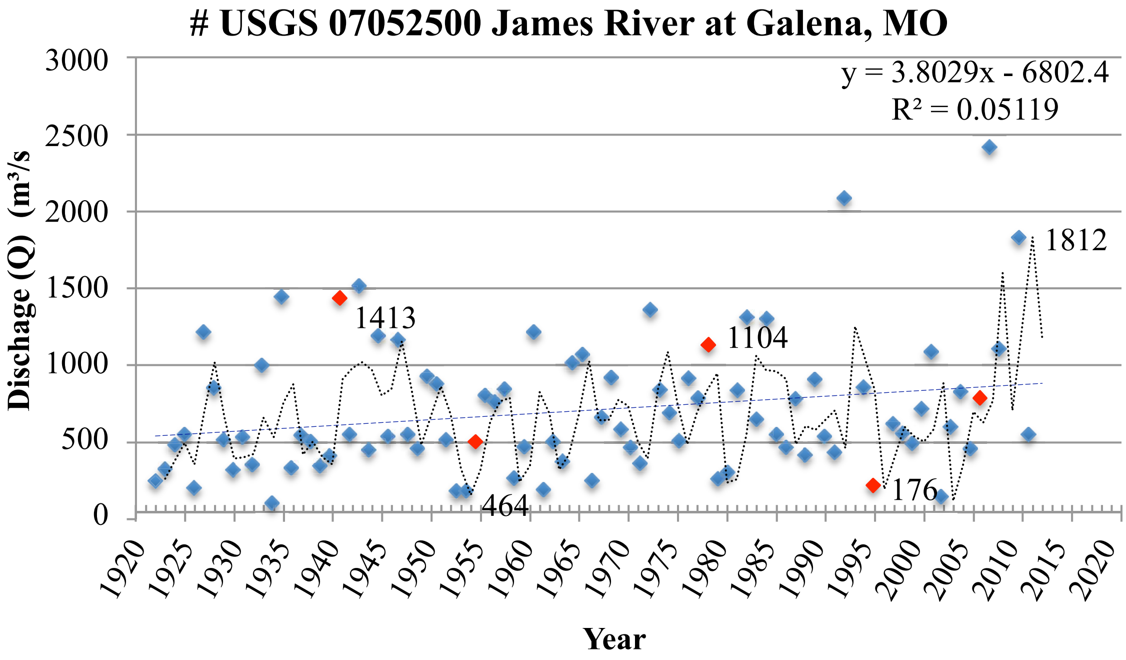


Figure 20. Peak discharge in James River. Dashed line = 2-point moving average. Red points = Floods less than 1 year from aerial photograph

**Gravel Remobilization**. At channel reaches of increased gravel deposition and HCB widths, bank erosion can remobilize buried paleo-bar deposits stored over the historical period. Similarly, the migrating channel can erode into gravelly colluvium flood plain sediments and introduce gravel and fine sediments back into transport (Figure 21). Finally, the remobilization of in-channel gravel bars during large floods allows this sediment to migrate toward other downstream disturbance locations for temporary storage. Martin and Pavlowsky (2011) found that mid channel gravel bars seemed to form downstream of disturbance reaches that had remobilized gravel deposits through channel extension and bed or bank erosion. This suggests disturbance reaches are both a sink and a source of gravel sediment within the main stem of Bull Creek.

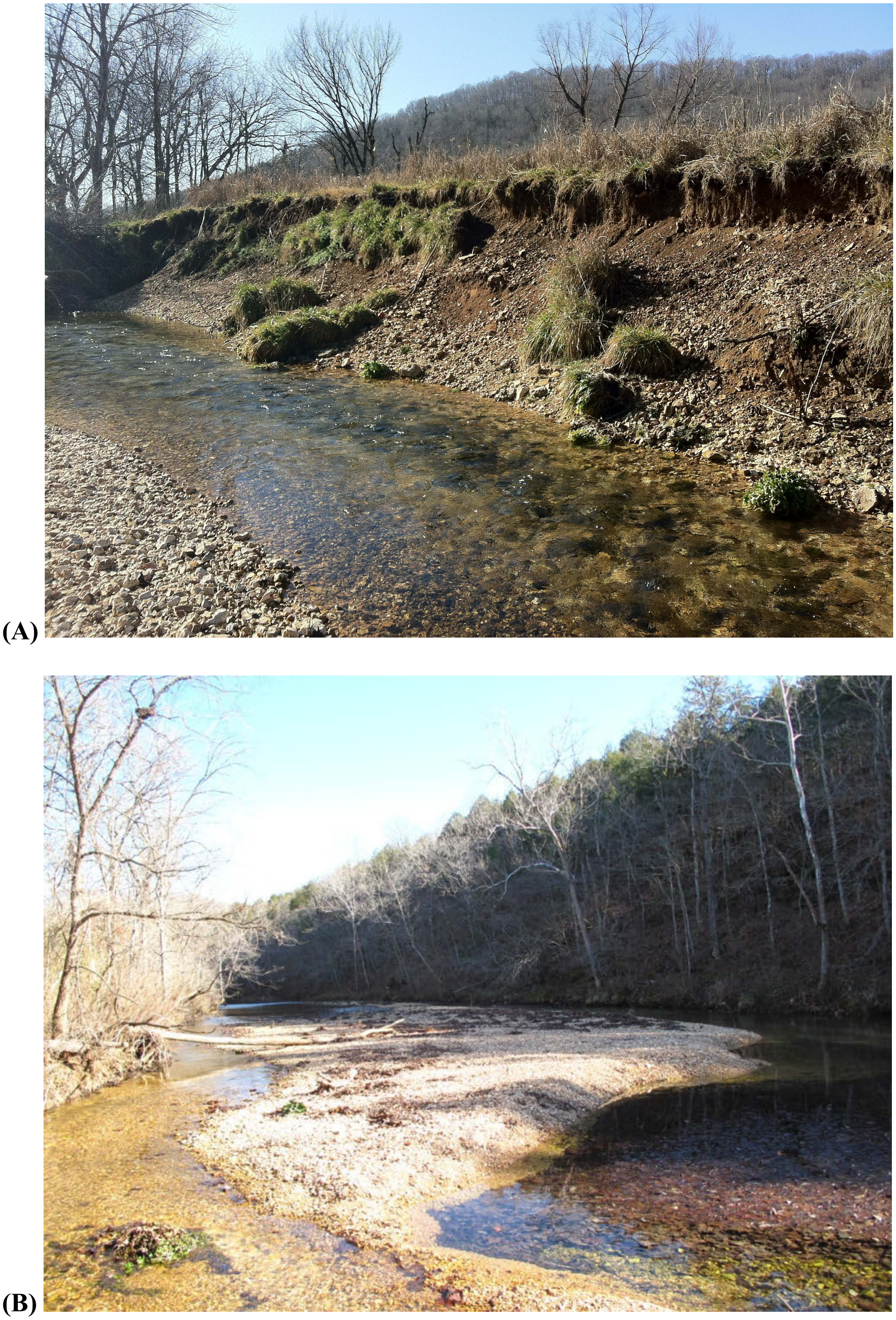


Figure 21. Gravel released from back erosion. (A) VC 11-12 across from recent channel widening due to mega-bar formation. (B) Mobile diagonal/point bar at VC 5.

**Tributary Gravel Length and Area.** In effort to understand gravel source timing, the visible gravel length and gravel area in the tributary channels was digitized in 1941 (leaf on) and in 2008 (leaf off) (Figure 22 and Figure 23). Leaf coverage may offset visible gravel data being and increase 1941 and decrease 2008. Tributary extension is evident in the fields and therefore aerial photograph leaf cover does not alter this data.

1941. The West Fork displayed gravel mostly in the upper reaches. The middle tributary, Bull Fork, displayed gravel predominantly around the middle reaches. While the Chadwick ATV property shows only two small tributaries and the main stem of Peckout Hollow. Furthermore, nearly zero tributary gravel is seen on the west side of the main stem of Bull Creek (Figure 23). In general, a large majority of gravel length present is located within upland 1$^{st}$ order tributaries in 1941 that extend into the upland fields containing Poynor or Clarksville soil series (Figure 22A). These upland soils contain 5-30% chert cobbles larger than three inches and 40-75% smaller chert fragments that increase in percentage with depth (Table 1). Tributary gravel signatures seen in aerial photographs support the hypothesis by Jacobson and Primm's (1994) of a historical gravel sources originating from head ward extension of first order tributaries receiving land clearing.

2008**.** Within the West Fork, gravel is found in the mostly the main channel and upper reaches of the tributary. Bull and West forks have gravel throughout the main stems of the primary tributaries as well as being dispersed throughout the main stem. The Chadwick ATV area has four tributaries with gravel and Peckout has gravel evident in the upper primary tributaries. Furthermore, the west side of the main stem has two tributaries that display gravel length and area (Figure 23).

Figure 22. Upland tributary gravel length in (A) 1941 and (B) recovery in 2008.

**Temporal Comparison of Tributary Gravel.** Recall that aerial photographs in 1941 were during leaf-on conditions and the 2008 photographs were taken during leaf-off conditions. Therefore it is expected that more gravel cover be identified in streams draining wooded valleys such as in MTNF. Never the less, recovery of first order tributaries is suggested. In comparing the dates, West Fork and Bull Fork have gravel area and length at relatively the same levels but further downstream since 1941 photographs (Figure 23). The East Fork decreased in gravel area since 1941, yet gravel length remains at a similar level (Figure 24). The Chadwick ATV property (east side of main stem) and the west side of main stem each have an increase of two tributaries with visible gravel length (Figure 23). Furthermore, Peckout Hollow displays a similar result with decreased area and increased length of gravel into the upper tributaries (Figure 23 & 24). Upland extension and channel disturbance into gravel rich soils is a significant source of gravel into the main stem of tributaries and ultimately the main stem of Bull Creek. Timing of gravel in tributaries suggests gravel loading due historical land use changes, while Peckout Hollow suggests a recent tributary extension effect and thus a more contemporary gravel supply and erosion from ATV trials to the main stem of Bull Creek.

While a potential source of gravel to the main stem is the ATV use area, other “undisturbed” tributaries have similar increases in 2008 tributary gravel signatures as well (Figure 25). Along the west side of the main stem 1st and 2nd order tributaries now show gravel signatures, yet they have a forested drainage area throughout the 70-year study period (Figure 17). This may be due to the combination of expanding road networks and increased magnitude and frequency of flooding that can alter drainage characteristics and ultimately channel geomorphology in the form of erosion and gravel supply to the main stem of Bull Creek. Expanding road/trail networks have been found to correlate to gravel bar area within the Current River, Missouri and other streams (Wemple, et.al, 2001; Jacobson, and Gran, 1999; Montgomery, 1994). This increase of drainage connectivity through road and trail networks paired with steep gravel rich soils enables many Bull Creek tributaries to remain a substantial source of gravel to the present-day channel as well as historically.

In summary, the sources of gravel are mainly tributary input and the gravel bar disturbance reaches along the main stem. Climate and flooding promote transport of gravel sediment from tributaries and increase disturbance reaches by increasing stream power. Overall, the tributary gravel area sources decreased by nearly half between 1941 and 2008 (Figure 24C). While the visual area of gravel decreased, the length of visual gravel remained the same and only the location changed within the tributaries. Within the main stem, gravel sources are found at gravel bar hot spots, widening HCB's into floodplain deposits, and in-channel gravel deposits. Therefore, disturbance reaches serve as a sink for gravel as well as a source of gravel sediment to the main stem. While climate change and increased flooding will increase disturbance areas through increased erosion, deposition, and transport rates the sources of gravel are relatively fixed to certain tributaries and stream channel reaches. Finally, the tributary of the Chadwick ORV area is more of a contemporary source of gravel than a historical source. Therefore, with recent decreases in gravel bar and tributary gravel levels, the landowners may be looking at local increases of erosion and gravel remobilization, but not at historical levels.

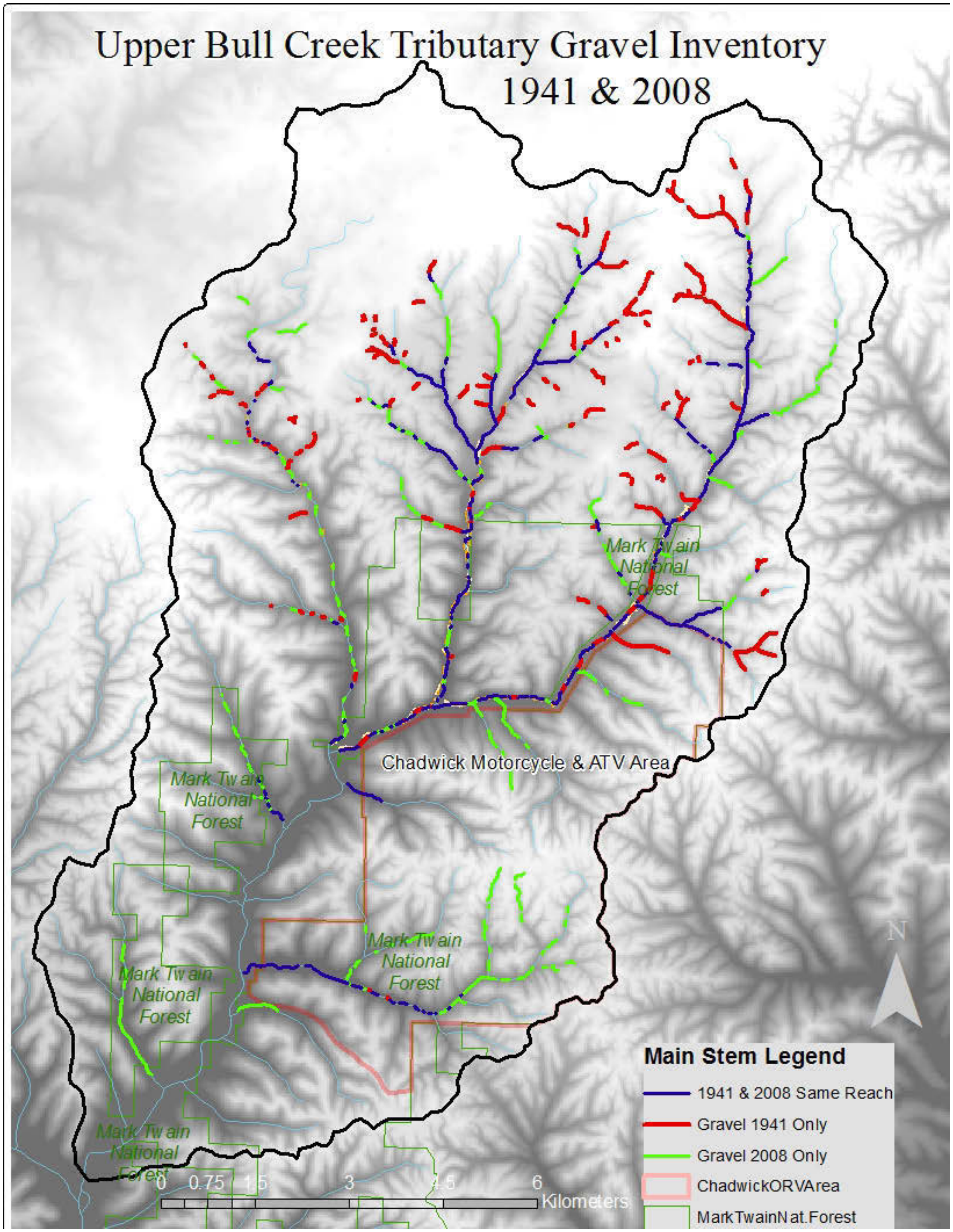


Figure 23. Aerial photograph tributary gravel during 1941 and 2008.

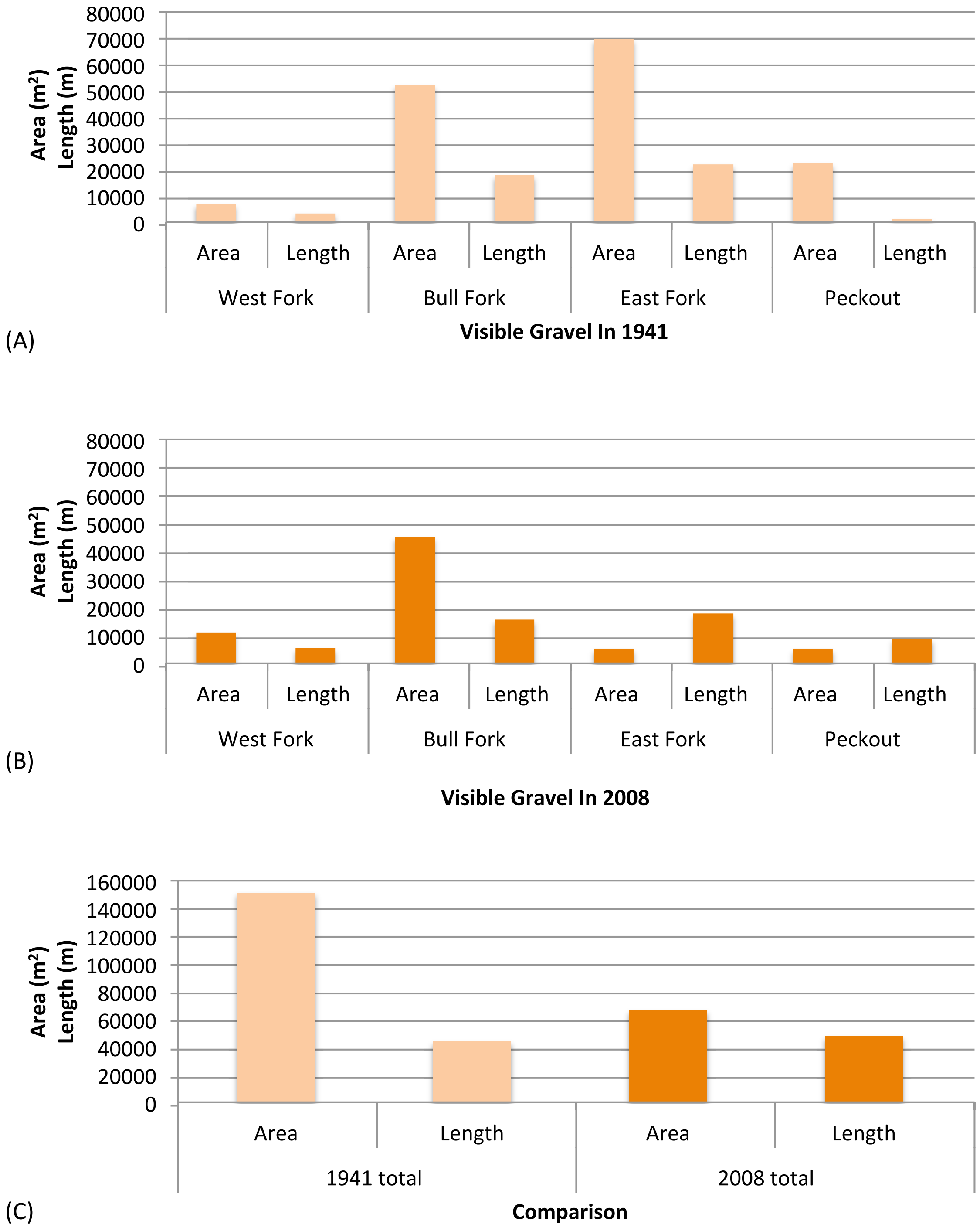


Figure 24. Visible gravel in tributary channels. A. 1941  B. 2008 C. Total comparison

## Influence of ORV Land Use

ORV impacts would be expected to affect lower segments more than upper segments due to Peckout Hollow draining the majority of the ORV use area. Therefore, comparison of bar area and channel disturbance history within Bull Creek can be used to evaluate the potential influence of ORV use within Peckout Hollow.

Valley-scale controls on disturbance reaches vary between the two segments. While the largest disturbance reaches in both segments form before and after valley bends and/or constrictions in the valley width, the upper and lower segments do not share the same number of these features. The upper has an increased number of straight valley cells (10 vs. 4), increased valley width (226 m vs. 179 m), and number of valley cells containing in-channel bedrock (7 vs. 2) (Table 6). Thus, the narrow winding valley of the lower segment has increased meander belt widths (40.3 m vs. 26.6 m), and gravel bar area (96.3 $km^2$ vs. 23.4 $km^2$).

While increased bar areas in the lower segment may be partially linked to gravel supply from Peckout Hollow in 1979 due to ATV disturbance (Carden-Jessen, 1998), The increased gravel levels prior to 1979 cannot be linked to ATV use since Honda first introduced the first ATV in 1970 (Honda, 2013). While the lower reach is more "predisposed" to gravel bar accumulation due to valley-scale conditions such as a narrow valley width, increased valley bends, and decreased in-channel bedrock. Therefore, the increased gravel area in 1979 may be an affect in partial degree by previous land use history and climatic influence.

The increased gravel bar area in the lower segment is predominantly due to valley-scale characteristics, which are predisposed to accumulate and transport sediment episodically from upstream bank erosion, tributary inputs, and disturbance reaches. Jacobson and Gran (1999) found similar results in the Current River where valley scale characteristics accentuated pulses or waves of gravel from tributaries to form vertical and horizontal wave-like forms of accumulated gravel. Furthermore, these wave-like forms of 1500 km$^2$ passed through some large Ozark streams by the 1940's (Jacobson 1995). Therefore, the increased gravel bar area in the lower segment is likely the result of valley-scale characteristics and a lagging historical gravel transport episode from tributaries and storage in main stem HCB.

In final evaluation of ATV impacts to the main stem, total gravel bar area within the main stem aerial photographs was compared. Comparisons in overall gravel bar area within the two segments reveals the lower segment has significantly more gravel than the upper segment (Figure 25). The overall range in gravel bar area within the lower segment is much higher, fluctuating from ~37,000 to ~15,000 m$^2$/km of stream channel versus the upper segment varying from ~21,000 to ~11,000 m$^2$/km of stream channel. It should be noted that the upper segment appears to be experiencing a recent increase in gravel bar activity that surpasses the lower segment. While higher bar area in the lower segment suggests the ORV area may be impacting Bull Creek, it is critical to understand that valley-scale controls largely determine gravel bar deposition and generally these are independent of ORV use and USFS management.

In summary, inherent geomorphic differences between the upper and lower segments are significant enough to create different historical gravel bar distributions. Valley-scale geologic characteristics such as valley width, valley bends, and bedrock presence in Bull Creek have produced disturbance reaches in the lower segment due to increased gravel bar hotspots and increased HCB width frequency. Thus, these differences may have created unwarranted concern among some landowners that gravel bar activity and sediment sources of upper Bull Creek being primarily related to the Chadwick ATV Area. Perceptions of more gravel in Bull Creek today may be correct since increased flood frequency and magnitude over the past two decades may have remobilized disturbances zones and thus the recent appearance of increased channel activity and gravel bar area, particularly in the upper segment.

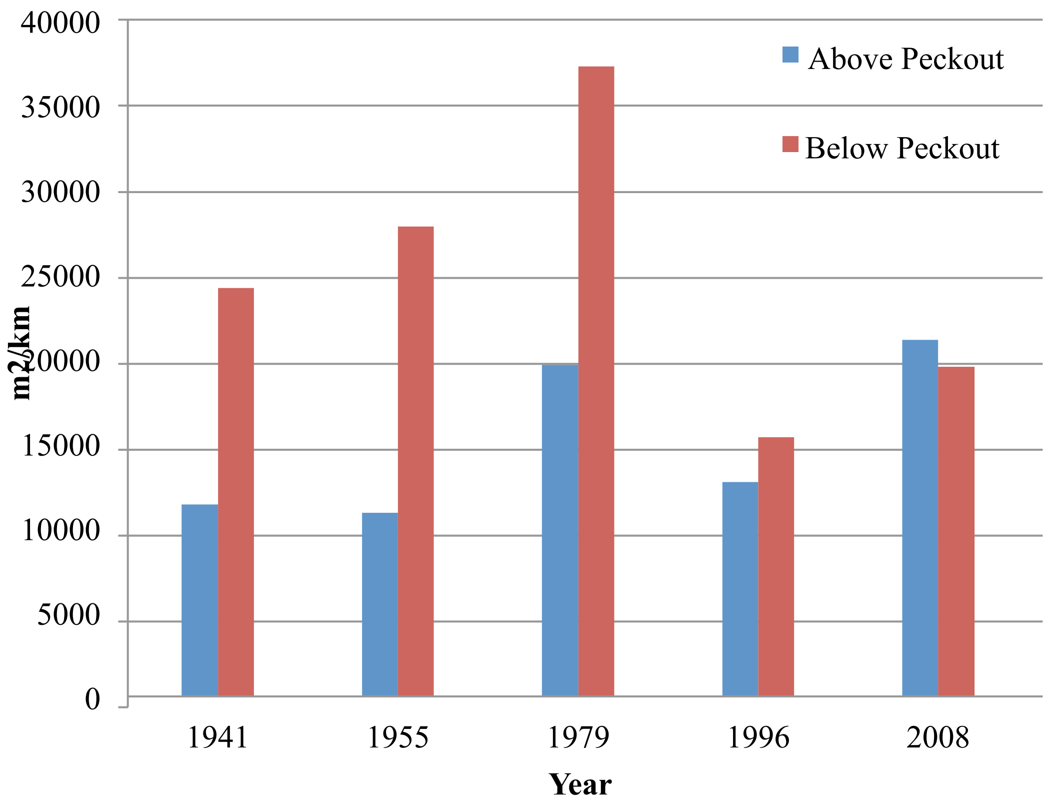


Figure 25: Downstream trend in gravel bar area between upper and lower segments of Bull Creek.

Table 6. Geomorphic Indications for Upper and Lower Segments

(A)

| | Main Stem Segment | |
|---|---|---|
| Valley-scale Characteristics | Upper | Lower |
| Average Valley Slope % | 0.25 | 0.29 |
| Valley Centerline Length (m) | 4.3 | 4.8 |
| Channel Sinuosity | 1.08 | 1.10 |
| Average Valley Width (m) | 226.4 | 179.6 |
| Minimum Valley Width (m) | 189 | 148 |
| Average HCB Width (m) | 26.6 | 40.3 |
| Average Gravel Bar Width (m) | 16.8 | 26.7 |
| | | |
| Cell-scale Characteristics | | |
| Valley Bend Cells | 5 | 11 |
| Valley Straight Cells | 10 | 4 |
| Bluff Cells | 9 | 9 |
| Terrace Cells | 5 | 6 |
| Bedrock Cells | 7 | 2 |
| Hot Spot Cells | 4 | 6 |
| Tributary Confluence Cells | 7 | 6 |

(B)

| Gravel Bar Area (km$^2$) | Upper | | Lower | |
|---|---|---|---|---|
| | 1941 | 2008 | 1941 | 2008 |
| Bend/Narrow | 7.7 | 17.2 | 54.4 | 26.7 |
| Bend/Wide | 15.7 | 25.5 | 41.9 | 37.9 |
| Straight/Narrow | 13.2 | 30 | 16 | 13.7 |
| Straight/Wide | 19.8 | 33.8 | 16.5 | 18 |
| Total | 56.4 | 106.5 | 128.8 | 96.3 |
| Mean Riparian Forest Width (m) | 43 | 59 | 53 | 94 |

# CHAPTER 5: SUMMARY & CONCLUSIONS

It is generally understood that early settlement and land clearing prior to 1920 resulted in headwater channel erosion and increased gravel sediment delivery to main stem river channels in the Ozark Highlands (Jacobson and Primm, 1994; Owen et al. 2011). These gravel inputs resulted in widespread aggradation and excess gravel bar sedimentation in many rivers with gravel waves passing downstream and bed elevations returning to normal levels by 1950 or so (Jacobson and Gran, 1999). However, the spatial patterns of gravel deposition and channel adjustments since that time is not well understood and variations in geomorphic response among different Ozark rivers has not been sufficiently addressed yet. Further, the public perception that gravel bar activity and related bank erosion problems have increased in Ozark streams during the past two decades has underscored our lack of knowledge of Ozark river behaviors.

To address the above gap in knowledge, this thesis has investigated the historical trends in gravel bar deposition and channel change in Bull Creek, an Ozark stream located about 50 km southeast of Springfield. While this stream is used as an example for ecological reference by management agencies, reports also indicate that excess gravel sedimentation is destabilizing the channel in places and riparian landowners are concerned about bank erosion and sediment problems. Furthermore, off-road vehicle use has been allowed on National Forest lands that drain into Bull Creek since the 1970s and the influence of this practice on gravel supply and channel sedimentation has been an ongoing concern. This study used aerial photograph analysis from 1941 to 2008 to evaluate the causes of gravel bar sedimentation and sources of gravel to Bull Creek.

There are five major conclusions of this study:

The first conclusion of the study is that gravel bar activity has been spatially persistent within disturbance reaches located near valley constrictions, valley bends, and tributary junctions. Since 1941 gravel bar widths have increased in upper segment valley bends by 20 m and decreased in lower segment valley bends by 15 m (Table 6). Furthermore, gravel bar hotspots were located where the channel was entering (in) and leaving (out) of a valley bends and where tributaries joined the main channel (Table 5). These results indicate that bedrock beds and valley obstructions probably provide a critical control for the location of sedimentation areas in Bull Creek. Furthermore, major disturbance reaches as identified using GIS hot-spot analysis tend to occur at narrow constrictions, in/out of valley bends, and often near/below tributary confluences with main channel. The finding that disturbance reach locations are persistent over time is supported by studies from other Ozark rivers to the east and west of Bull Creek (Jacobson and Gran, 1999; Martin, 2005; Martin and Pavlowsky, 2011; Owen et al., 2011). Outside of the Ozarks, Fotherby (2009) also found that larger channel bar areas occur within narrow valleys controls on the Platte River in Nebraska. Therefore, in upper Bull Creek, and maybe other Ozark streams, valley morphology appears to play a greater role in determining the location of disturbance reaches and gravel bar storage compared to land use factors. However, land use disturbances may control the upland supply rates of gravel from tributaries to the main valley and therefore control the degree of activity within a given disturbance reach.

The second conclusion is that since 1979 gravel bar area has decreased by nearly half within the lower segment of study area and increased slightly in the upper segment (Figure 25). Increased bar activity in the upper segment is likely the result of recent increases in flooding and gravel transport along Bull Creek and its tributaries so as to increased recent gravel loads form upland streams and remobilization of stored gravel in tributaries and the main stem. Increased flood magnitudes may not only be a result of increased annual precipitation, but also related to new drainage improvements associated with nationally high rates of suburban development in Christian county, but this effect was not evaluated in this study. Overall since 1941, watershed forest and riparian corridor conditions improved with land management practices implemented on private and Forest Service lands. Therefore, with the decrease in gravel bar area in the lower segment, Forest Service lands and ORV use do not seem to provide an exceptional source of gravel sediment to Bull Creek.

The third conclusion is that this study did not find a relationship between excess gravel bar activity in Bull Creek and ORV use and Peckout Hollow gravel inputs. The historical peak in gravel bar disturbances was 1979 and Forest Service management within the Bull Creek watershed began in 1975 (Carden-Jessen 1998). Moreover, Honda’s first all terrain cycle wasn’t available until 1970 and had only seven horse-power, with balloon tires that suffered flats from “harvested crop stubble” and therefore could not be widely utilized on the steep rocky slopes of Bull Creek (ATV.INFO, 2013). It wasn’t until the early 1980’s that more powerful racing versions entered the market that were first utilized for erosive “hill-climb races” along Bull Creek (Carden-Jensen, 1998).

Therefore, ATV traffic on Bull Creek is probably not a major contributor of gravel sediment at this time.

The forth conclusion is that present-day tributaries contain in-channel gravel deposits at levels similar to those in the 1940's. Thus, tributaries may be supplying gravel to Bull Creek at relatively high rates in recent time. Aerial photography analysis indicated that early tributaries were head-cutting into gravel-rich upland soils of Bull Creek in 1941 (Figure 22). This observation supports Jacobson and Primm's (1997) suggestion that tributary channel incision and bank erosion provided a major source of sediment to Ozark streams prior to 1930. However, channel erosion and excess gravel transport apparently occurred later on into the 1950s in Bull Creek. Based on field observations and recent aerial photographs, historical gravel deposits are still stored within tributary valleys as channel fill and gravel bar deposits that, if remobilized, can provide a future source of gravel to Bull Creek.

Finally, watershed soil conditions and vegetation cover has probably recovered to some degree from land use disturbance prior to 1930 in Bull Creek. However, large gravel bar areas and high sediment load indicators are still present within tributary channels and main stem disturbance reaches due to remobilization of previously stored gravel and release of new gravel by ongoing soil erosion and tributary incision. Gravel remobilization and transport rates may have increased recently due to the effect of increased flood magnitude and frequency during the past two decades in the Bull Creek watershed (Figure 6A). Thus, local residents may actually be seeing a real increase in recent gravel bar activity and channel disturbances related to climate change factors and more frequent flooding. In addition to climate effects, the geomorphic effectiveness of increased runoff rates may also by enhanced by suburban infrastructure expansion and the remobilization of historical gravel storages.

Besides the direct influence of larger and more frequent floods on river geomorphology, the seasonality and/or episodic nature of floods may also affect gravel loads in Ozark rivers. Climate change models in the Midwest forecast extended dry periods followed by extreme flood events (Kunkel et. al, 1999; Groisman et. al, 2005). Following this scenario, gravel bar activity will probably decrease during the dry periods and allow bar surfaces to become colonized by vegetation. However, the denser growth of woody vegetation within the channel will decrease the cross-sectional area of the channel and floodway. Limiting the flow area increases flow depth and local velocity and will promote bank erosion and disturbance reach instability during subsequent flood events (McKenny et.al. 1995). The Ozark Highlands have experienced similar climate shifts in the last three centuries that have also been associated with peak gravel bar activity in area streams (Jacobson and Pugh, 1995). Barring large climactic shifts, Jacobson and Pugh (1995) hypothesized that it would take over 100 years for complete geomorphic recovery from channel gravel disturbances in Little Piney Creek which is located 120 km to the Northeast of upper Bull Creek. Therefore, complete recovery of disturbance reaches in Ozark rivers is unlikely and so knowing where spatially-persistent disturbance reaches are located within a river system is critical information to provide landowners and managers to help guide future management decisions.

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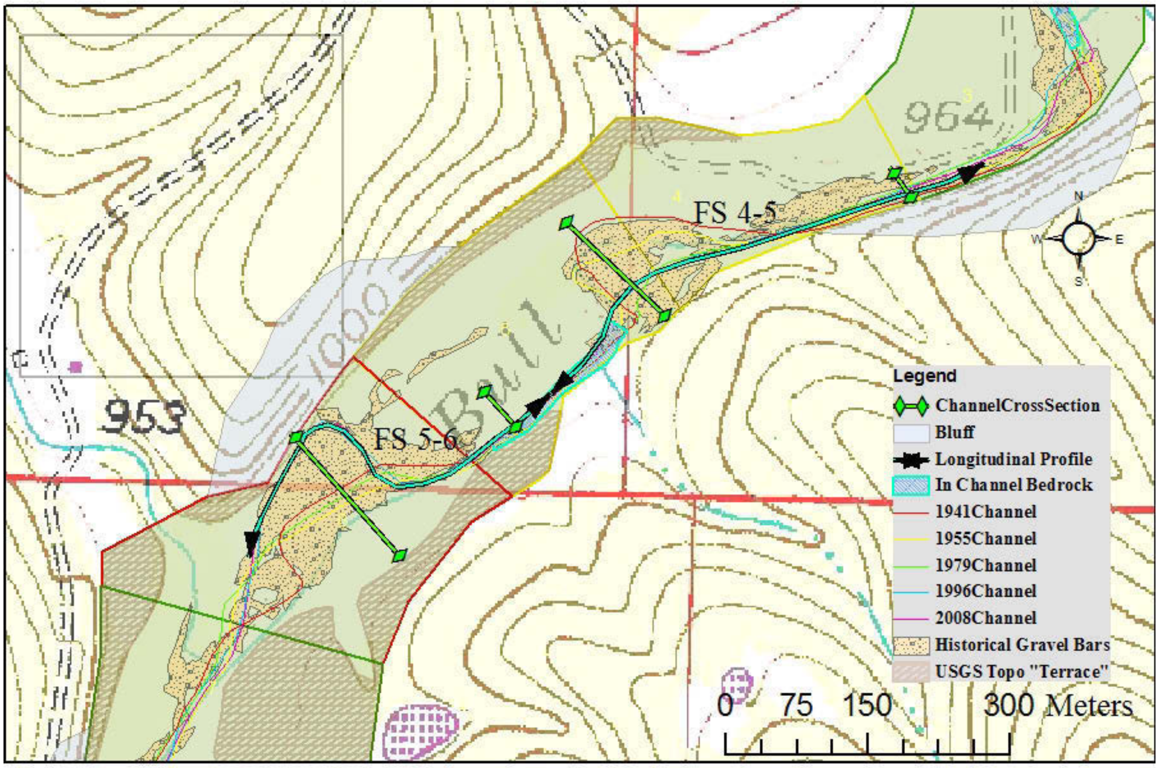
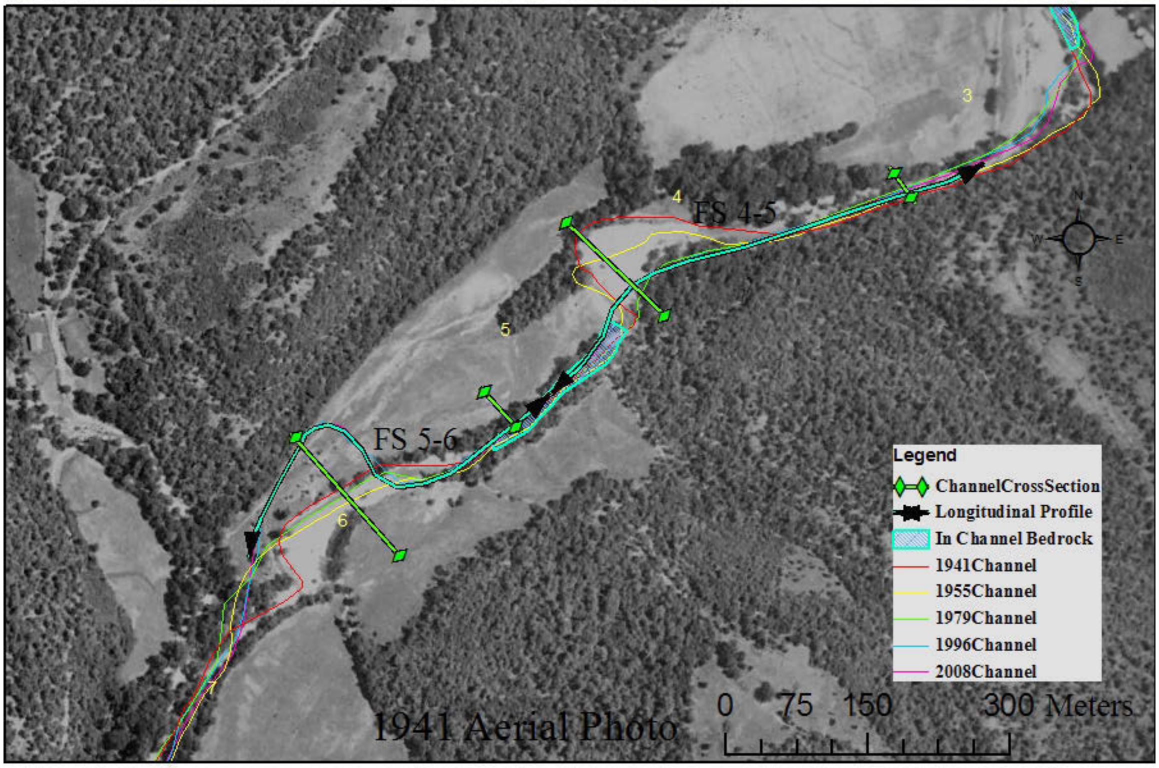
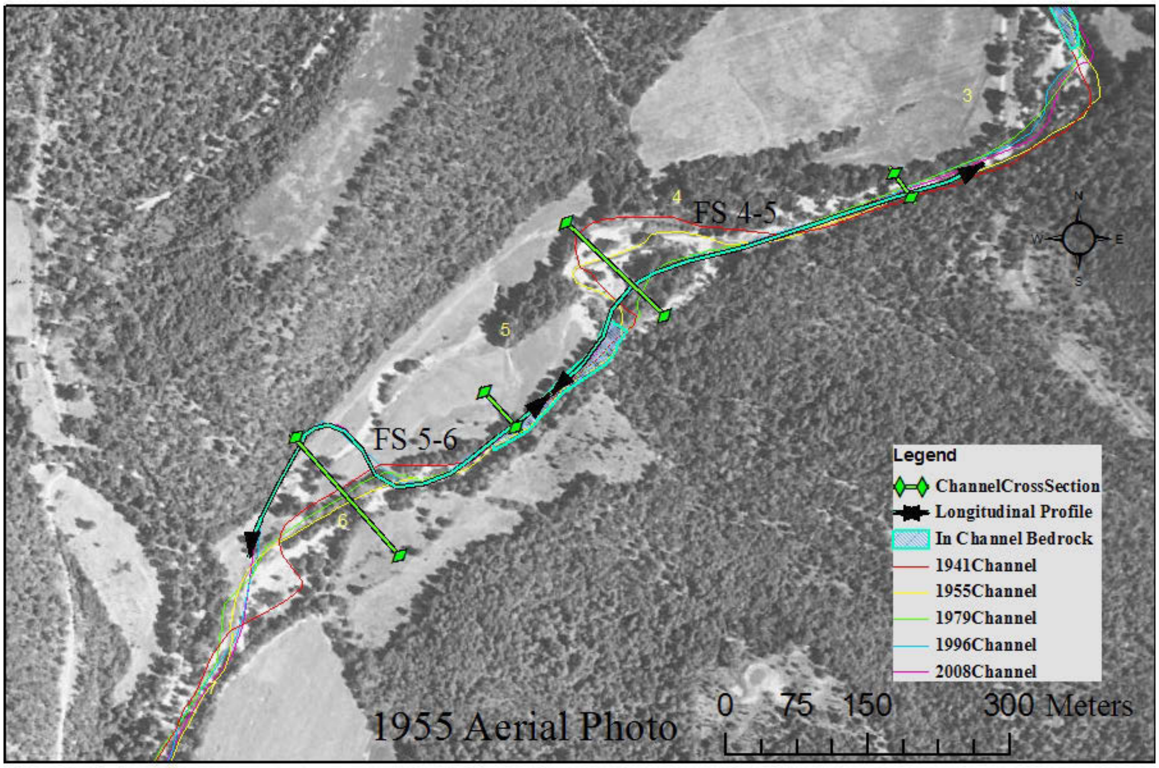
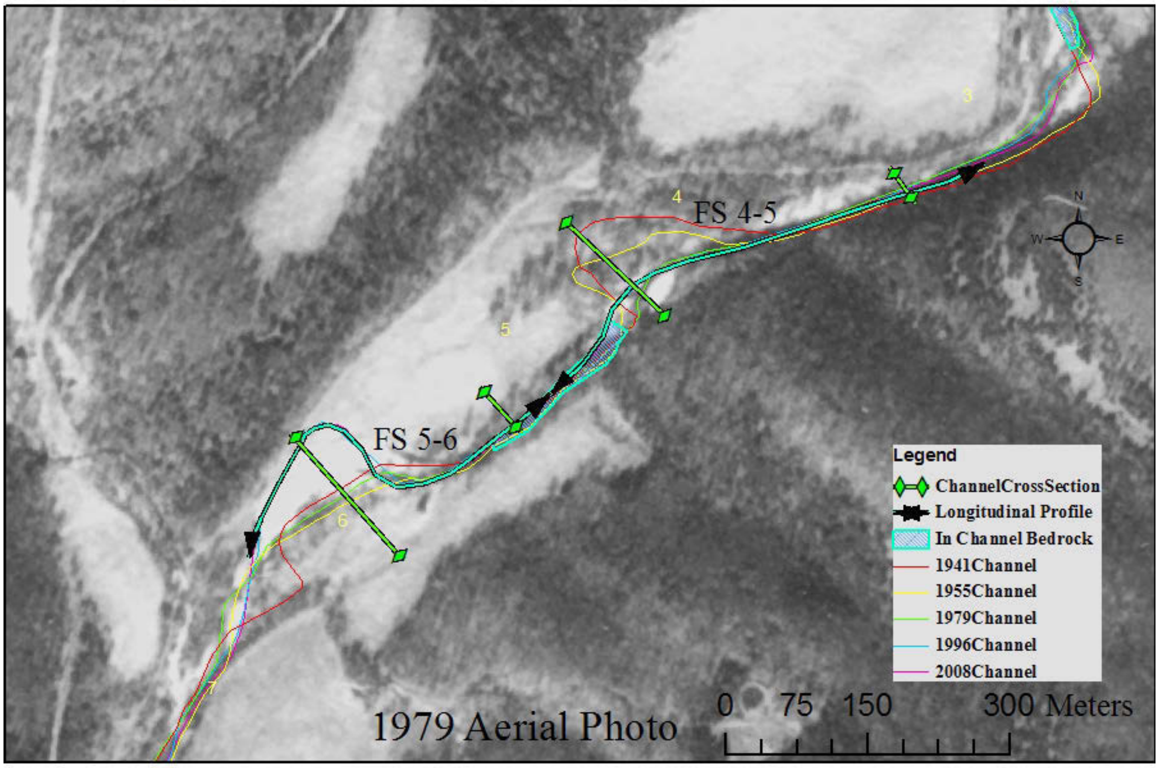
# APPENDICES

## Appendix A: Field Site 4-5 & 5-6






3
4
FS 4-5
5
FS 5-6
6
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
1955 Aerial Photo
0 75 150 300 Meters


3
4
FS 4-5
5
FS 5-6
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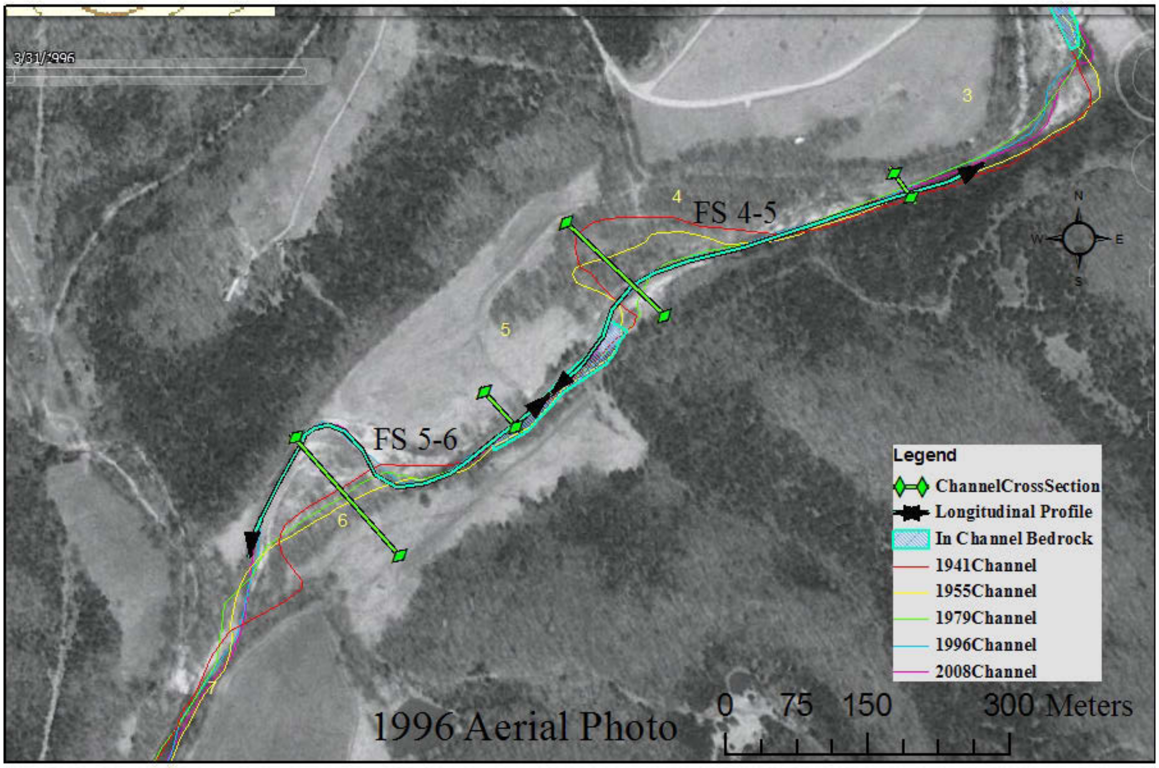
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
1979 Aerial Photo
0 75 150 300 Meters


3/31/1996
3
4
FS 4-5
5
FS 5-6
6
7
N
W
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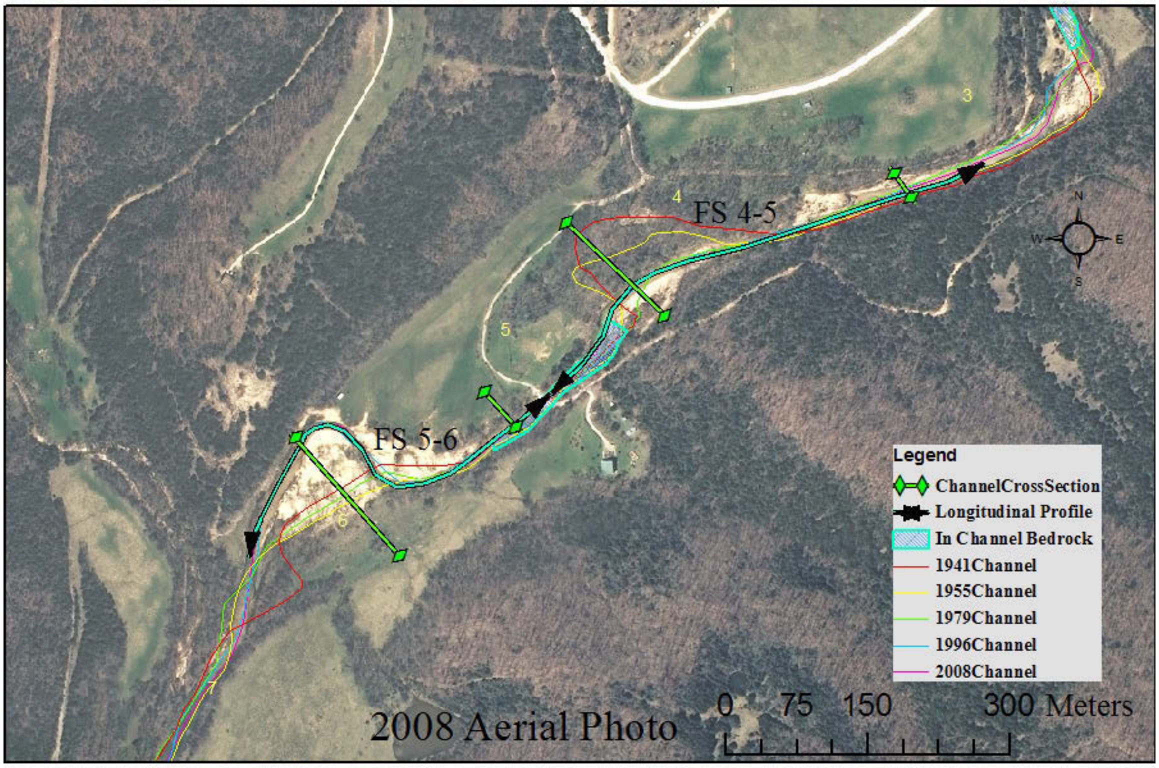
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters
1996 Aerial Photo


3
4
FS 4-5
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FS 5-6
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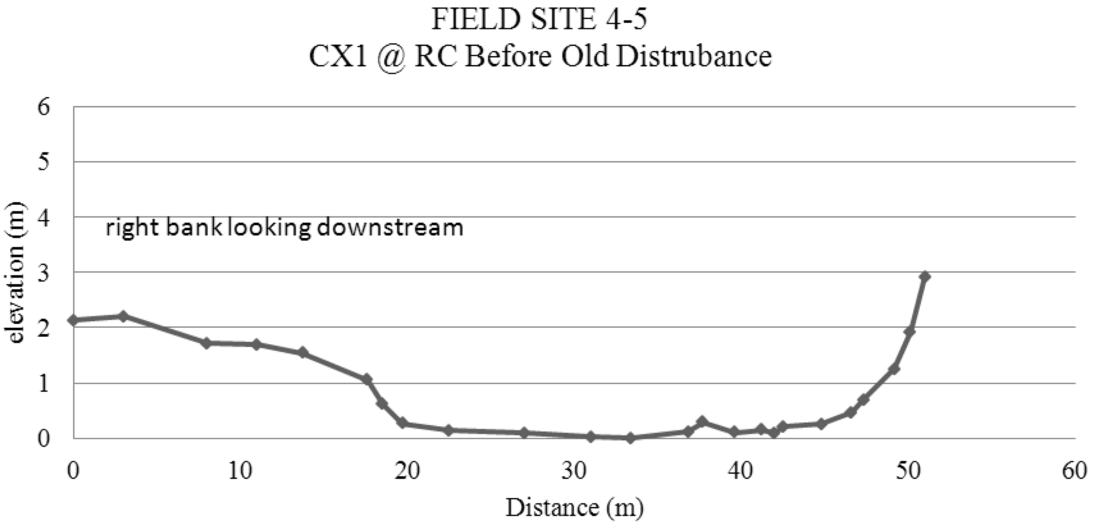
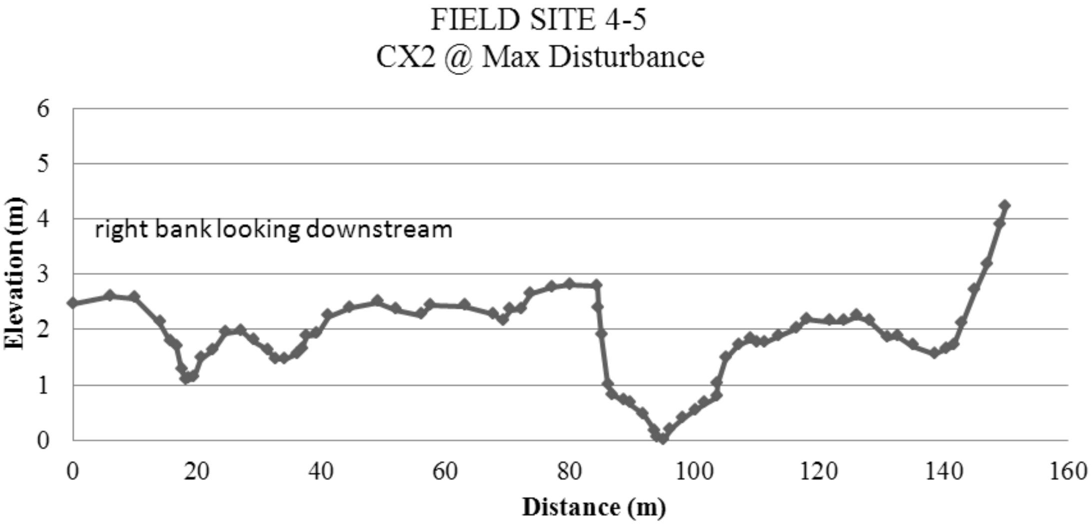
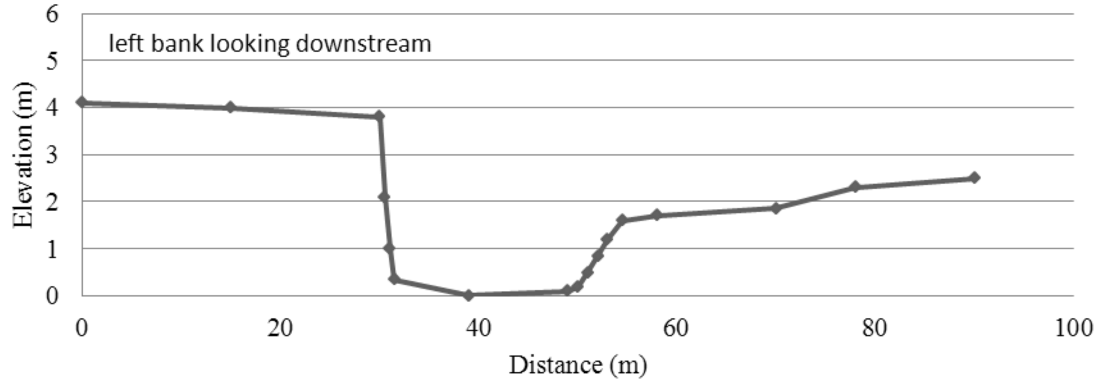
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters
2008 Aerial Photo

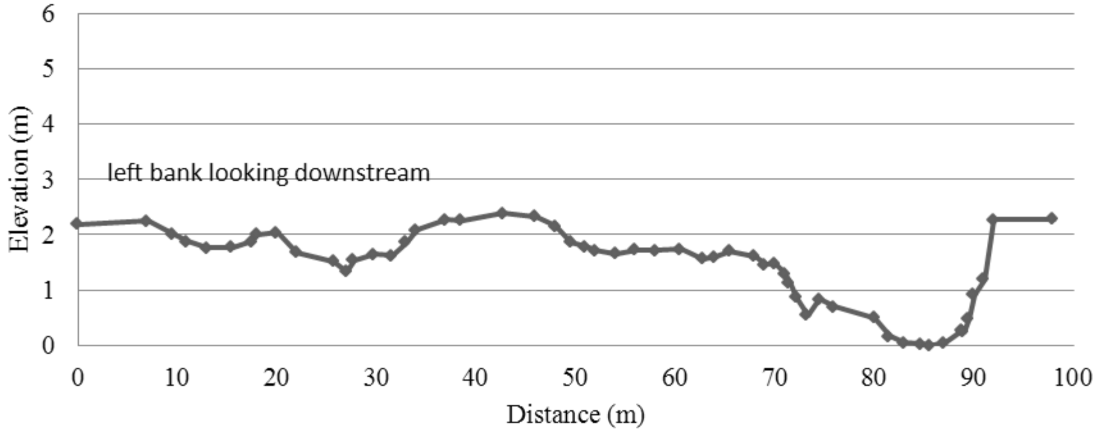

FIELD SITE 4-5
CX1 @ RC Before Old Distrubance

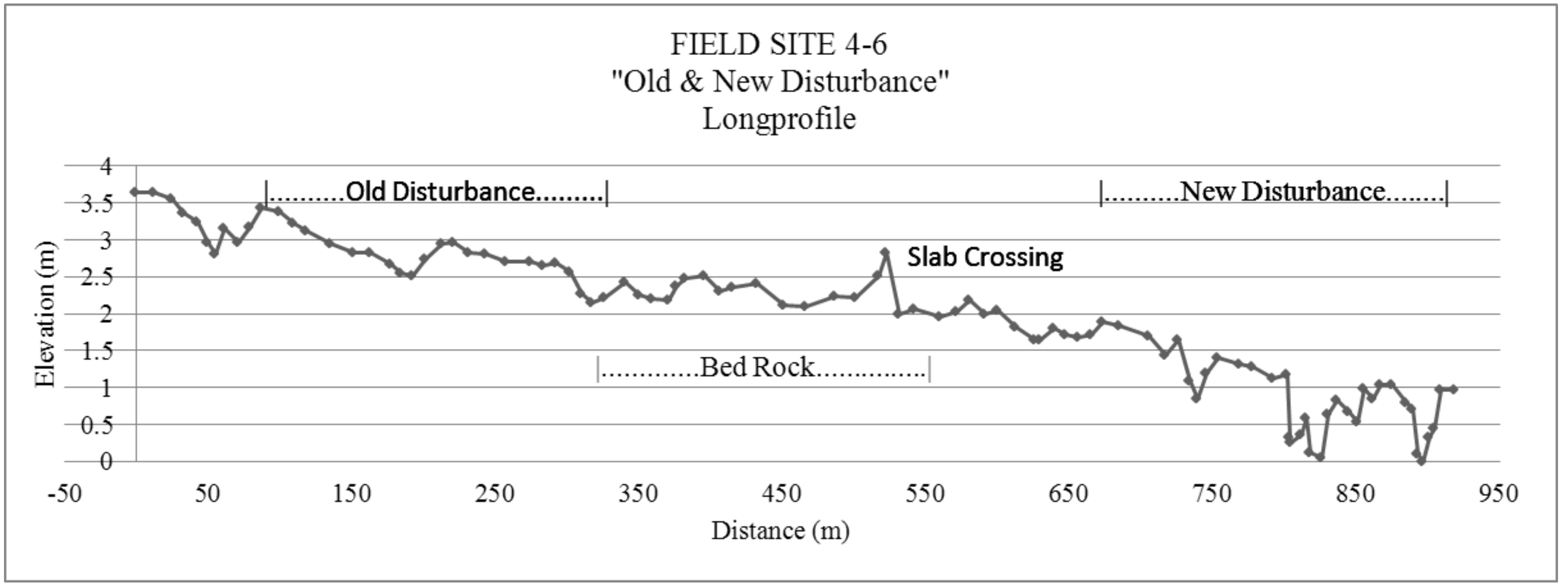

FIELD SITE 4-5
CX2 @ Max Disturbance

FIELD SITE 5-6
CX1 @ Bedrock RC Before Disturbance



FIELD SITE 5-6
CX2 @ Max Disturbance

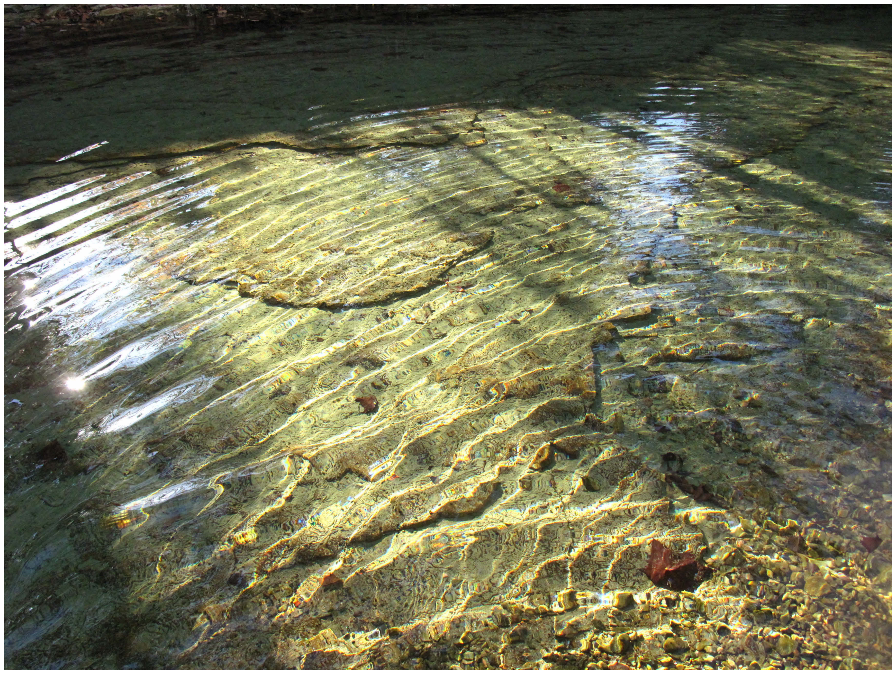



FIELD SITE 4-6
"Old & New Disturbance"
Longprofile
Elevation (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
-50
50
150
250
350
450
550
650
750
850
950
Distance (m)
|..........Old Disturbance.........|
|..........New Disturbance........|
Slab Crossing
|.............Bed Rock...............|

CX1 with DavidDickson running the stadia rod. Note large logs submerged in left of photo.

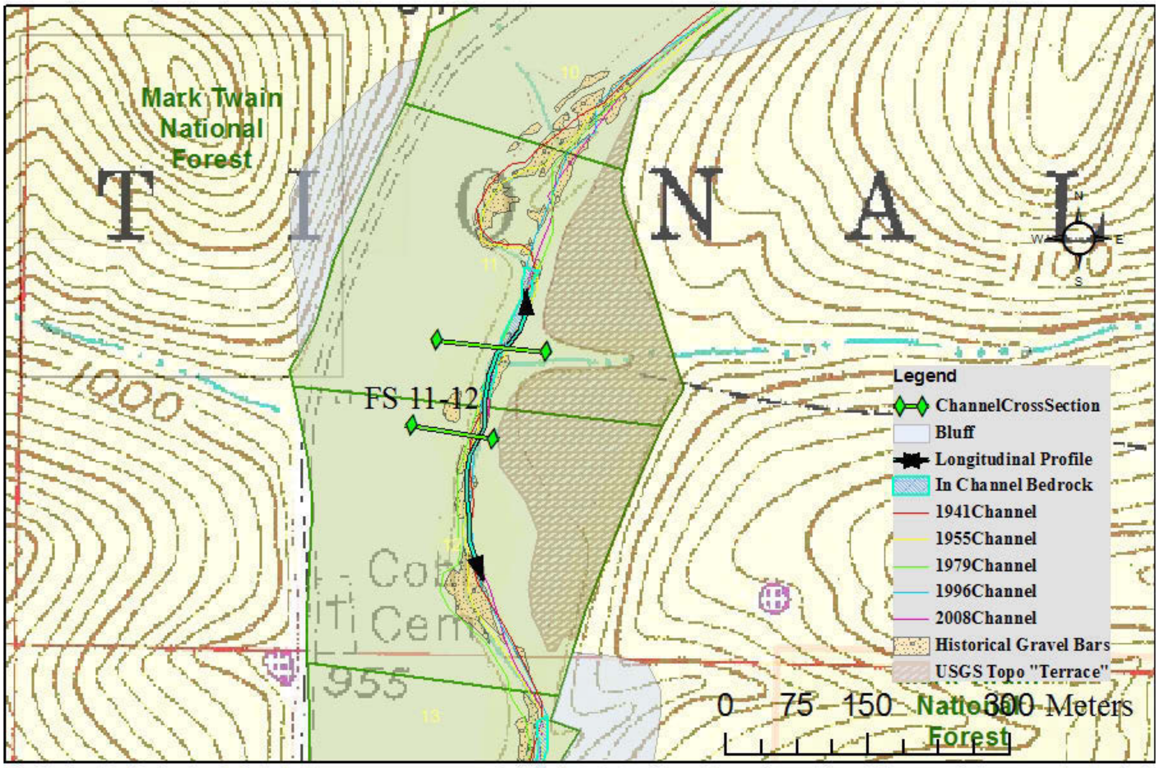
Mega bar of loose gravel directly above cross section one at FS5-6.

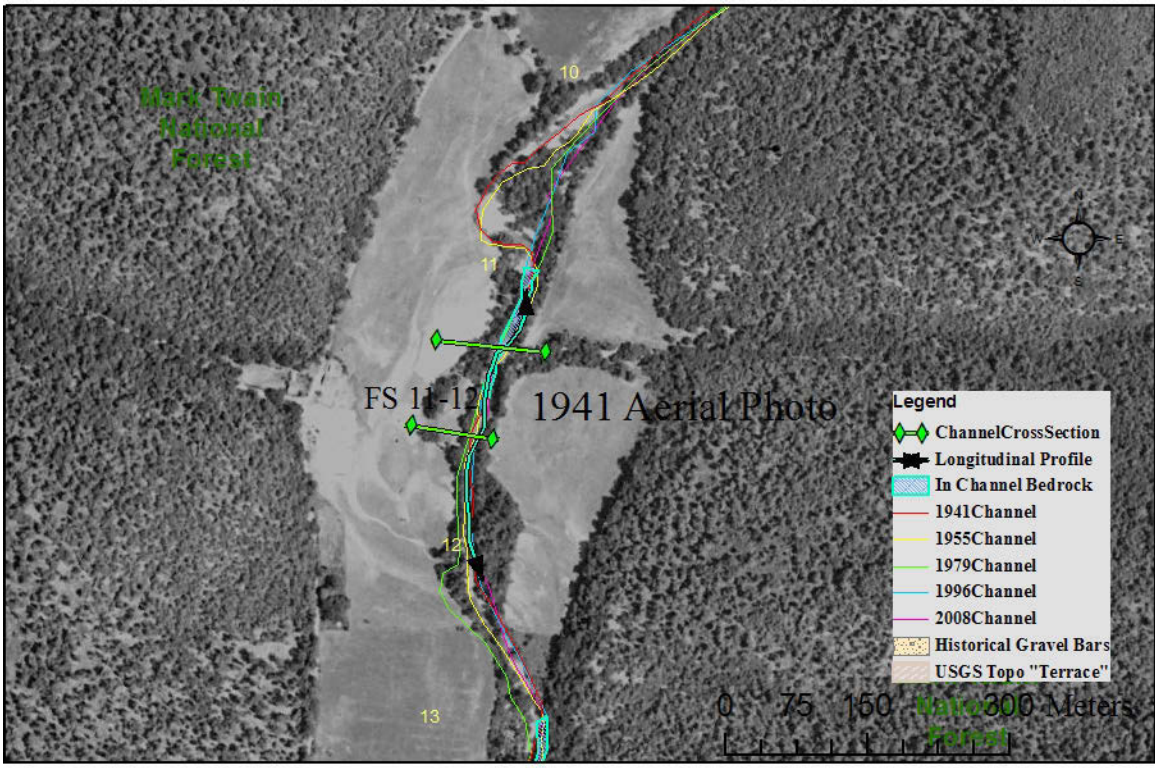
Kyle Kosovich next to Srath terrace at FS5-6 stable channel reach

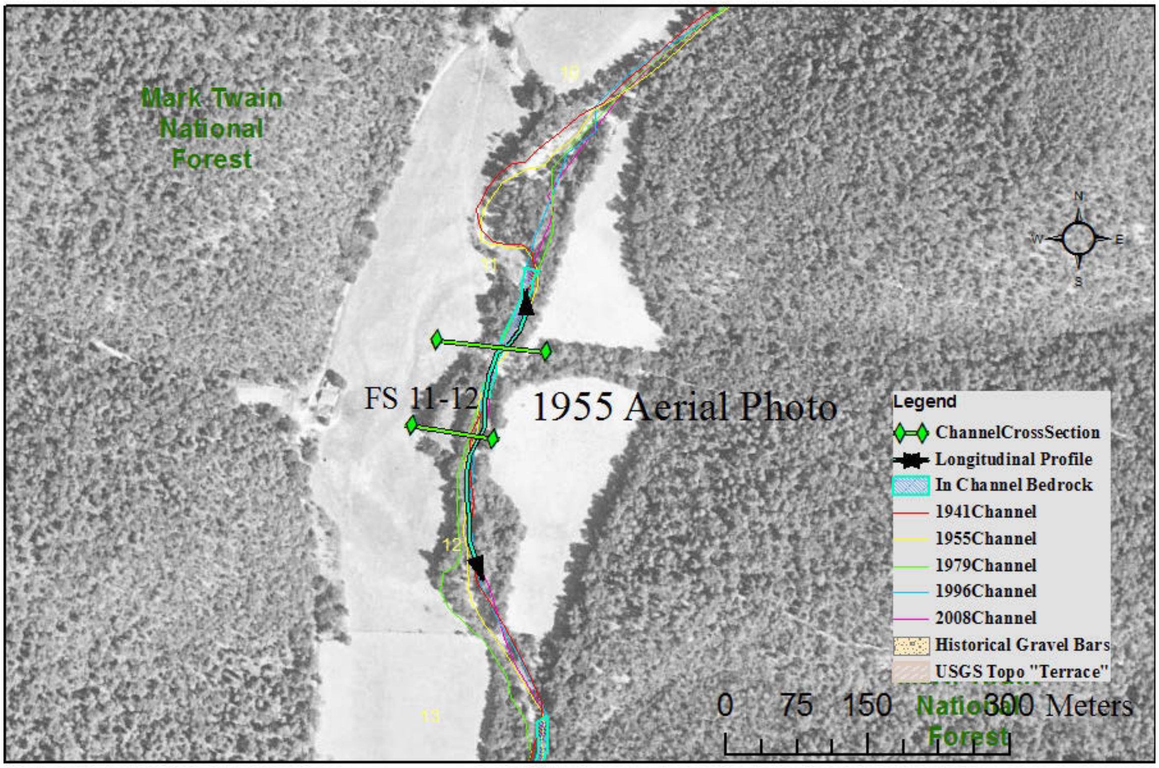


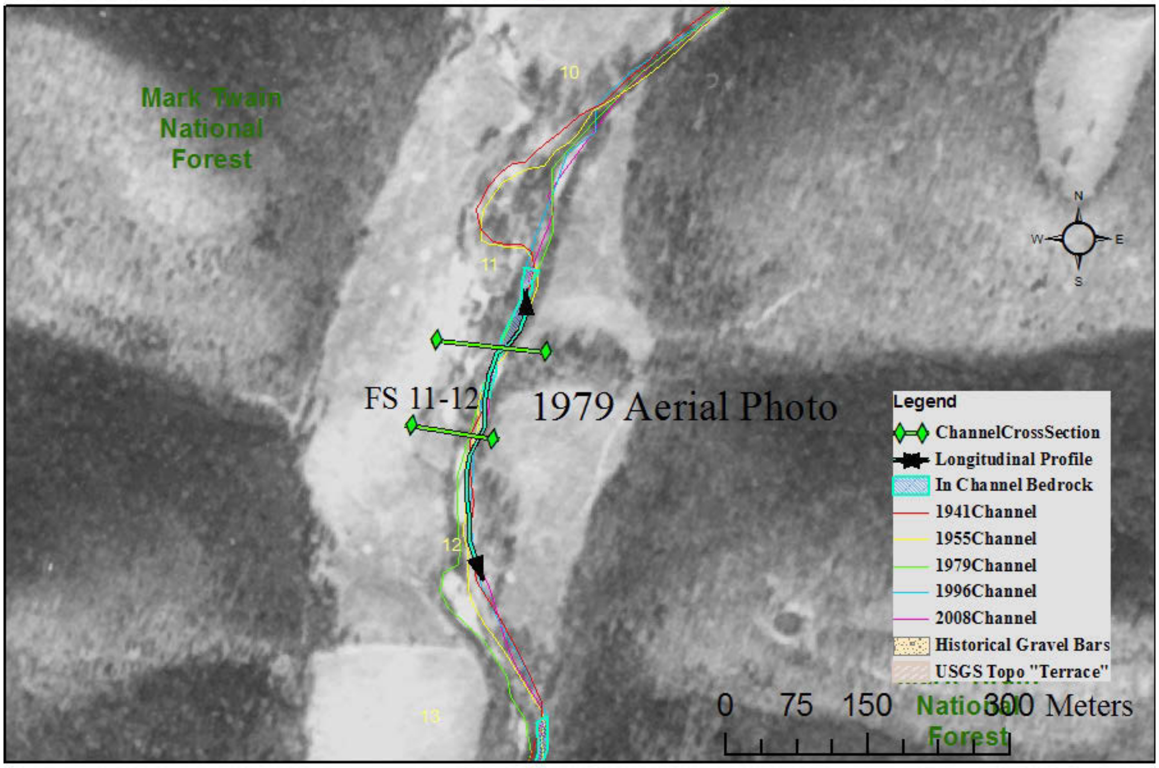
In-channel bedrock example FS5-6

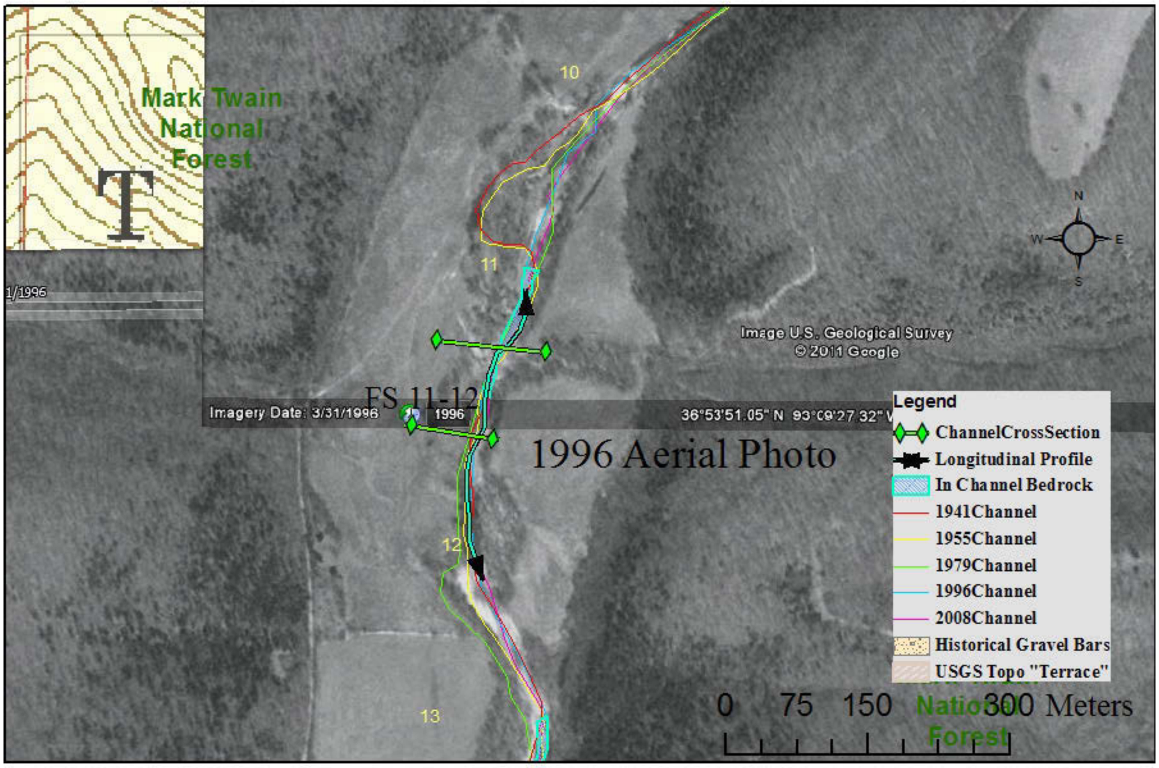
# Appendix B: Field Site 11-12

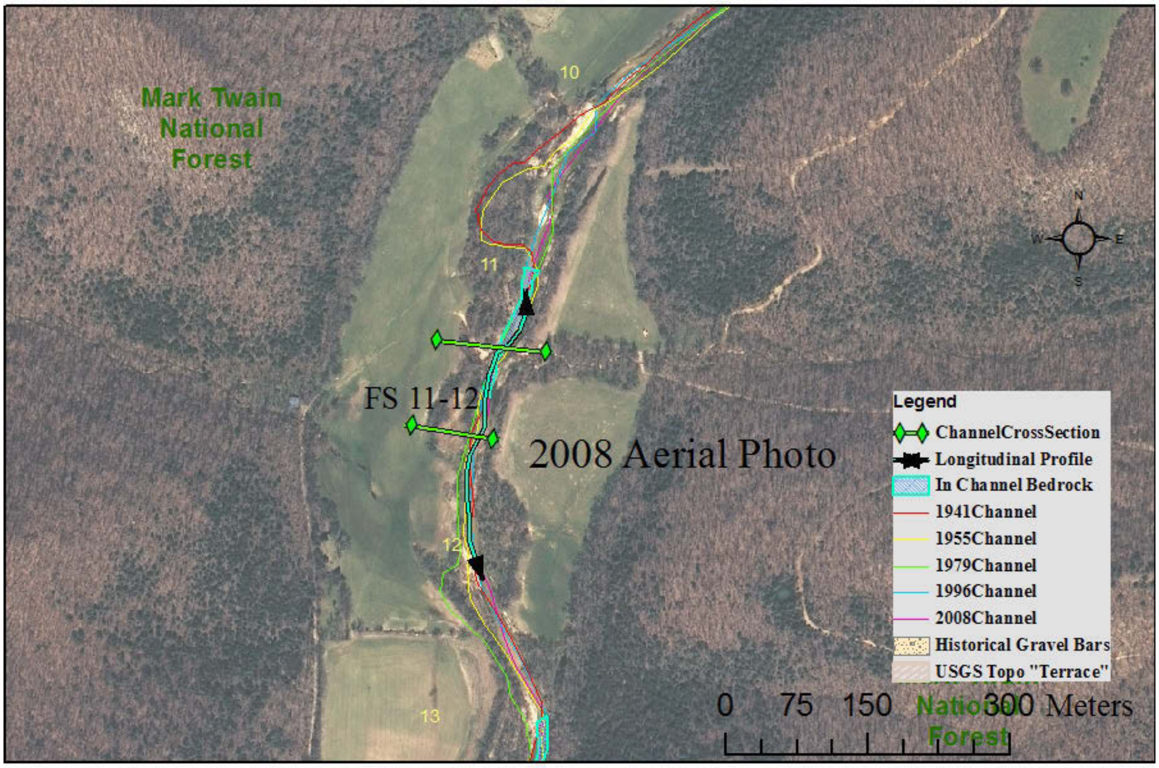





Mark Twain
National
Forest
10
11
FS 11-12
1955 Aerial Photo
12
13
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
0 75 150 300 Meters
National
Forest


Mark Twain
National
Forest
10
11
FS 11-12
1979 Aerial Photo
12
13
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
0 75 150 300 Meters
National
Forest


Mark Twain National Forest
T
1/1996
10
11
12
13
Image U.S. Geological Survey
© 2011 Google
Imagery Date: 3/31/1996
1996
36°53'51.05" N 93°09'27.32" W
FS 11-12
1996 Aerial Photo
N
E
S
W
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
0 75 150 300 Meters
National Forest


Mark Twain National Forest
10
11
12
13
FS 11-12
2008 Aerial Photo
N
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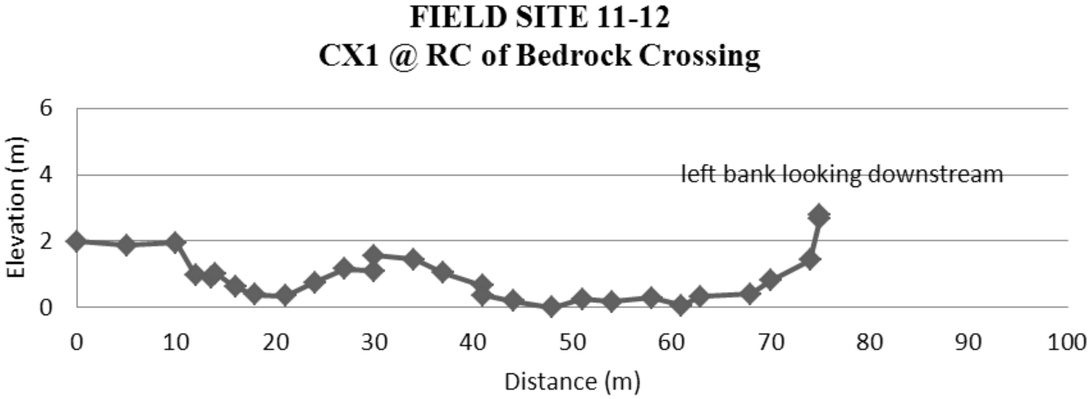
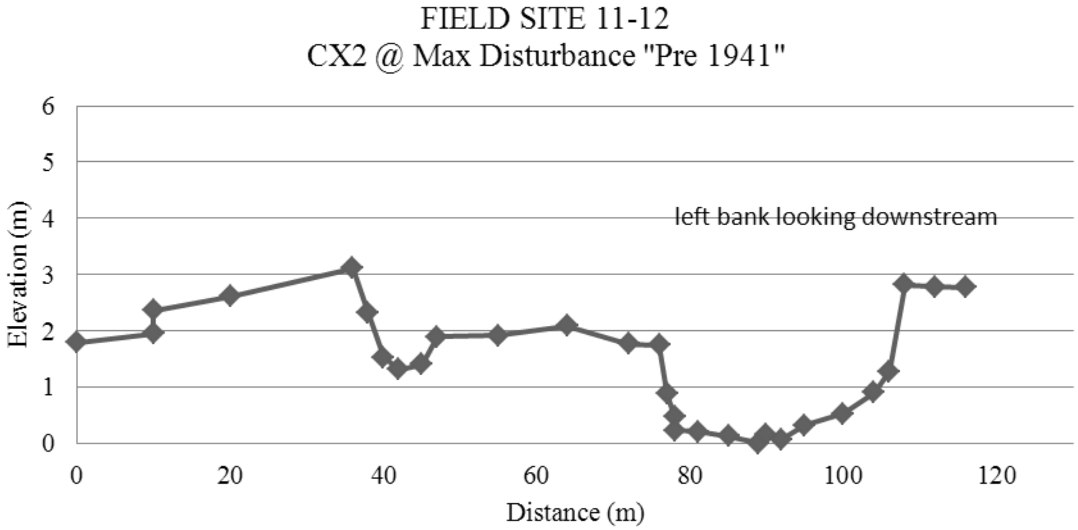
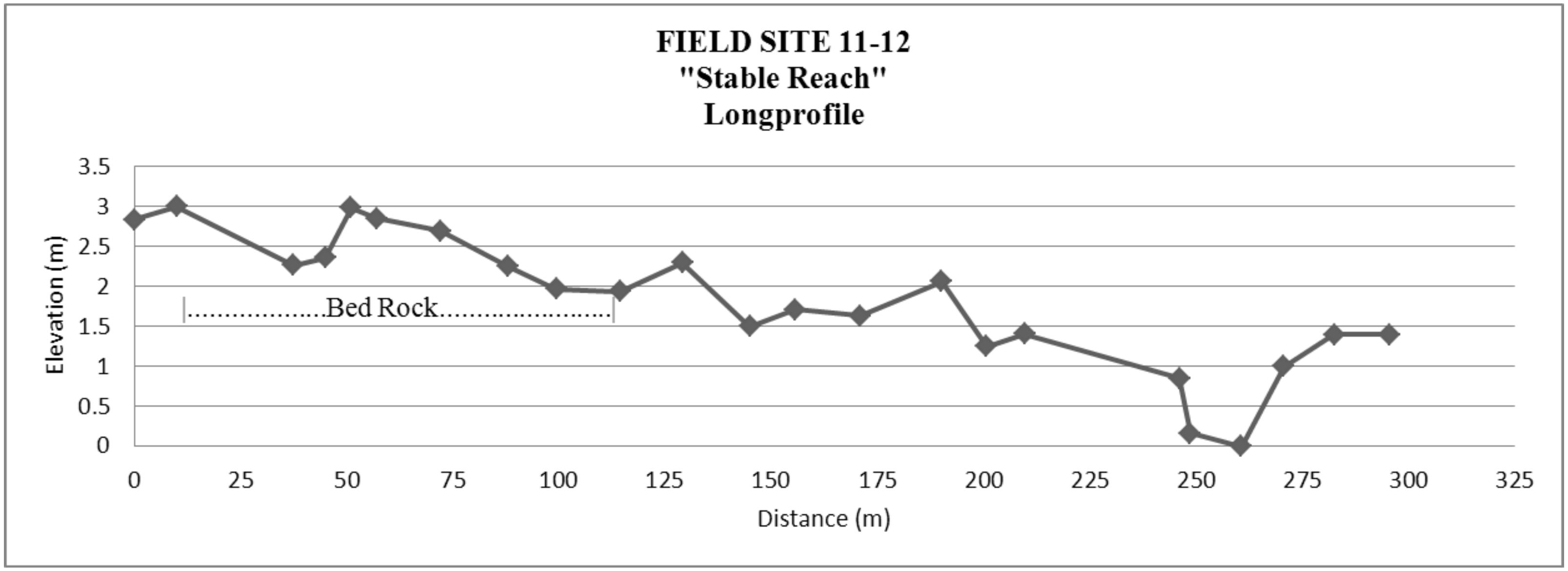
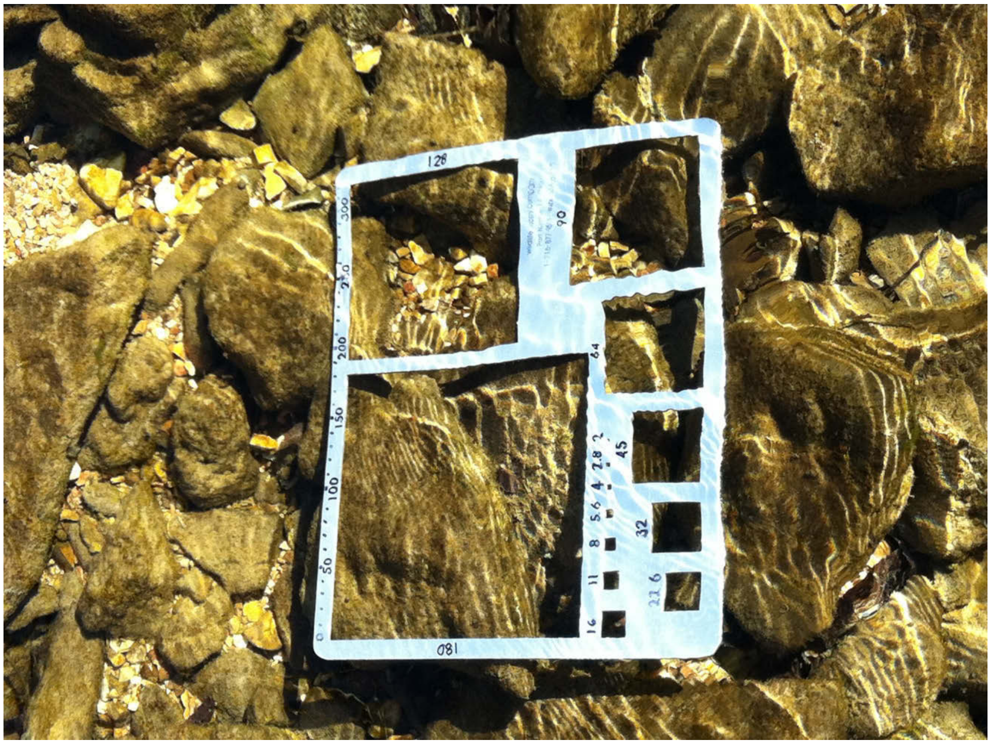
S
W
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
0 75 150 300 Meters
National Forest


**FIELD SITE 11-12**
**CX1 @ RC of Bedrock Crossing**


FIELD SITE 11-12
CX2 @ Max Disturbance "Pre 1941"

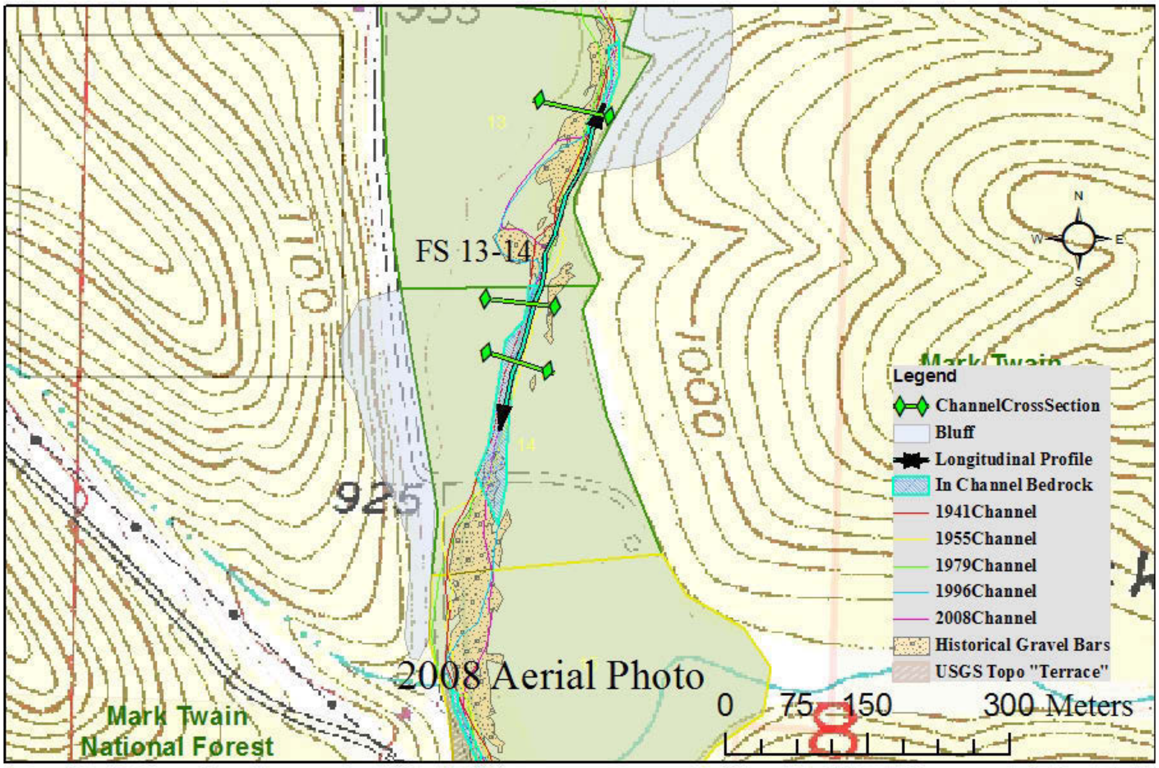

FIELD SITE 11-12
"Stable Reach"
Longprofile
Elevation (m)
3.5
3
2.5
2
1.5
1
0.5
0
Bed Rock
0
25
50
75
100
125
150
175
200
225
250
275
300
325
Distance (m)

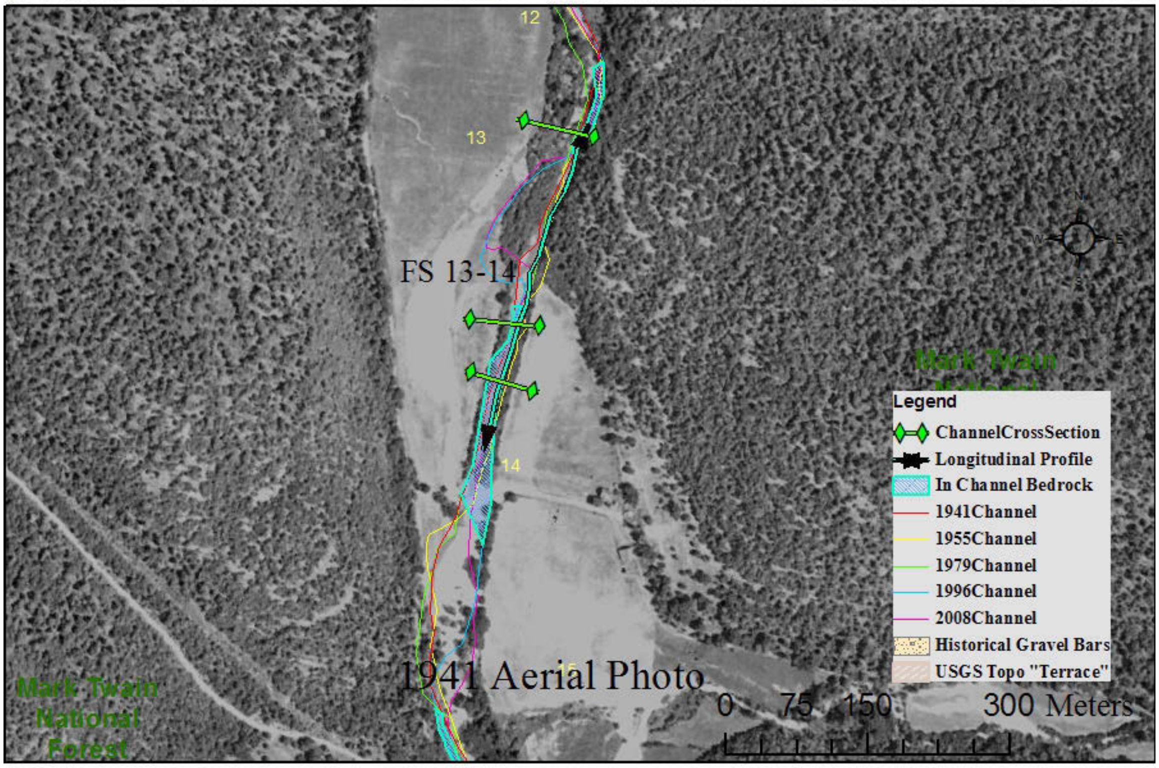


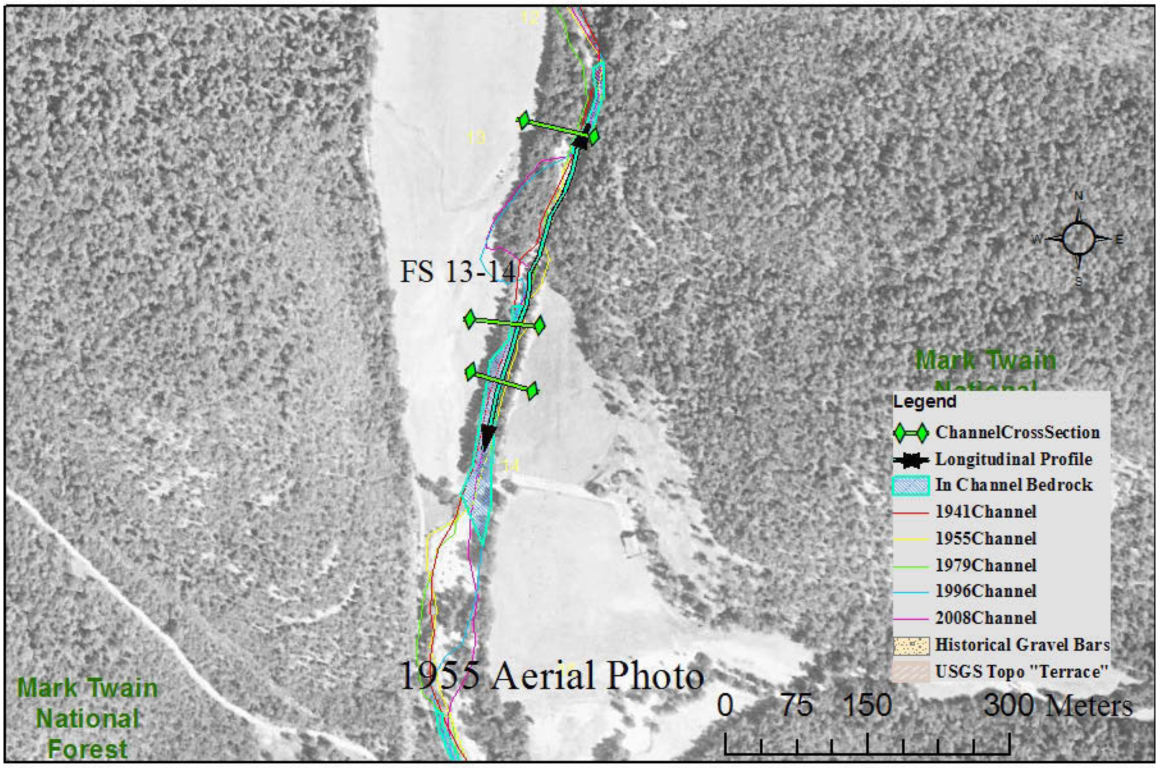
A picture from the riffel crest below the bedrock reach. An example of some of the large flat pieces on the far left of the image.

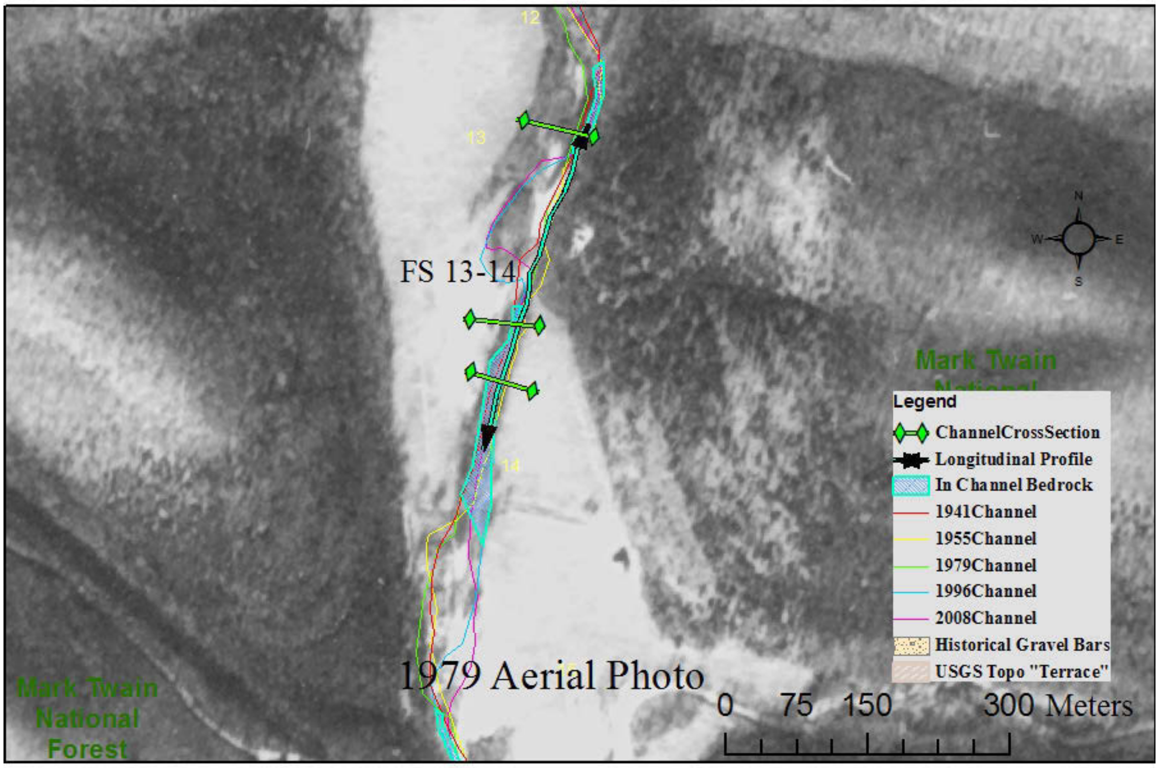
CX1 at FS 11-12, just upstream of bedrock crossing at riffle crest.

## Appendix C: Field Site 13-14






12
13
14
FS 13-14
N
W
E
S
Mark Twain National
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
Mark Twain National Forest
1955 Aerial Photo
0 75 150 300 Meters


12
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FS 13-14
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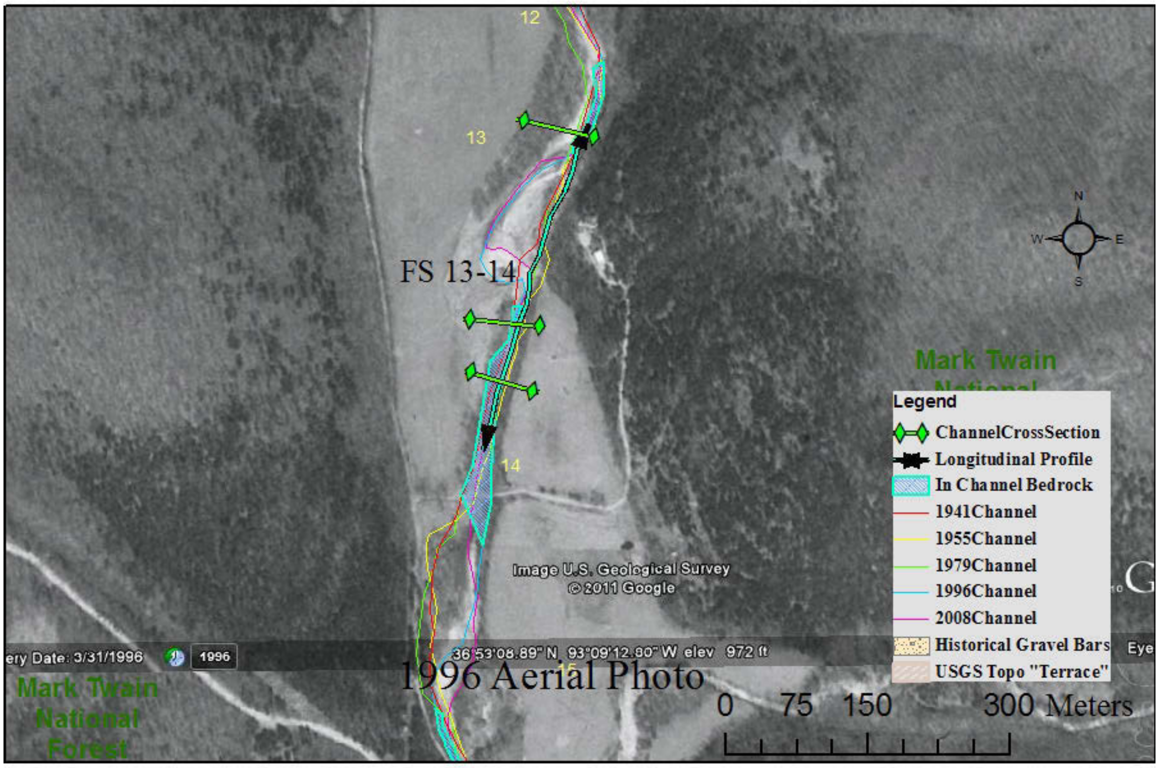
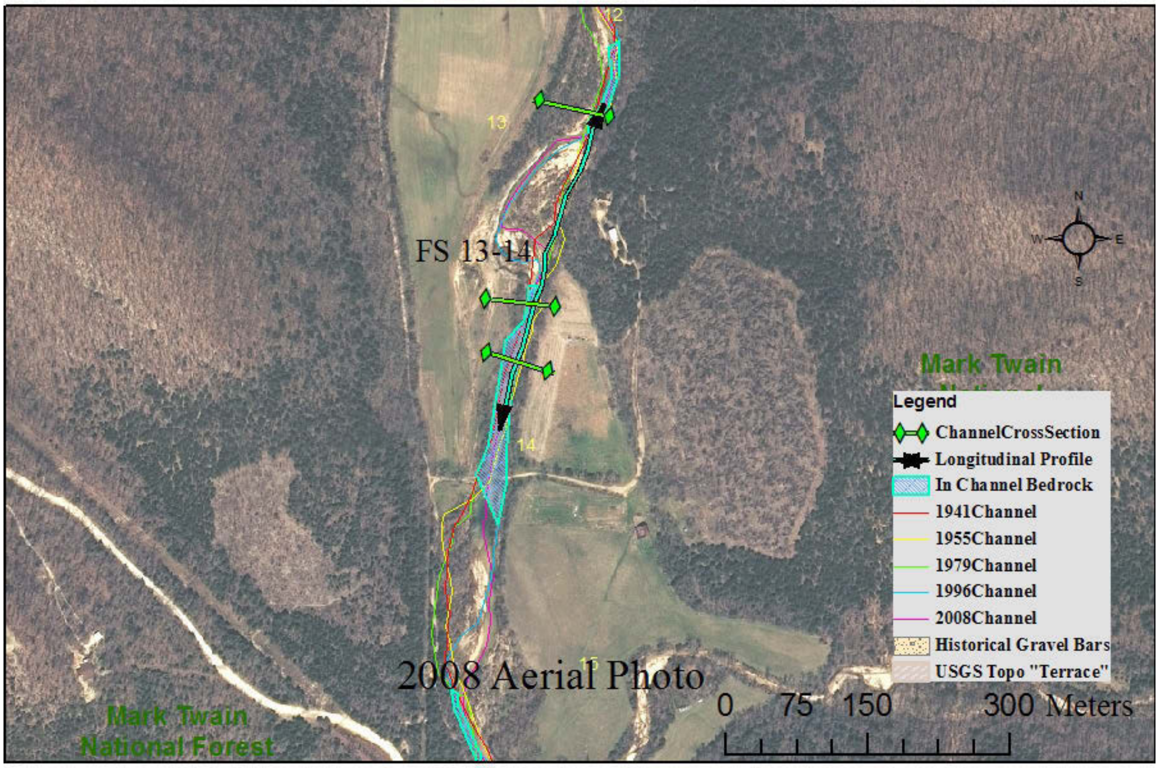
Mark Twain National
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
Mark Twain National Forest
1979 Aerial Photo
0 75 150 300 Meters


12
13
FS 13-14
14
15
Mark Twain National
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
Image U.S. Geological Survey
© 2011 Google
ery Date: 3/31/1996
1996
36°53'08.89" N 93°09'12.80" W elev 972 ft
Eye
1996 Aerial Photo
Mark Twain National Forest
0 75 150 300 Meters
N
W
E
S


12
13
FS 13-14
14
15
Mark Twain National
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Historical Gravel Bars
USGS Topo "Terrace"
2008 Aerial Photo
Mark Twain National Forest
0 75 150 300 Meters
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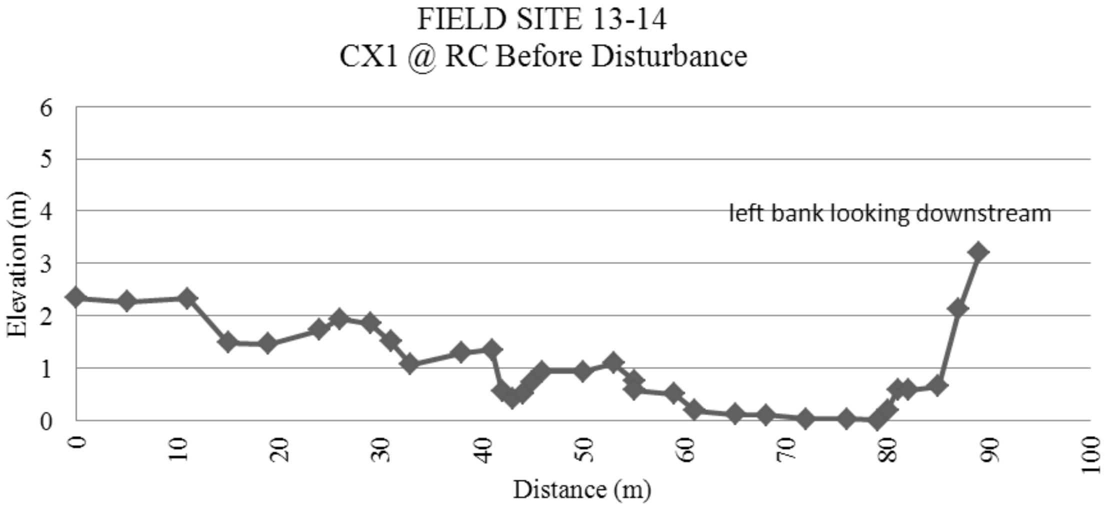
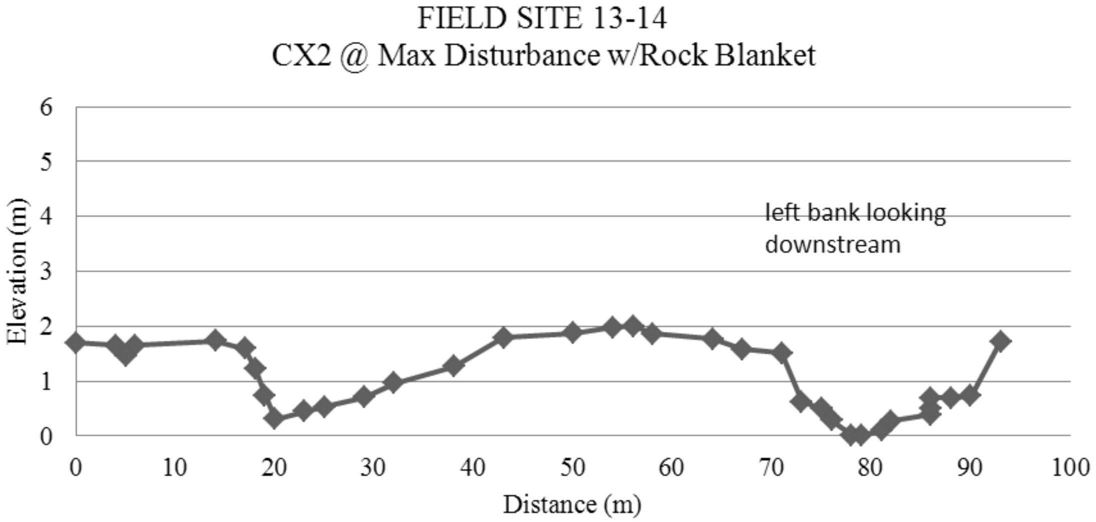
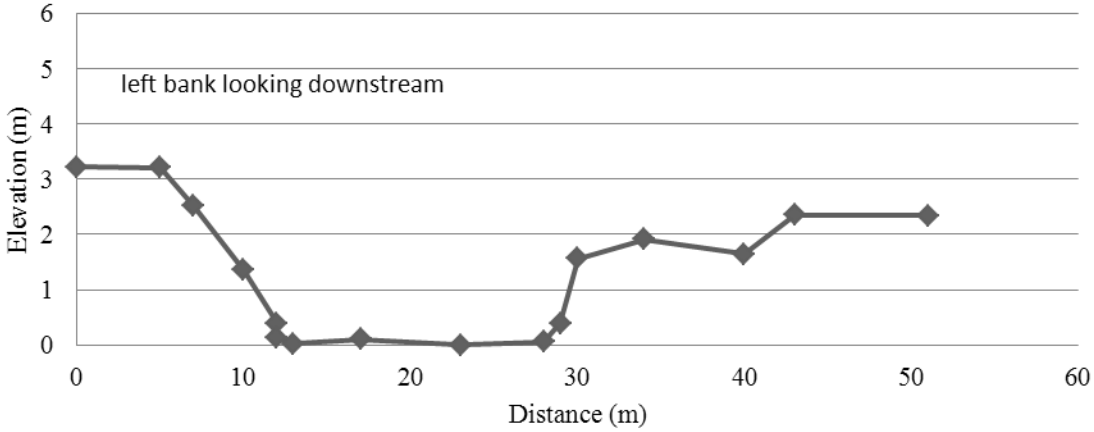


FIELD SITE 13-14
CX1 @ RC Before Disturbance

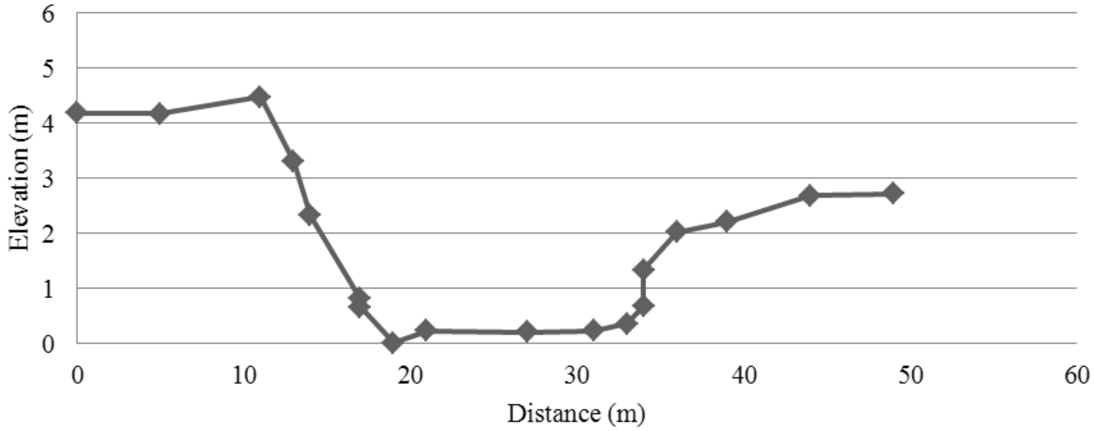


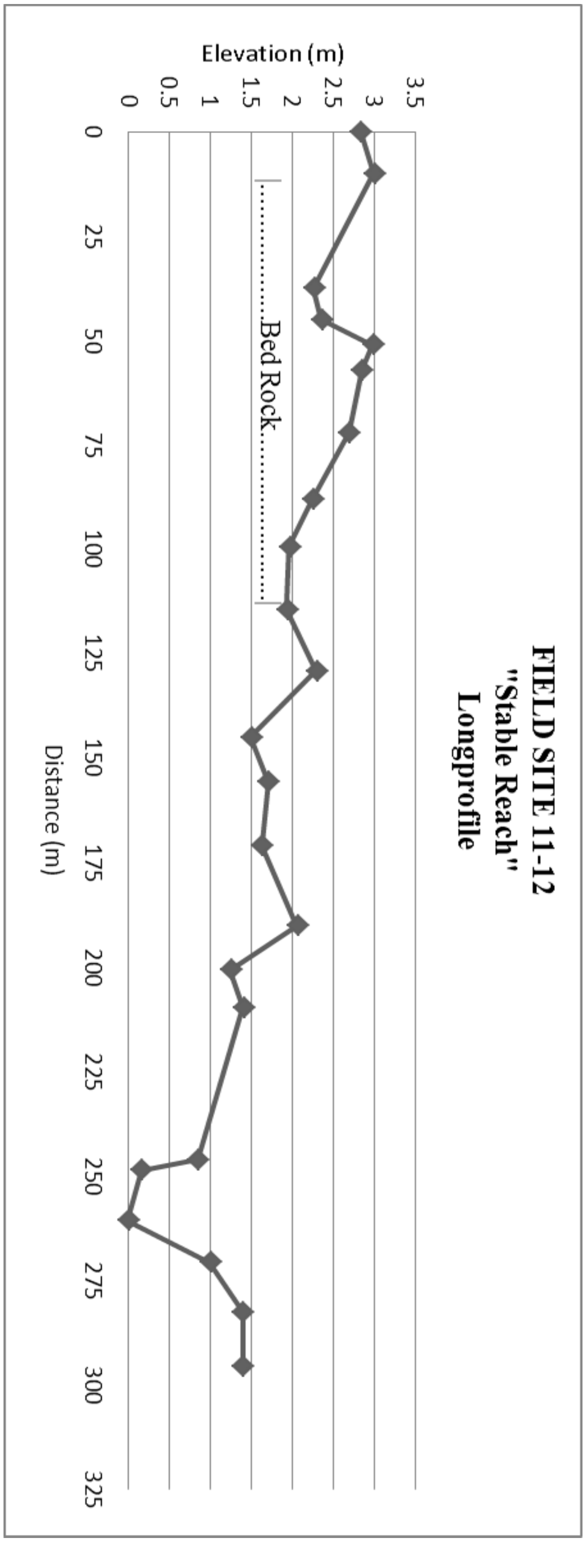
FIELD SITE 13-14
CX2 @ Max Disturbance w/Rock Blanket

FIELD SITE 13-14
CX3 @ Bedrock Reach



FIELD SITE 12-13
CX4 @ Bedrock Reach

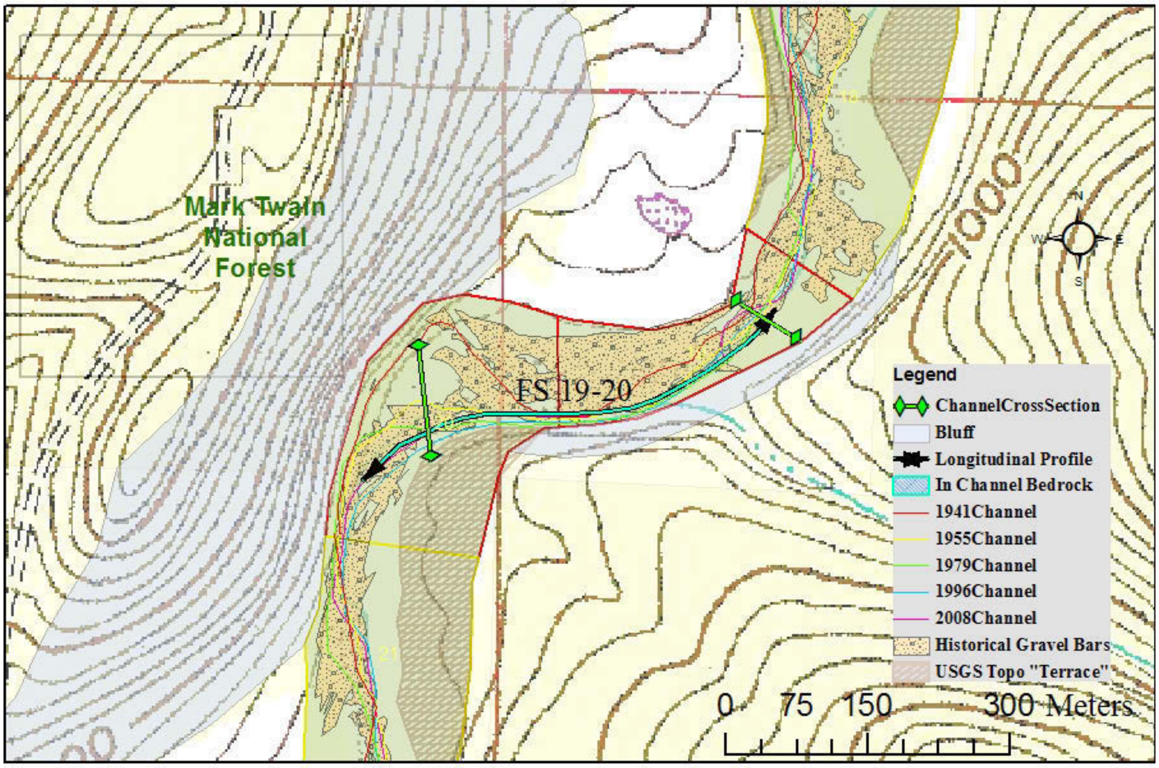


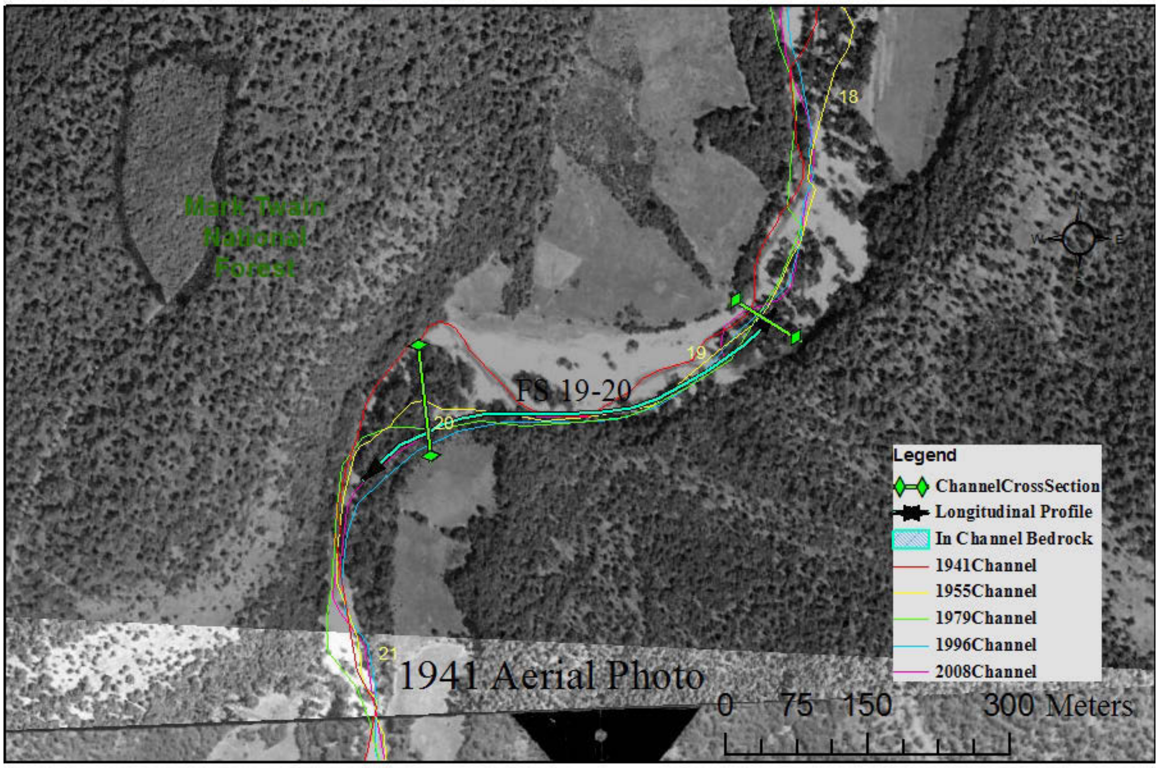

FIELD SITE 11-12
"Stable Reach"
Longprofile
Elevation (m)
0
0.5
1
1.5
2
2.5
3
3.5
Bed Rock
Distance (m)
0
25
50
75
100
125
150
175
200
225
250
275
300
325

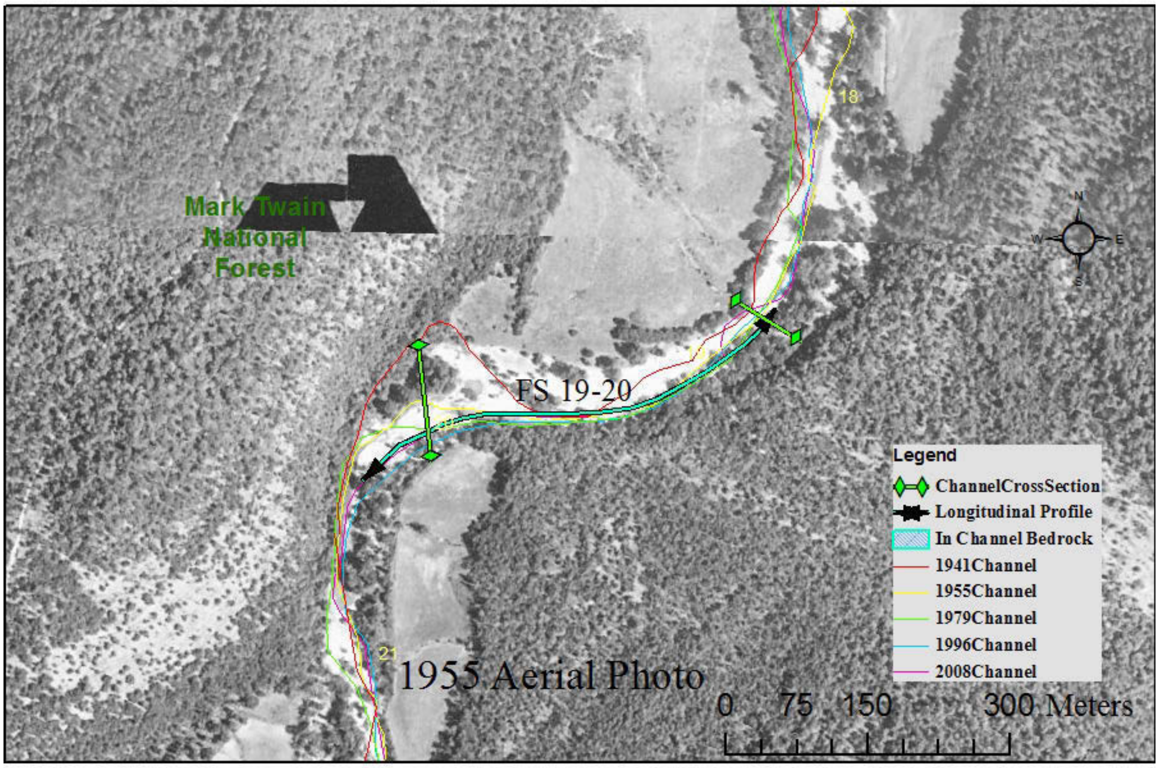
Megabar formation at FS 11-12. Pebble Count workers in background

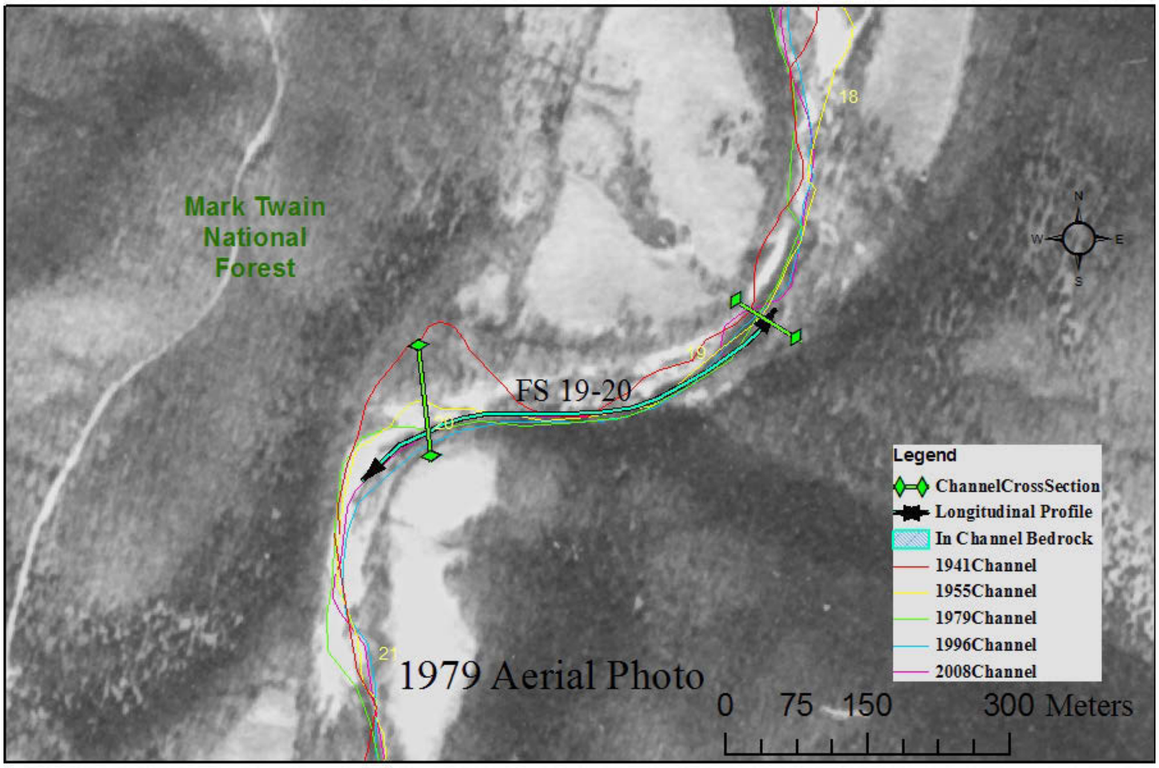
Adjacent of megabar at FS11-12 with erosion into floodplain coluvium

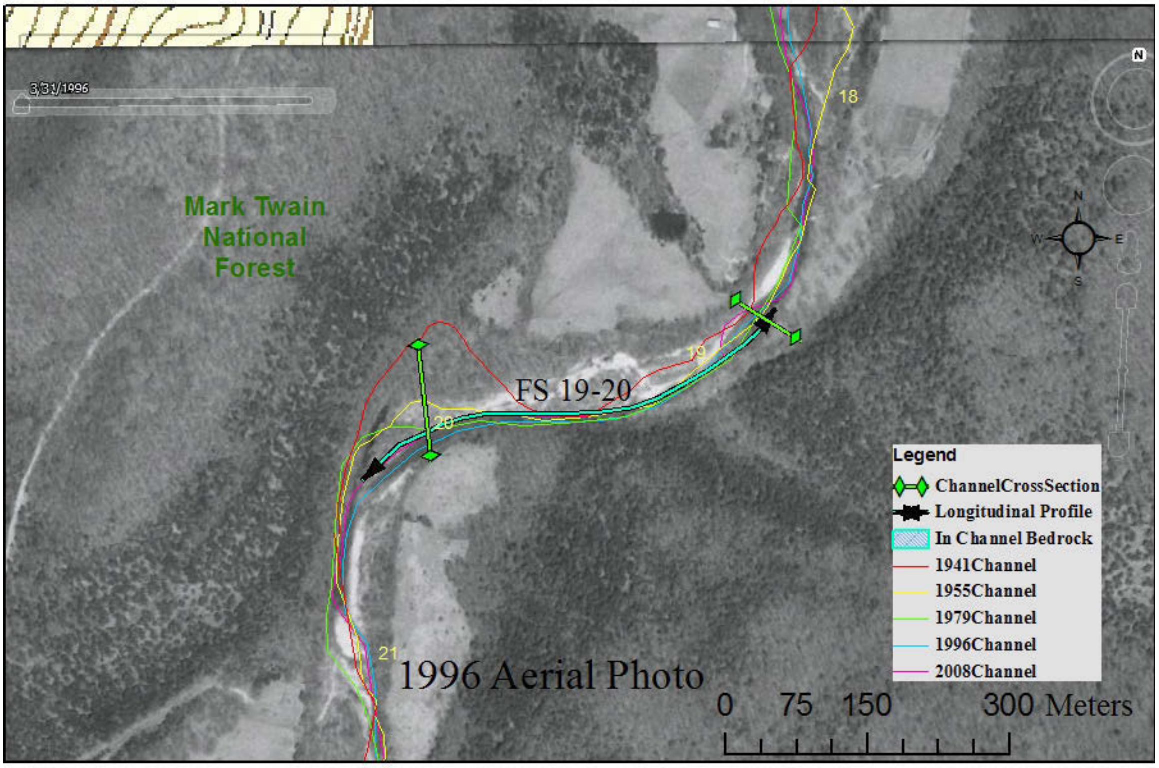
## Appendix D: FieldSite 19-20

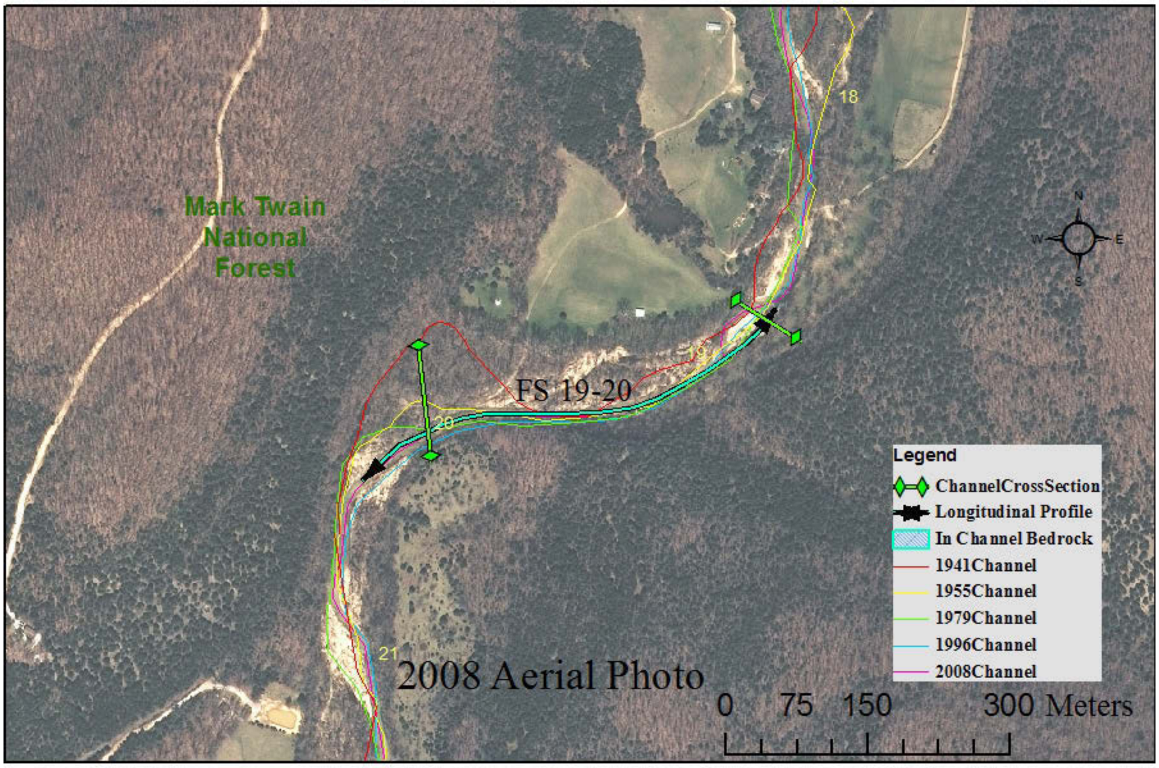


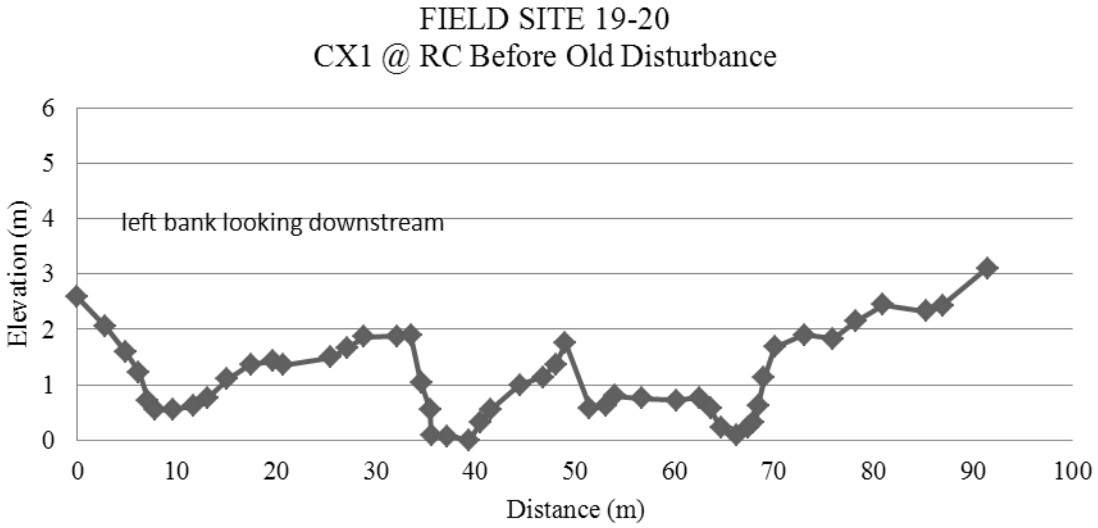


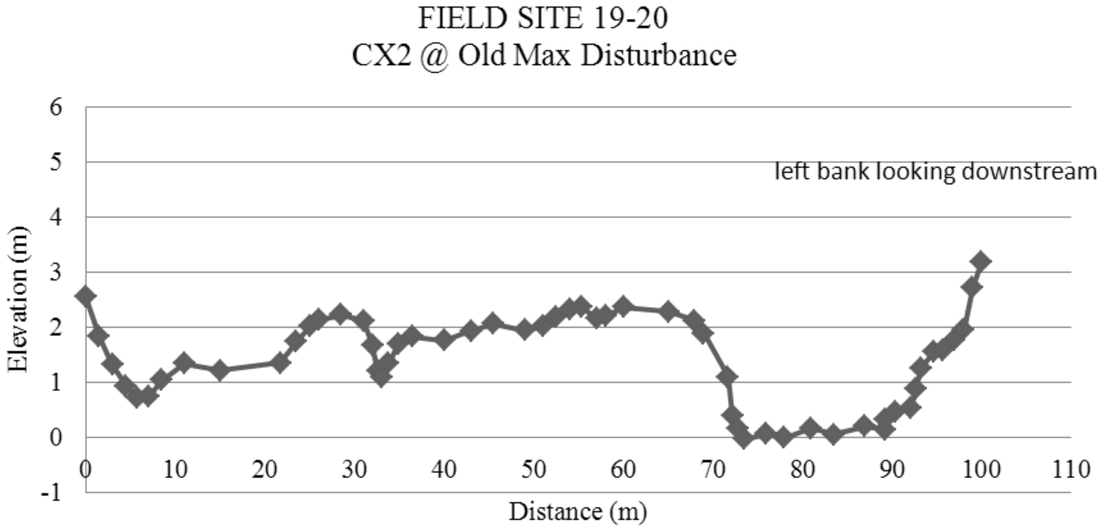

Mark Twain
National
Forest
18
FS 19-20
21
1955 Aerial Photo
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters

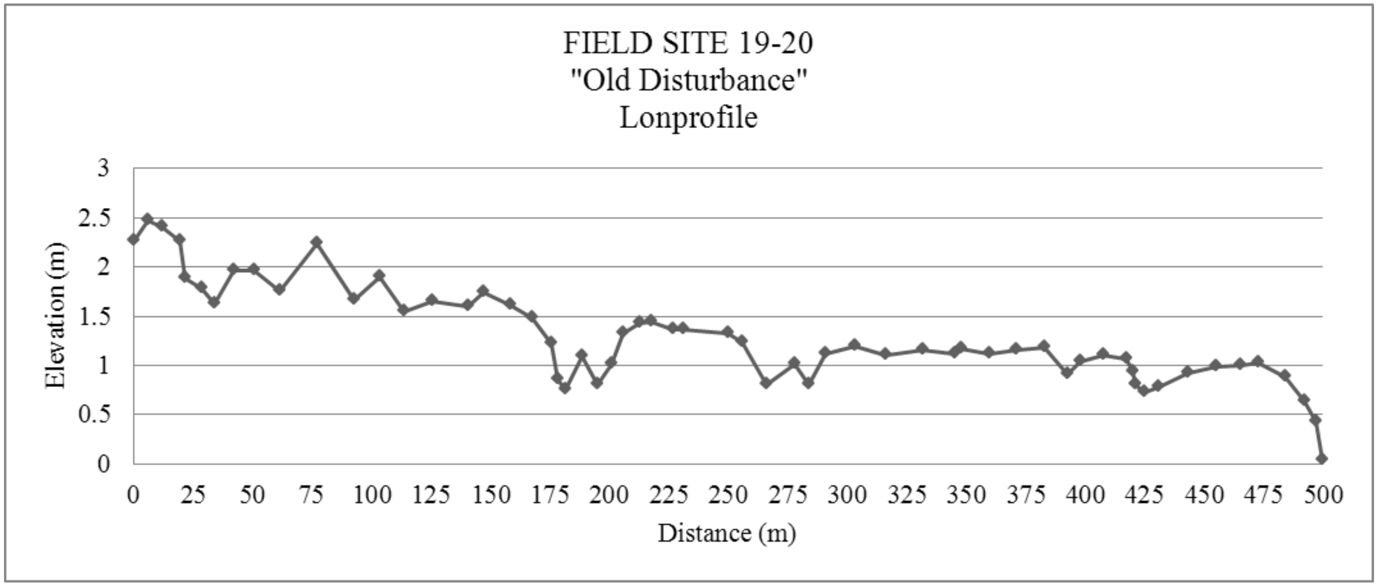

Mark Twain
National
Forest
18
19
FS 19-20
20
21
1979 Aerial Photo
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters


3/31/1996
18
Mark Twain National Forest
19
FS 19-20
20
21
1996 Aerial Photo
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters


18
Mark Twain National Forest
19
FS 19-20
20
21
2008 Aerial Photo
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
0 75 150 300 Meters

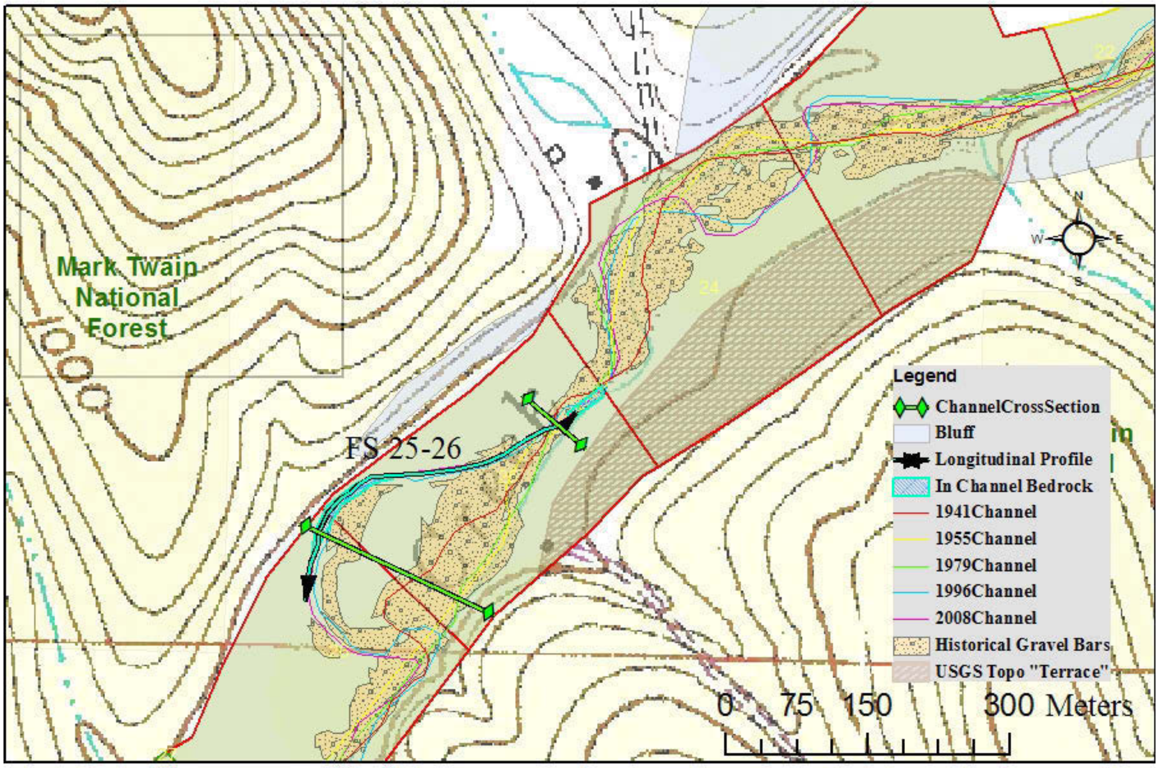

FIELD SITE 19-20
CX1 @ RC Before Old Disturbance
left bank looking downstream
Elevation (m)
0
1
2
3
4
5
6
Distance (m)
0
10
20
30
40
50
60
70
80
90
100

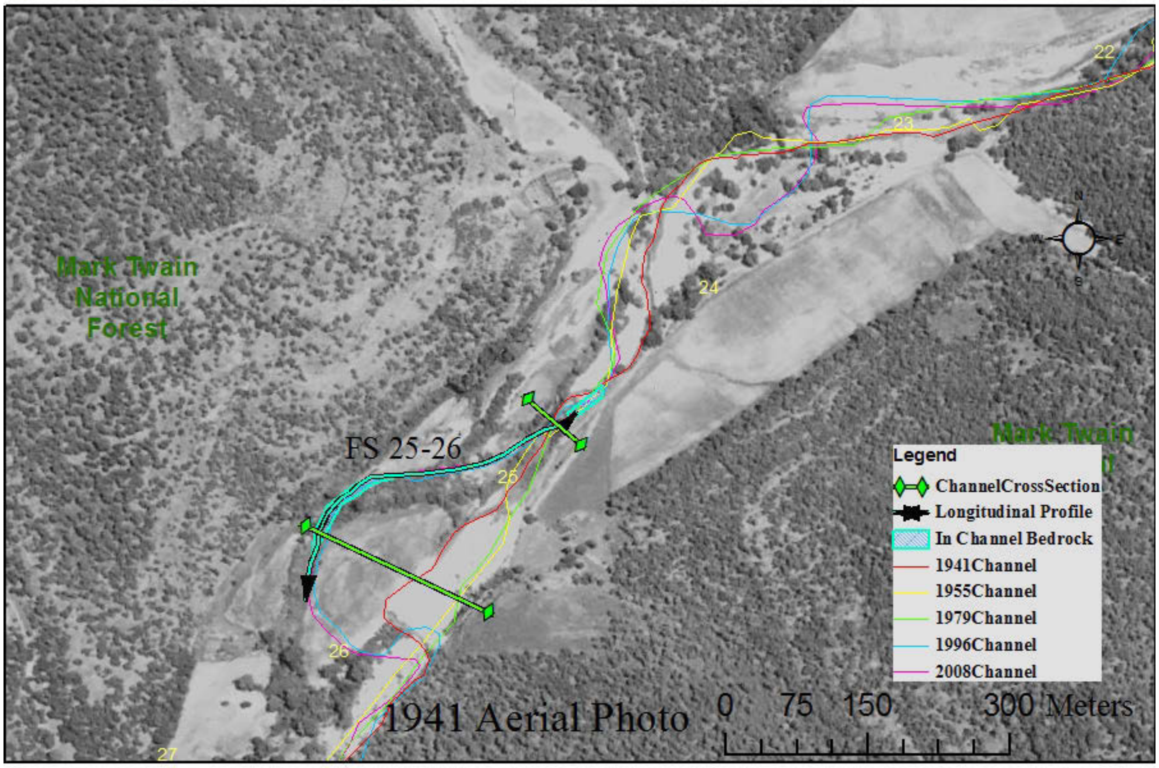

FIELD SITE 19-20
CX2 @ Old Max Disturbance
left bank looking downstream
Elevation (m)
-1
0
1
2
3
4
5
6
Distance (m)
0
10
20
30
40
50
60
70
80
90
100
110

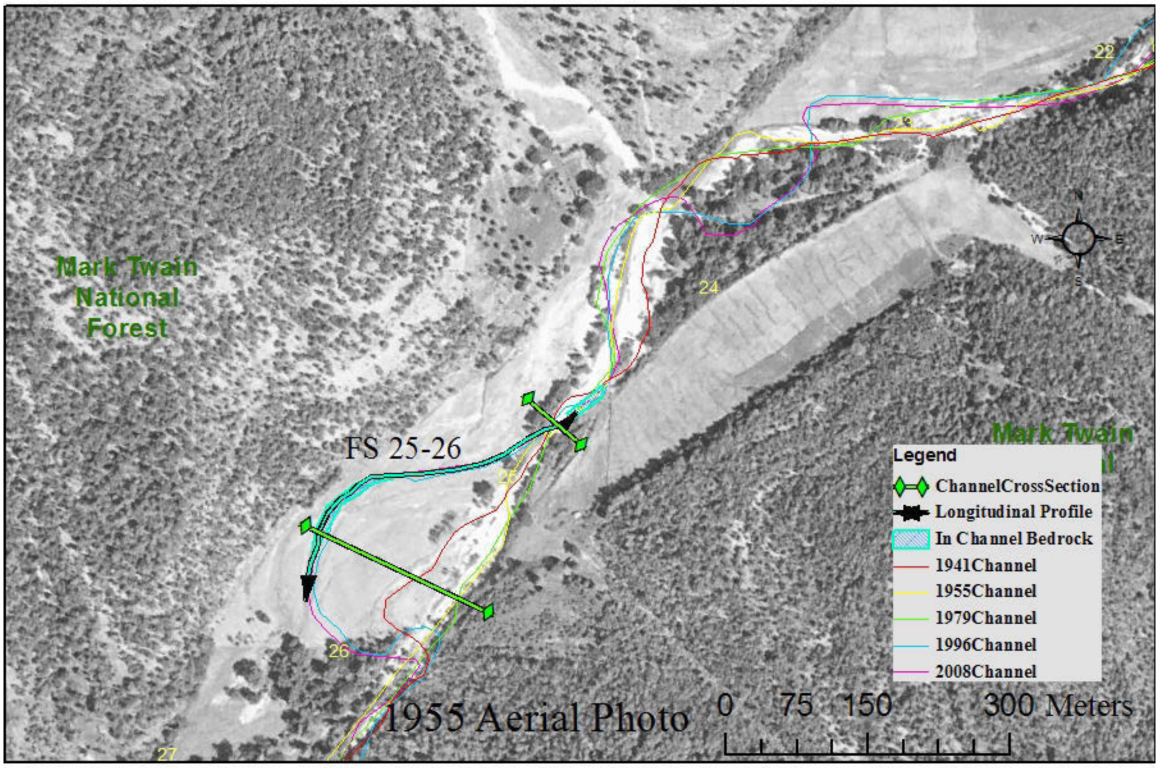

FIELD SITE 19-20
"Old Disturbance"
Lonprofile
Elevation (m)
3
2.5
2
1.5
1
0.5
0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
Distance (m)

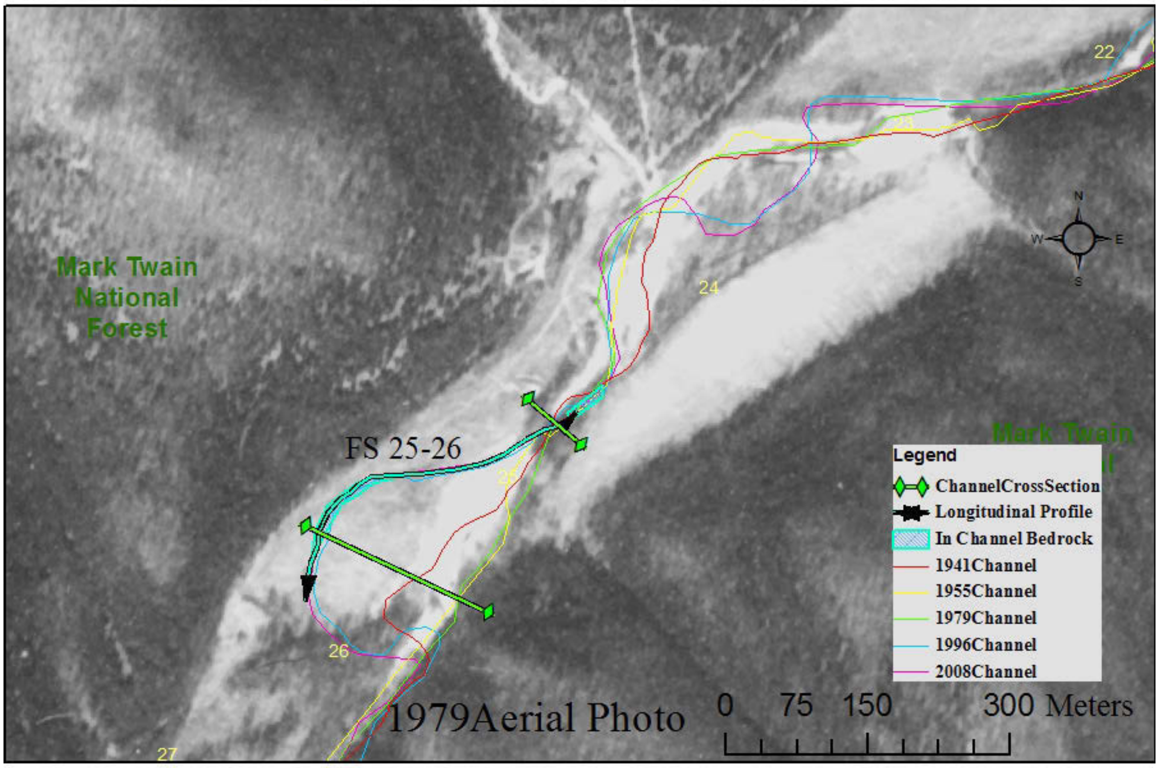
Bethany Kosovich standing in the 1955 channel with legacy sycamore fournd in historical 1941 and 1955 photographs.

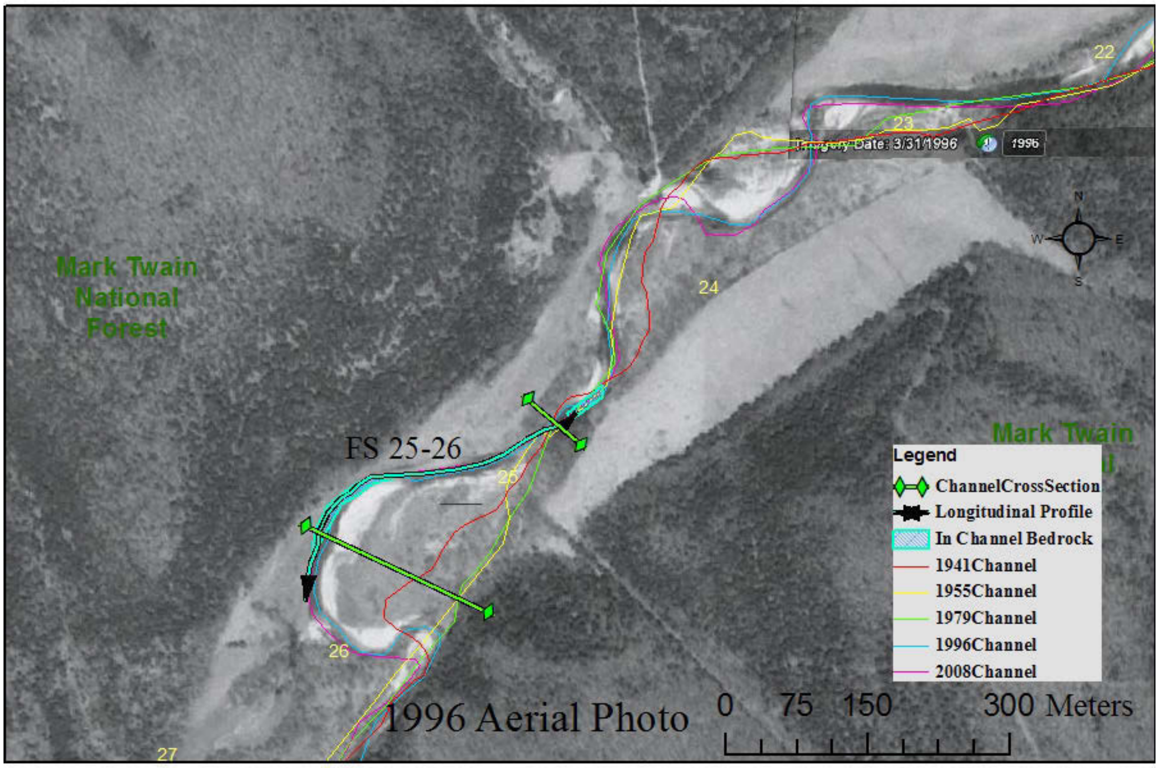
## Appendix E: Field Site 25-26

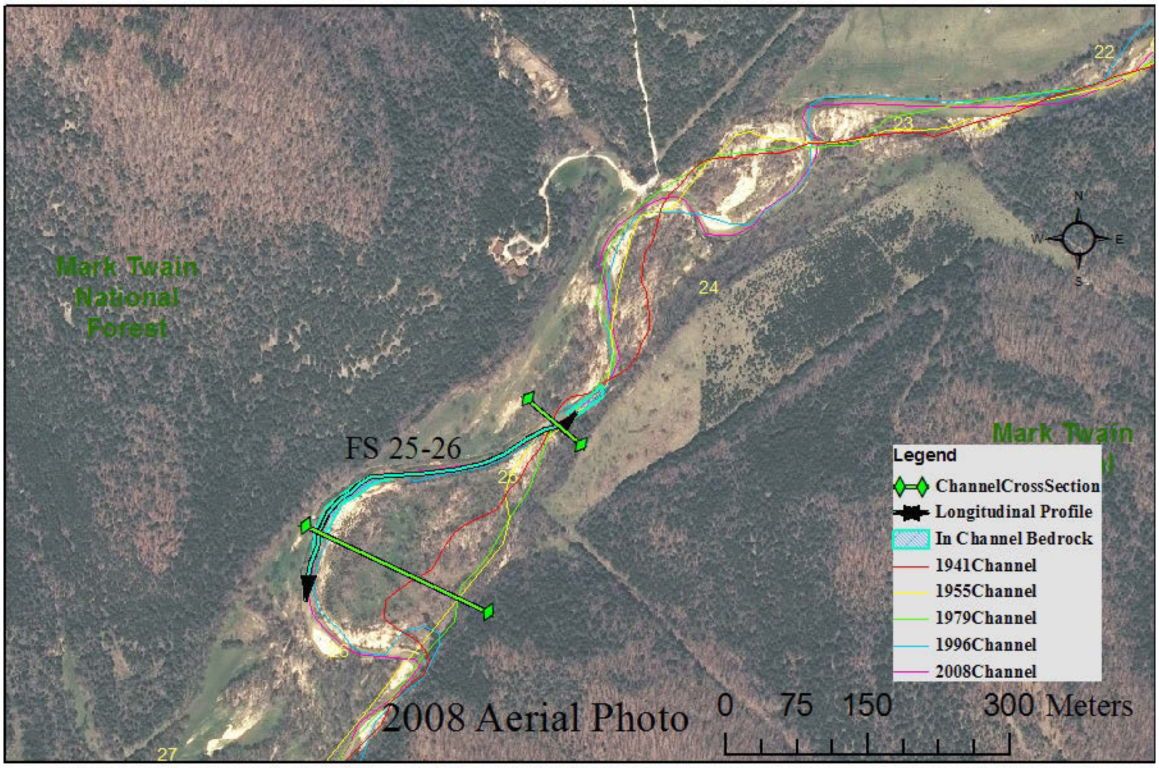




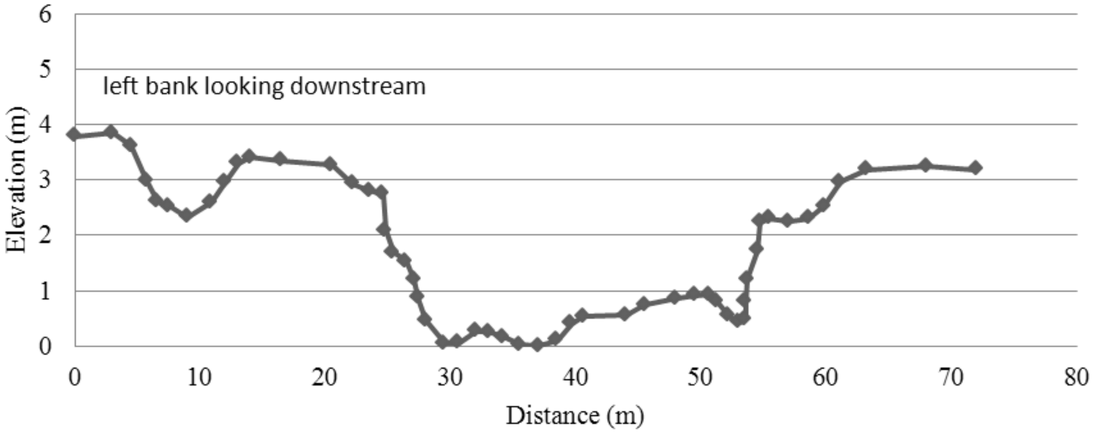

22
23
Mark Twain National Forest
24
N
W
E
S
Mark Twain National Forest
FS 25-26
25
26
27
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
1955 Aerial Photo
0 75 150 300 Meters


22
23
Mark Twain National Forest
24
N
W
E
S
Mark Twain National Forest
FS 25-26
25
26
27
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
1979Aerial Photo
0 75 150 300 Meters

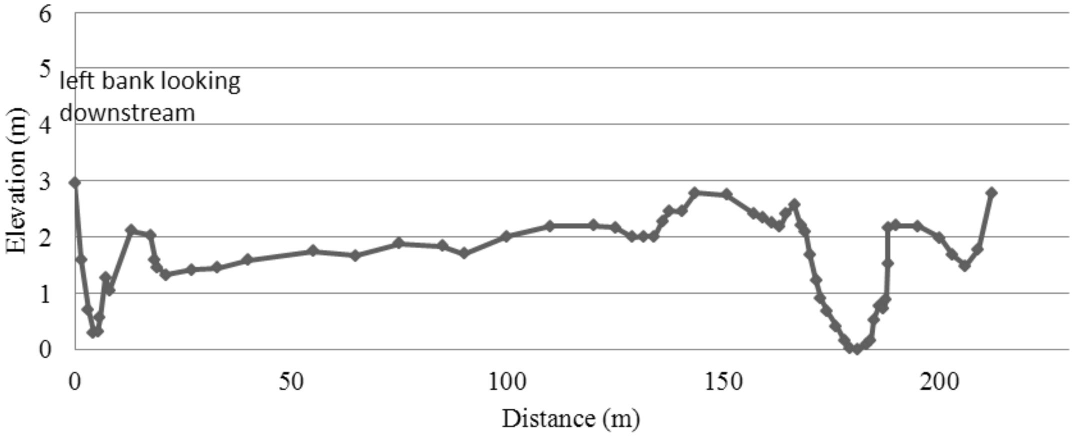

22
23
Imagery Date: 3/31/1996
1996
N
W
E
S
Mark Twain National Forest
24
Mark Twain
FS 25-26
25
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
26
1996 Aerial Photo
0 75 150 300 Meters
27

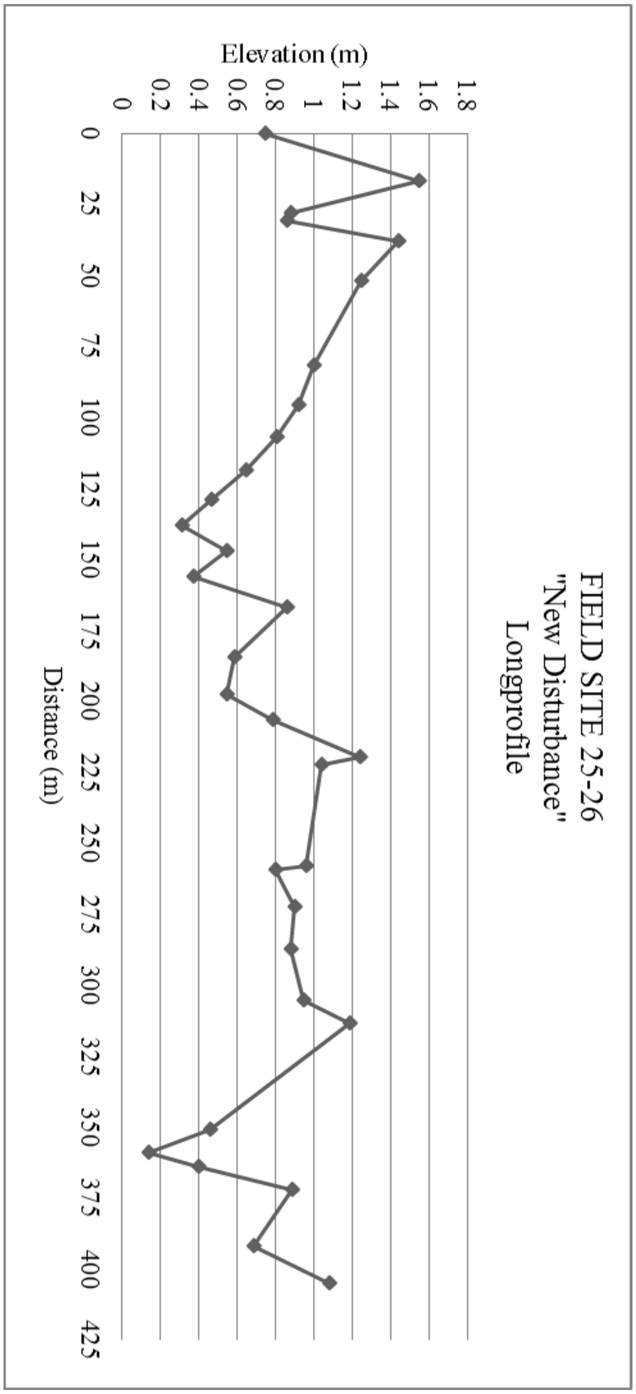

22
23
N
W
E
S
Mark Twain National Forest
24
Mark Twain
FS 25-26
25
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
26
2008 Aerial Photo
0 75 150 300 Meters
27

FIELD SITE 25-26
CX1 @ RC Before New Disturbance



FIELD SITE 25-26
CX2 @ Max New Disturbance




FIELD SITE 25-26
"New Disturbance"
Longprofile
Elevation (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Distance (m)
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

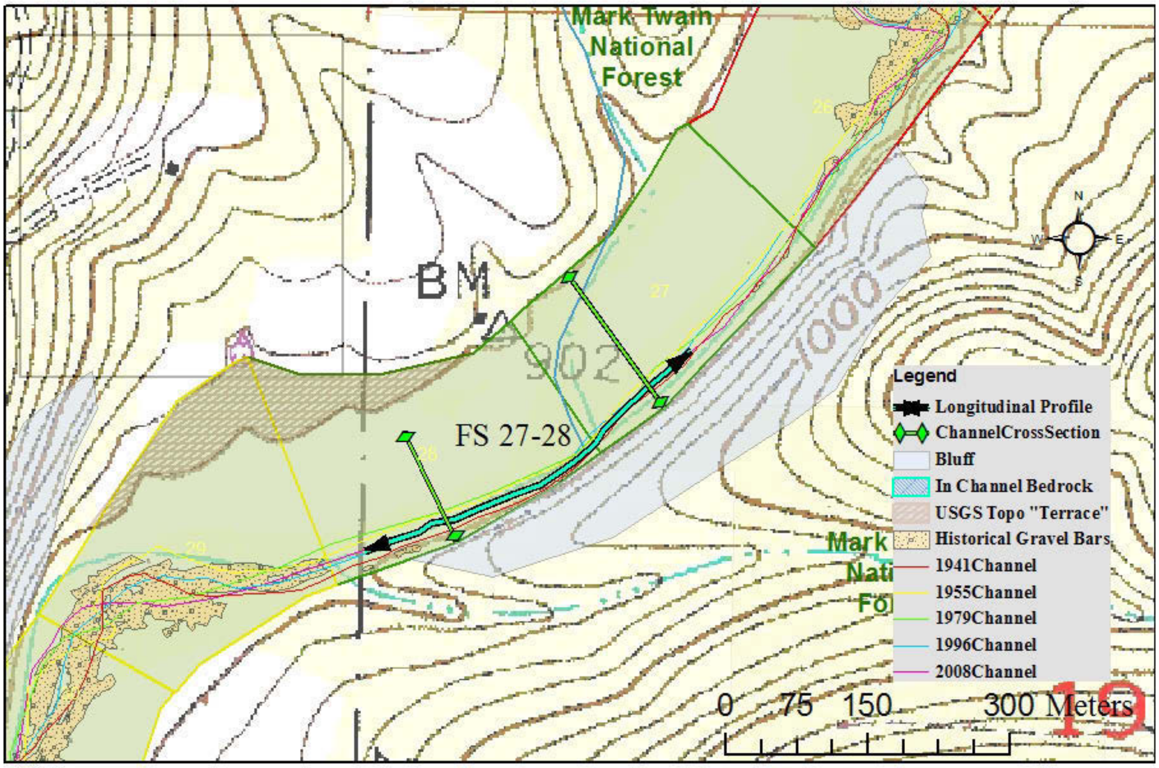
Gravel splay over bankfull height. 2meter stadia rod in photo at flood plain height.

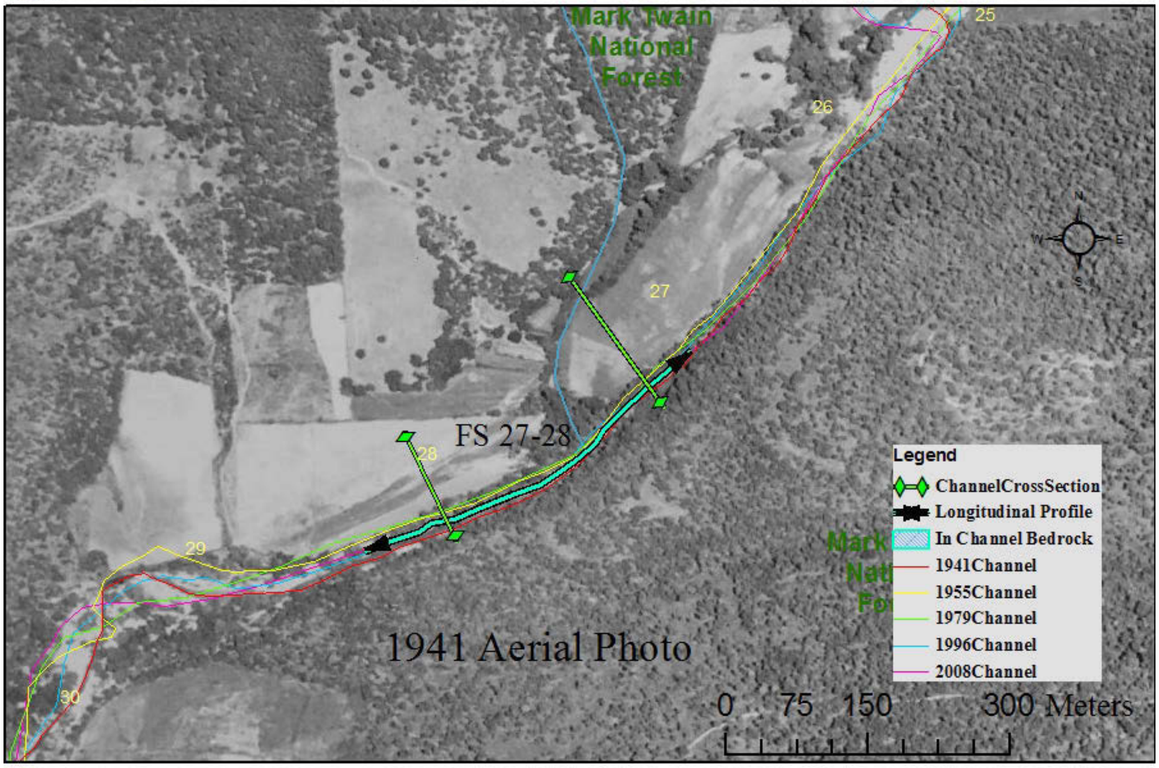
Left-Possible Burried soil showing channel stability followed by gravel at a time of instability  Right- abandoned channel with large gravel splay in right of photo buring tree to the right of stadia rod.

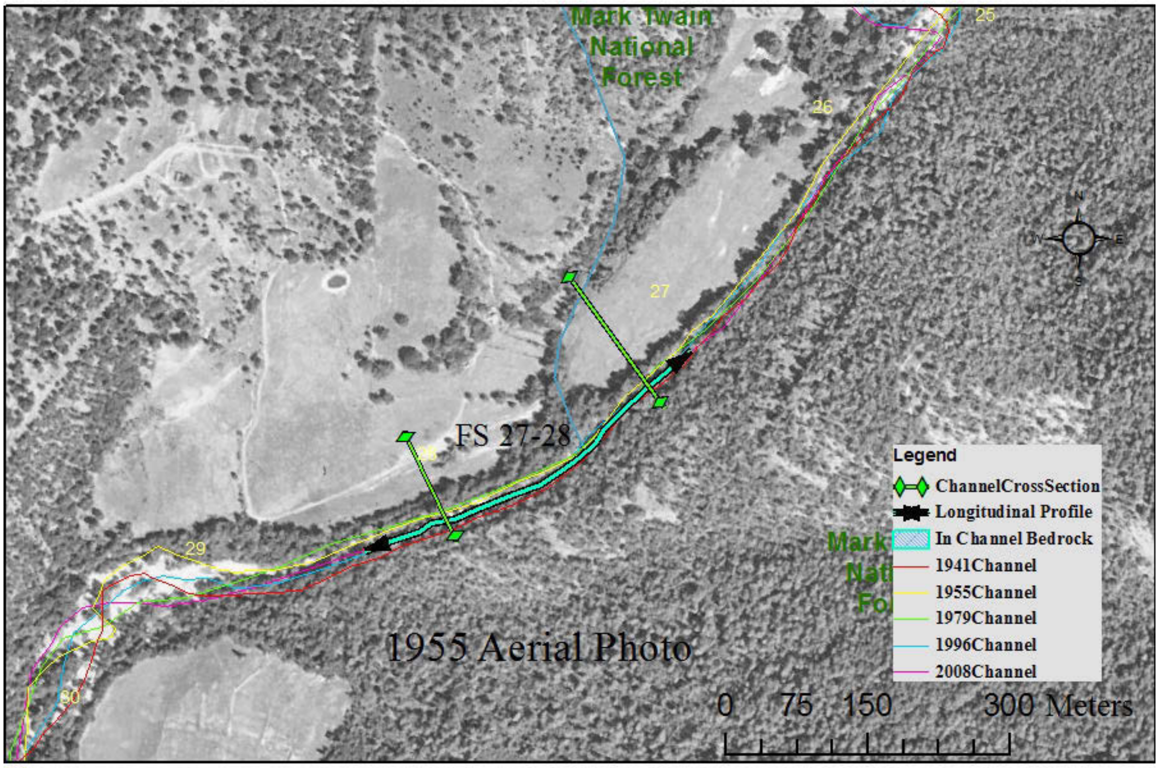
Lindsay Olson standing by sycamore tree being buried by gravel in the middle of the valley.

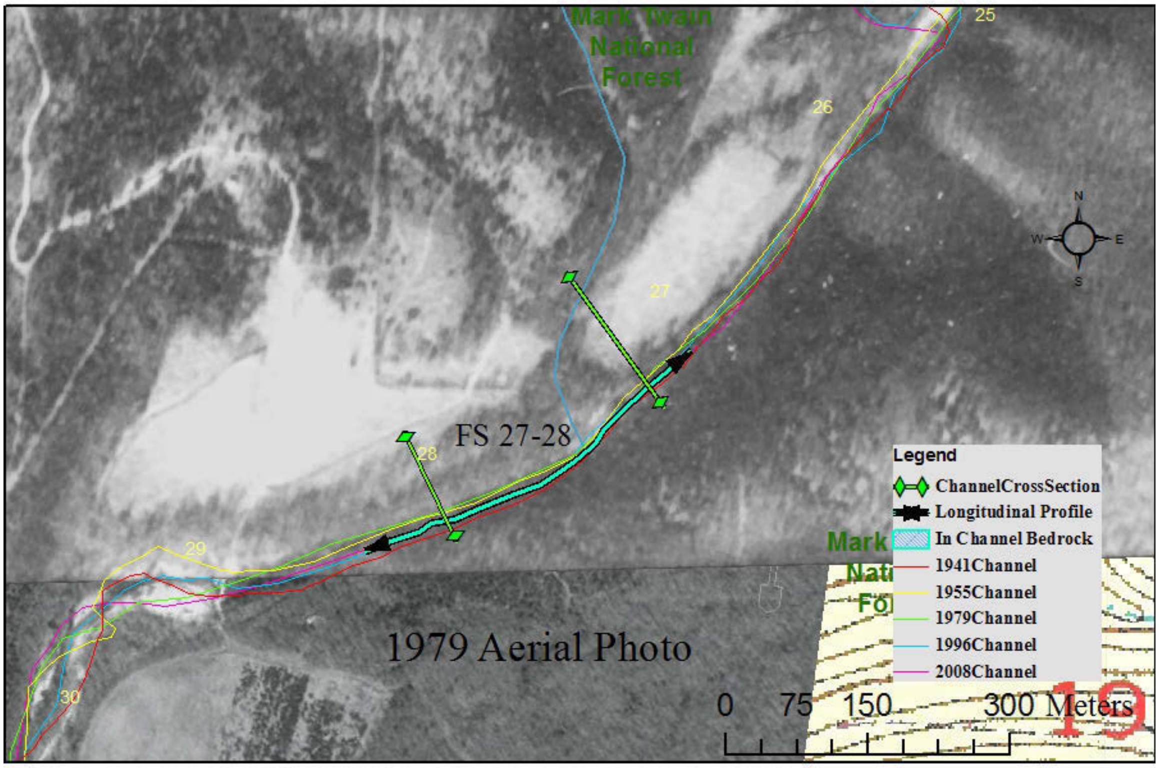
Large cutbank below first riffle in longprofile. Buried soil in previous picture in this bank.

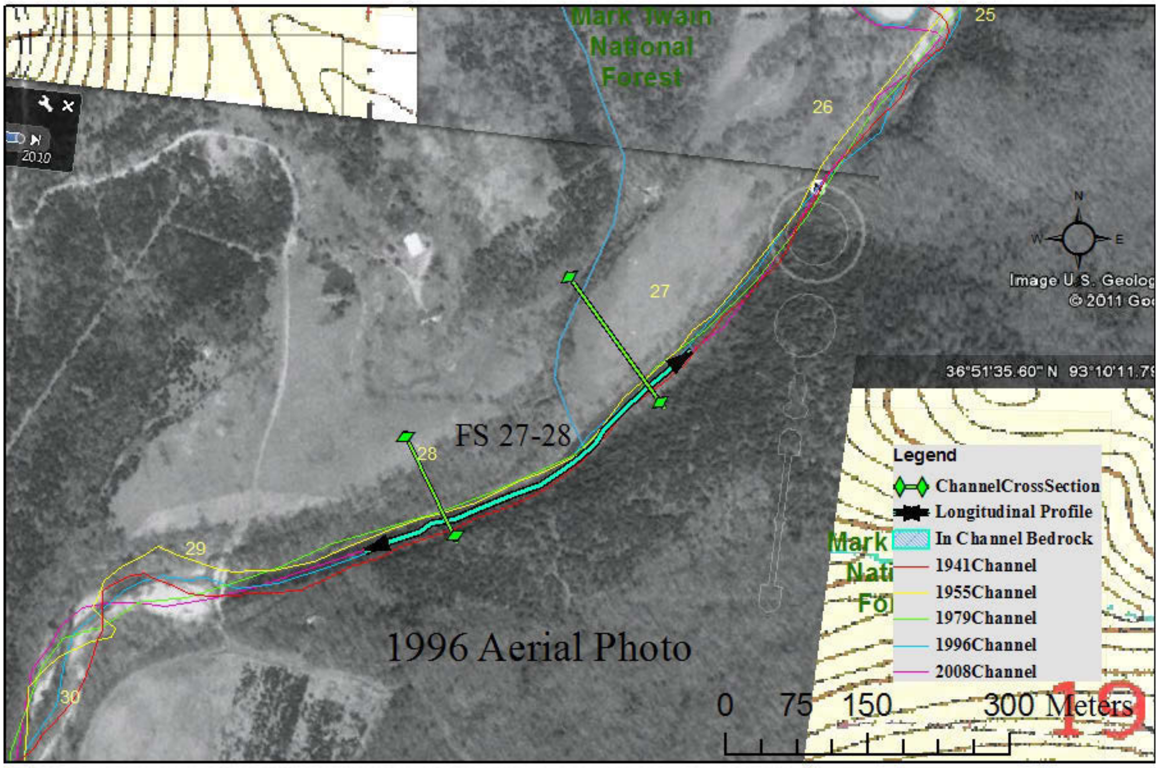
## Appendix F: Field Site 27-28

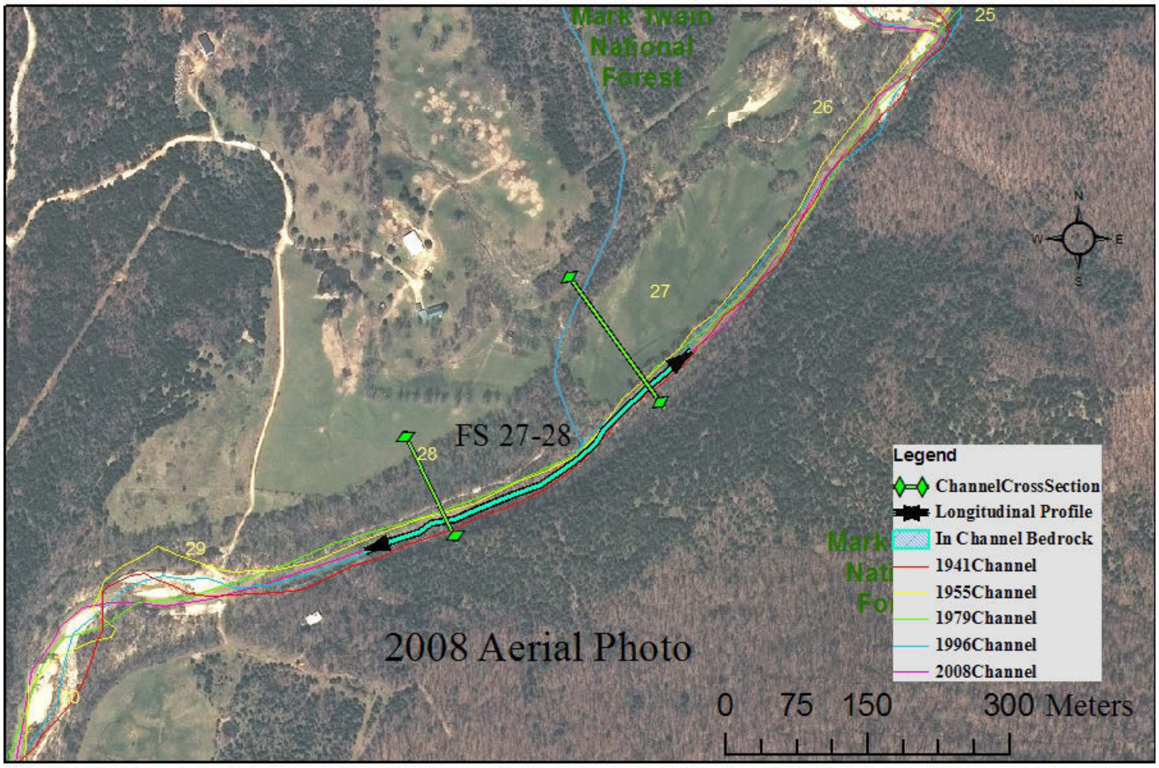


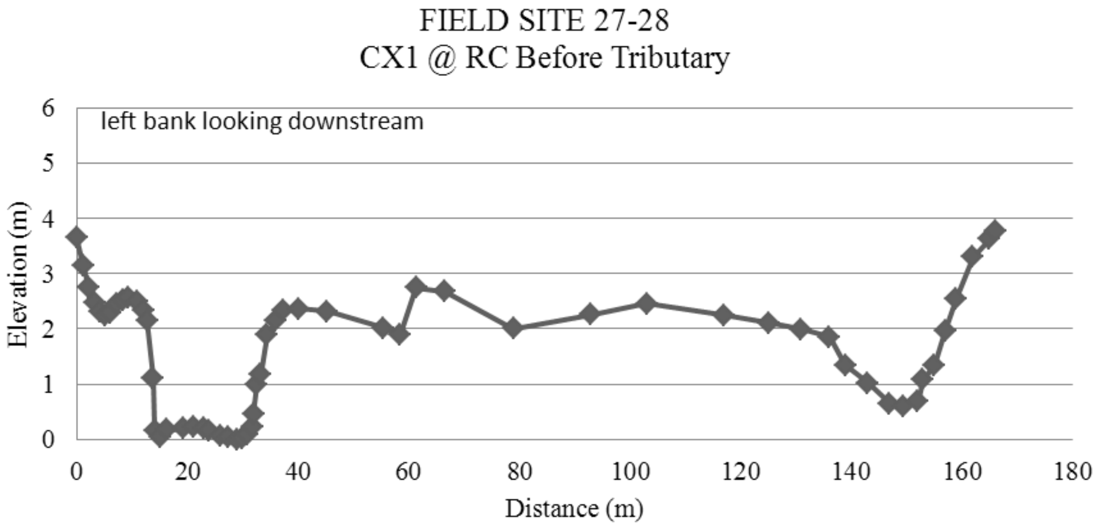


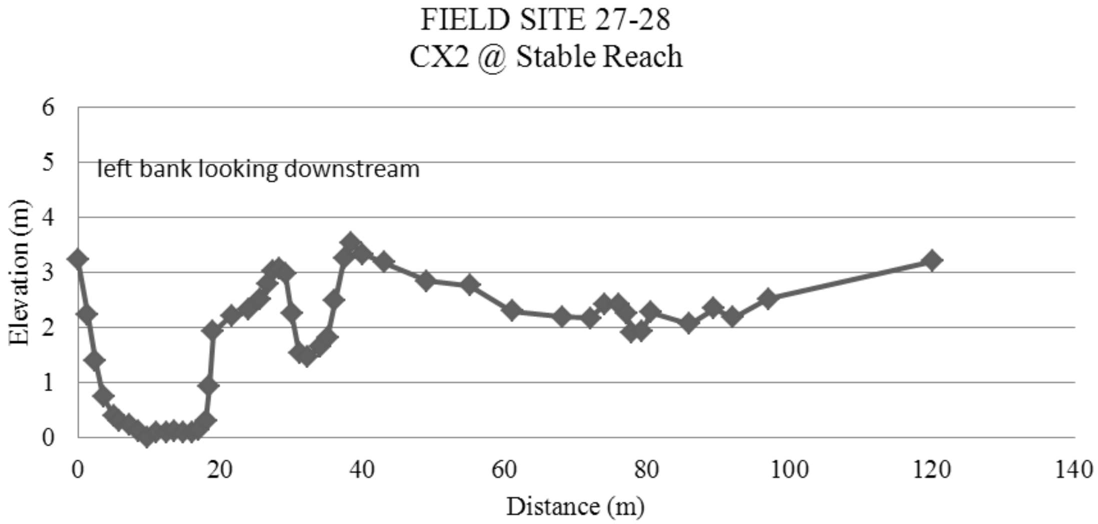

Mark Twain
National
Forest
25
26
27
FS 27-28
28
29
30
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Mark
Nati
Fo
1955 Aerial Photo
0 75 150 300 Meters

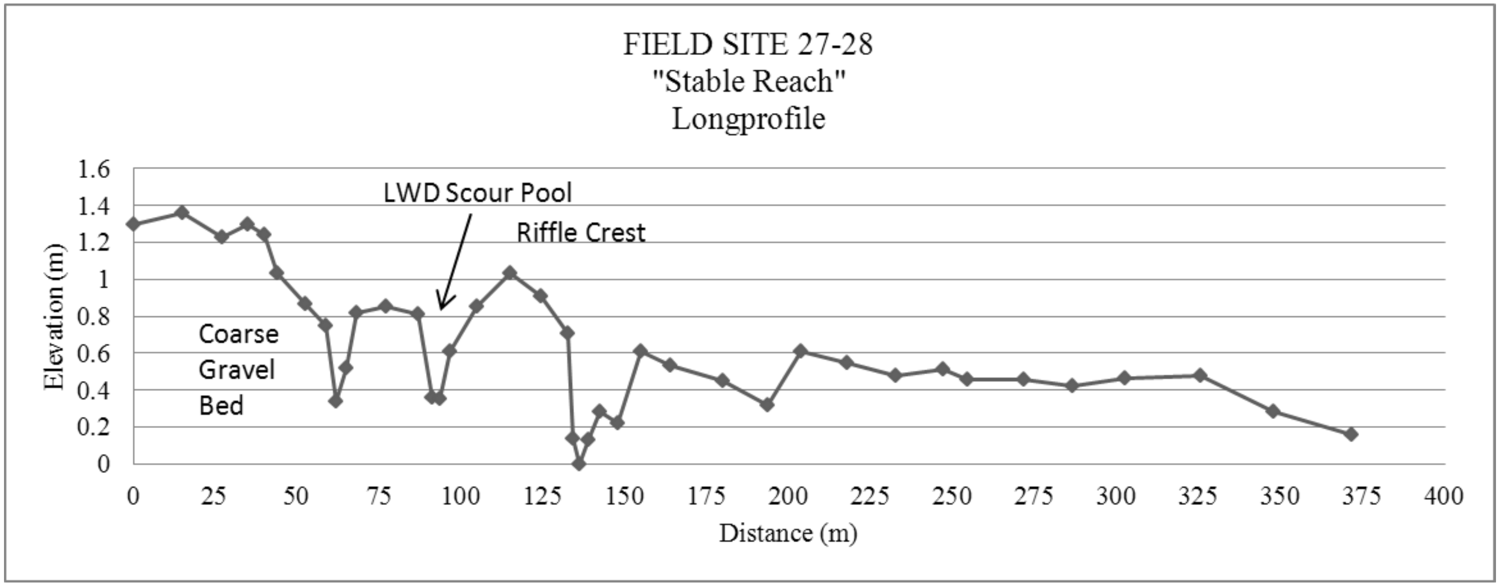

Mark Twain
National
Forest
25
26
27
FS 27-28
28
29
30
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
Mark
Nati
Fo
1979 Aerial Photo
0 75 150 300 Meters
19


Mark Twain National Forest
25
26
27
28
29
30
FS 27-28
2010
Image U.S. Geolog
© 2011 Goo
36°51'35.60" N 93°10'11.79
N
W
E
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
1996 Aerial Photo
0 75 150 300 Meters
19


Mark Twain National Forest
25
26
27
28
29
FS 27-28
N
W
E
S
Legend
ChannelCrossSection
Longitudinal Profile
In Channel Bedrock
1941Channel
1955Channel
1979Channel
1996Channel
2008Channel
2008 Aerial Photo
0 75 150 300 Meters


FIELD SITE 27-28
CX1 @ RC Before Tributary
left bank looking downstream
Elevation (m)
0
1
2
3
4
5
6
Distance (m)
0
20
40
60
80
100
120
140
160
180


FIELD SITE 27-28
CX2 @ Stable Reach
left bank looking downstream
Elevation (m)
0
1
2
3
4
5
6
Distance (m)
0
20
40
60
80
100
120
140


FIELD SITE 27-28
"Stable Reach"
Longprofile
Elevation (m)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
LWD Scour Pool
Riffle Crest
Coarse
Gravel
Bed
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Distance (m)

## Appendix G: Field Data

Longitudinal Profile Percent Channel Slope

| Field Site | Classification | Riffle Crest | Bed Rock | Disturbance Riffle Crests | Mean |
|---|---|---|---|---|---|
| FS 4-5 | Old Disturbance | 0.3 | 0.07 | 0.33 | 0.36 |
| FS 5-6 | Recent Disturbance | 0.31 | 0.07 | 0.31 | 0.43 |
| FS 11-12 | Stable | 0.53 | 0.81 | No Dist. | 0.77 |
| FS 13-14 | Stable/Semi-Disturbed | 0.34 | -0.16 | 0.16 | 0.21 |
| FS 19-20 | Old Disturbance | 0.32 | NO BR | 0.15 | 0.28 |
| FS 25-26 | Recent Disturbance | 0.12 | 0.61 | 0.09 | 0.07 |
| FS 27-28 | Very Stable | 0.29 | Blocks | NO Dist. | 0.22 |

Cross Section Channel Morphology Comparison

| | | Bank Full | | | | Low Terrace | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cross Sect. | Width (m) | Max Depth (m) | Mean Depth (m) | Width/ Depth | Width (m) | Max Depth (m) | Mean Depth (m) | Width/ Depth |
| FS 4-5 | 1 | 38.1 | 1.7 | 1.2 | 31.5 | 47.0 | 2.2 | 1.6 | 29.7 |
| | 2 | 22.0 | 1.9 | 1.1 | 20.2 | 62.0 | 2.8 | 1.1 | 57.9 |
| FS 5-6 | 1 | 23.5 | 1.6 | 1.0 | 24.7 | 59.0 | 2.5 | 1.4 | 42.1 |
| | 2 | 18.0 | 0.9 | 0.5 | 35.3 | 85.0 | 2.4 | 1.0 | 86.7 |
| FS 11-12 | 1 | 29.0 | 1.9 | 1.2 | 24.0 | 75.0 | 2.6 | 0.9 | 79.8 |
| | 2 | 27.0 | 0.9 | 0.6 | 45.8 | 72.0 | 2.8 | 1.6 | 44.4 |
| FS 13-14 | 1 | 22.0 | 0.6 | 0.4 | 53.7 | 76.0 | 2.3 | 1.4 | 53.1 |
| | 2 | 19.0 | 0.7 | 0.4 | 51.4 | 52.0 | 1.7 | 1.0 | 52.0 |
| FS 19-20 | 1 | 40.0 | 1.9 | 1.1 | 36.7 | 91.0 | 3.1 | 2.3 | 39.6 |
| | 2 | 24.0 | 1.6 | 1.2 | 20.7 | 98.0 | 2.4 | 1.4 | 70.0 |
| FS 25-26 | 1 | 29.9 | 2.2 | 1.5 | 19.5 | 40.0 | 3.2 | 2.1 | 19.0 |
| | 2 | 32.0 | 2.2 | 1.3 | 24.1 | 200.0 | 2.8 | 1.6 | 125.8 |
| FS 27-28 | 1 | 28.0 | 2.4 | 1.6 | 17.3 | 160.0 | 2.7 | 1.3 | 125.0 |
| | 2 | 20.0 | 2.2 | 1.8 | 11.4 | 120.0 | 3.5 | 1.6 | 75.0 |
| Average | CX1's | 30.1 | 1.8 | 1.1 | 29.6 | 78.3 | 2.7 | 1.6 | 55.5 |
| Average | CX2's | 23.1 | 1.5 | 1.0 | 29.8 | 98.4 | 2.6 | 1.3 | 73.1 |
| Avg. Stable | | 24.2 | 1.5 | 1.0 | 33.9 | 92.5 | 2.6 | 1.3 | 71.6 |
| Avg. Disturb | | 28.4 | 1.7 | 1.1 | 26.6 | 85.3 | 2.7 | 1.6 | 58.9 |

Pebble Count Size Distribution (cm)

| Field Site | Bar |  |  | Bar Mid Max (AVG) | Largest Blocks (AVG) | Riffle Crest Max (AVG) |
|---|---|---|---|---|---|---|
|  | D50 | D85 | D94 |  |  |  |
| FS 4-5 | 16 | 32 | 45 | 91 | no blocks | 155 |
| FS 5-6 | 22.6 | 53 | 102 | 95 | no blocks | 152 |
| FS 11-12 | 11 | 22.6 | 45 | 147 | no blocks | 795 |
| FS 13-14 | 11 | 22.6 | 32 | 59 | no blocks | 195 |
| FS 19-20 | 11 | 22.6 | 32 | 69 | 432 | 142 |
| FS 25-26 | No Access |  |  |  |  |  |
| FS 27-28 | 22.6 | 45 | 64 | 229 | 1310 | 781 |

Channel Morphology Comparison

|  |  | Historic Active Channel |  |  |  |
|---|---|---|---|---|---|
|  | Cross Section | Photo Width (m) | Field Width (m) | Absolute Difference | % Difference |
| FS 4-5 | 1 | 15.7 | 25.1 | 9.4 | 59.9 |
|  | 2 | 80.9 | 76.4 | -4.5 | -5.6 |
| FS 5-6 | 1 | 11.2 | 17.5 | 6.3 | 56.3 |
|  | 2 | 81.5 | 72.6 | -8.9 | -10.9 |
| FS 11-12 | 1 | 9.6 | 27.0 | 17.4 | 181.3 |
|  | 2 | 12.2 | 19.0 | 6.8 | 55.7 |
| FS 13-14 | 1 | 14.7 | 18.0 | 3.3 | 22.4 |
|  | 2 | 46.9 | 58.0 | 11.1 | 23.7 |
| FS 19-20 | 1 | 13.3 | 30.7 | 17.4 | 130.8 |
|  | 2 | 112.6 | 83.5 | -29.1 | -25.8 |
| FS 25-26 | 1 | 14.9 | 28.0 | 13.1 | 87.9 |
|  | 2 | 163.4 | 173.0 | 9.6 | 5.9 |
| FS 27-28 | 1 | 15.6 | 14.9 | -0.7 | -4.5 |
|  | 2 | 22.8 | 30.3 | 7.5 | 32.9 |
| Average | Riffle | 13.6 | 23.0 | 9.5 | 69.7 |
| Average | Disturbance | 74.3 | 73.3 | -1.1 | -1.4 |

Main stem field sites with GIS based attributes.

| Site | Classification | Gravel Area ($m^2$) per Field Site Cells | Channel Migration Width (m) | | |
|---|---|---|---|---|---|
| | | | mean | max | min |
| FS 4-5 | Old Disturbance | 4,294 | 23 | 58 | 11 |
| FS 5-6 | Recent Disturbance | 6,168 | 35 | 58 | 11 |
| FS 11-12 | Stable | 1,347 | 33 | 74 | 11 |
| FS 13-14 | Stable/Recent-Disturb | 2,614 | 32 | 54 | 14 |
| FS19-20 | Old Disturbance | 9,686 | 42 | 104 | 24 |
| FS 25-26 | Recent Disturbance | 7,892 | 58 | 151 | 16 |
| FS 27-28 | Very Stable | 98 | 34 | 41 | 29 |

## Appendix H: Tributary Assessment

Tributary west of FS11-12, mostly cobble and bedrock with little gravel present.

Eest Fork of Bull Creek above confluence with Bull Creek with megabar.

Dr. Robert Pavlowsky at Peckout Hollow showing scale to aggraded gravel bed.

Megabar formation at Peckout hallow causing channel instability and  falling trees.

Dr. Pavlowsky at a headcut found within a ATV trail along Peckout Hollow.

Tributary northwest of FS25-26 with excess gravel buring sycamore trees

Forested watershed of FS25-26 Tributary with bank erosion sources of gravel

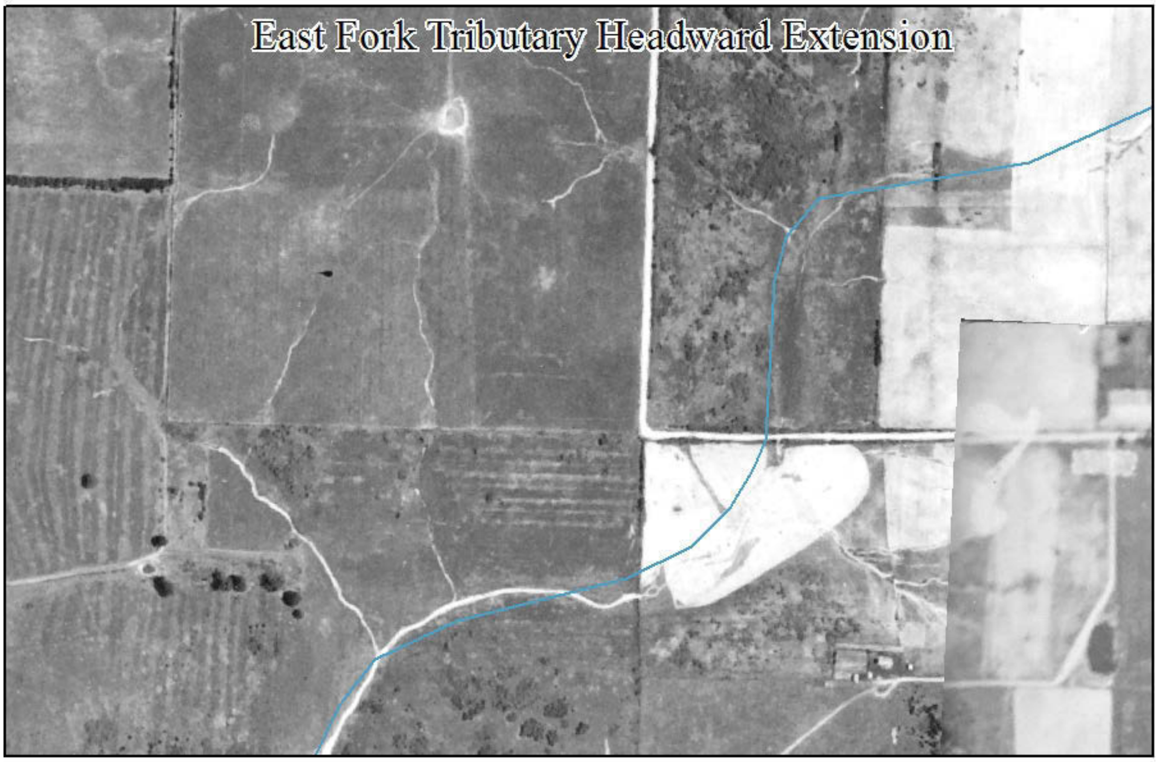
FS25-26 Tributary bank profile showing gravel deposits.

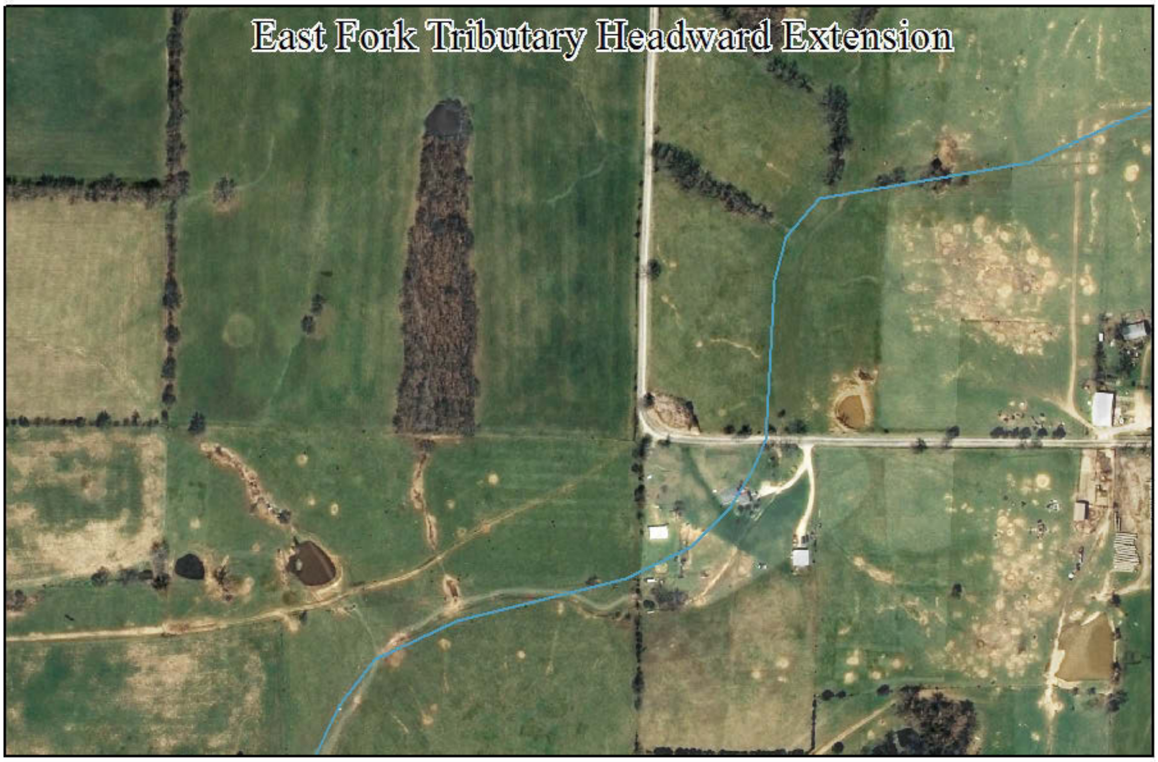
Fallen trees at valley-cell22 that was not designated as a “disturbance reach”. Possible recent (2011) disturbance flood event.

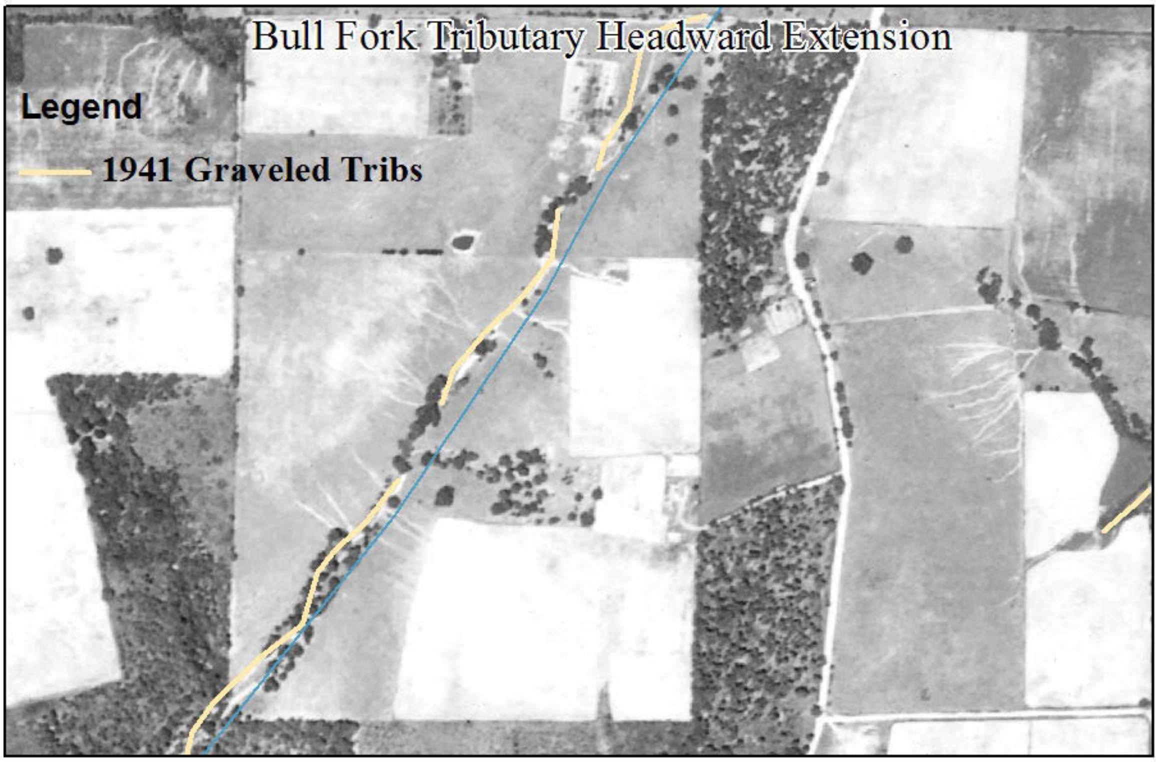
West Fork of Bull Creek above small private reservoir about 500 m.

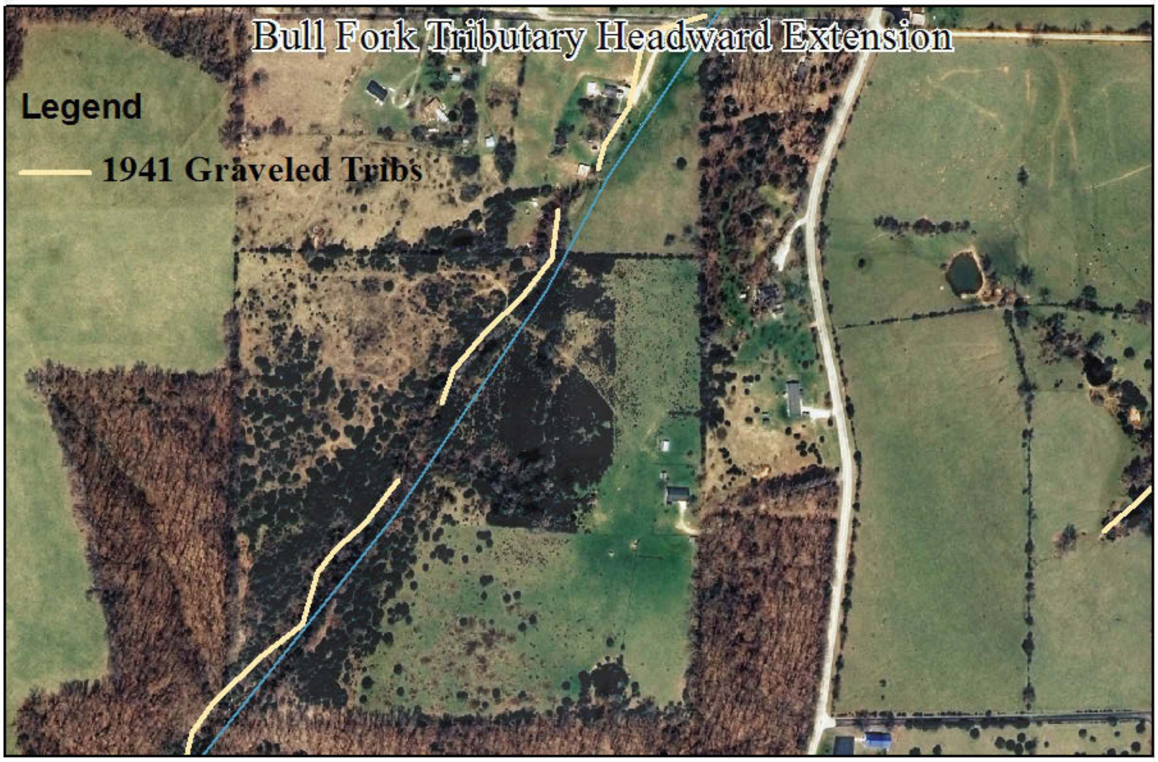
West Fork, just above small privae reservoir. Gravel deposits and signs of excavation evident.

## Appendix I: Tributary Extension/Recovery


East Fork Tributary Headward Extension


East Fork Tributary Headward Extension


Bull Fork Tributary Headward Extension
Legend
1941 Graveled Tribs


Bull Fork Tributary Headward Extension
Legend
1941 Graveled Tribs


West Fork Tributary Headward Extension
Legend


West Fork Tributary Headward Extension
Legend


Peckout Hollow Headward Extension
100 50 0 100 Meters


Peckout Hollow Headward Extension
100 50 0 100 Meters