A STREAM PHYSICAL HABITAT ASSESSMENT IN AN URBANIZING WATERSHED OF THE CENTRAL U.S.A.

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By:

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

A STREAM PHYSICAL HABITAT ASSESSMENT IN AN URBANIZING WATERSHED OF THE CENTRAL U.S.A.

Presented by Lynne Hooper,

a candidate for the degree of Master of Science

and hereby certify that, in their opinion, it is worthy of acceptance.

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A Stream Physical Habitat Assessment in an Urbanizing Watershed of the Central U.S.A.

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ABSTRACT

Longitudinal variations in aquatic biological habitat in a watershed (frequently associated with land-use in mixed-land-use watersheds) can be quantified by means of a physical habitat assessment (PHA). PHA indices include but are not limited to width (channel, bankfull, and wetted), bank height and thalweg depth. Hinkson Creek (Boone County, Missouri) was placed on the Missouri Department of Natural Resources list of impaired waters (Section 303d) of the Clean Water Act in 1998. A PHA conducted in 2013-2014 provided quantitative data characterizing physical habitat characteristics every 100 m of the 56 km channel. Bankfull width ranged from a maximum of 74 m to a minimum of 1.8 m (mean = 24.2 m, SD = 9.4 m). Bank height ranged from 5.8 m to 0.3 m (mean = 2.8 m, SD = 1 m). Increases in bankfull width and bank height were variable with stream distance. Trench pools were the dominant channel unit at 70% of sample transects. Thalweg depth at low to median flow ranged from 330 cm to 0 cm (mean =50.3 cm, SD = 38.7 cm). Streambed size classifications included 58.4% small (< 16 mm), 33.6% intermediate (16 mm to 1000 mm, vegetation, wood), 7.8% large (> 1000 mm, riprap, bedrock). Study results better inform land-use planners in Hinkson Creek watershed and similar multi-use watersheds of the central United States for future management decisions and development scenarios.

CHAPTER I

INTRODUCTION

1.1 The Effects of Land-Use on Stream Hydrogeomorphology

Stream ecological condition depends to a great extent upon geologic and hydrologic processes occurring at different spatial and temporal scales (Vaughan et al. 2009, Hutchens et al. 2009, Zuellig and Schmidt 2012). Hydrology, geology and morphology interact in a hierarchical and generally predictable manner as flows carve channels through the landscape and transport constituents downstream (Piégay and Schumm 2003). Moving from the headwaters to the mouth, the hydrogeomorphology of a stream determines substrate composition, bank slope, channel depth, and a variety of stream habitat characteristics with stream distance (Vannote et al. 1980, Piégay and Schumm 2003). An examination of the hierarchy of stream organization at multiple spatial scales can provide information about the degree of change to aquatic physical habitat (Benda et al. 2004, Thomson et al. 2001).

Human land-use changes can have a detrimental impact on aquatic physical habitat because development of land for agriculture and urban expansion can alter the natural hydrogeomorphology of stream systems primarily due to altered streamflow resulting from increased overland flow (Allan 2004). Heterogeneity of habitat available for aquatic biota is altered by changes in hydrogeomorphology such as increased streamflow velocity that changes the size, amount, and depositional regimes of sediment (Roy et al. 2003). For example, increased sediment deposition on the streambed can fill habitat suitable for macroinvertebrates that occupy interstitial spaces in gravel beds, while increasing habitat for those that burrow in soft substrate (Rabeni et al. 2005).

In forested systems, human land-use changes for agriculture or urban development frequently begin with deforestation. Deforestation can result in a range of detrimental effects on stream physical habitat, including the reduction of riparian corridor (Reid et al. (a) 2010), increased sediment loading (Stone et al. 2005), higher average stream temperature (Biondi 2008), increased runoff (Hogg and Norris 1991), and increased erosion (Reid et al. (a) 2010). The combined effects of deforestation on aquatic physical habitat are not necessarily proportional to the size or shape of a catchment, and an intense forest harvest upstream is more likely to have a greater proportional impact on a stream with a smaller drainage area (Reid et al. (a) 2010).

Agricultural land-use after deforestation, either upstream from or lateral to receiving waters, can further impact water quality and/or physical habitat (Allan et al. 1997). Overland flow from agricultural fields after precipitation events may erode surface soils and transport sediment and adsorbed chemicals including fertilizers and pesticides to receiving waters thereby altering water quality (Rasmussen et al. 2012, von Bertrab et al. 2013). In addition to the potential impacts of sediment and chemicals on water quality, increased overland flow into a stream may affect physical habitat by increasing erosion of streambanks and altering sediment regimes in the streambed (Reid et al. (a) 2010). As an additional complication, effects of land-use changes may not be immediately detectable. It may take decades or longer for the legacy effects of the initial deforestation and/or agricultural use on stream water quality or physical habitat to be observed (Allan 2004).

The various effects of deforestation and agricultural practices are potentially confounded in a watershed with additional land-use types such as industry or urban development (mixed-land-use watershed) (Allan 2004). Effects of land-use changes may be cumulative or non-linear due in part to interactions with natural variability in factors such as climate or underlying geology and multiple simultaneous scale-dependent processes, making it difficult to trace effects on water quality and availability of certain microhabitats downstream to a specific land-use (Allan 2004, Vander Laan et al. 2013).

Urban development has been shown to reduce overall stream habitat heterogeneity in some streams (Paul and Meyer 2001). Stream segments may be channelized in urban areas, either to increase availability of land bordering the stream for development, or as a means of flood control to facilitate rapid movement of water out of a watershed (Brookes 1988, Brooks et al. 2003). Channelization often reduces the hydrologic connectivity of a stream to the surrounding landscape (Brooks et al. 2003). Decreased hydrologic connectivity can have other effects including disconnection of shallow groundwater from stream channels, decreased lag time between peak rainfall and peak discharge, and increased magnitude of peak discharge in the stream hydrograph (Brooks et al. 2003, Jacobson and Faust 2013). Rapid removal of water from the watershed via channelized stream reaches also reduces the time available for soil infiltration and recharge of subsurface water storage (i.e. bankfull storage, vadose zone storage, groundwater) and can result in reduced interflow and baseflow (Poff et al. 2006).

If stream hydrogeomorphology is altered by land-use, the altered hydrogeomorphology can consequently alter stream physical habitat, resulting in altered stream ecological function (Poff et al. 2006). For example, higher flow volumes of stormwater runoff increase stage of streamflow and wetting of the streambanks making streambanks more susceptible to erosion

(Wolman 1959). As streambanks are eroded, riparian cover can be lost, further reducing the stability of streambanks, thus increasing bank erosion processes. Increased flow volumes and velocities of stormwater runoff can also erode gravel and sediment from the streambed (i.e. channel scouring), potentially to bedrock (Shepherd et al. 2011), which may decrease physical habitat for aquatic biota.

Impervious surfaces such as asphalt or concrete in urban systems prevent soil infiltration, increase overland flow into receiving waters, and may amplify peak discharge in a stream (Paul and Meyer 2001). Increased discharge may lead to more frequent flooding events locally or downstream (White and Greer 2006). Meyer et al. (2005) and Walsh et al. (2005) discussed an urban stream syndrome, resulting from increased flow volume and velocity downstream of urban areas largely due to increased impervious surface cover, with potential effects on downstream ecological function. Increased flow volume and velocity downstream of urban centers has been shown to increase channel incision, streambed scouring and channelization, to alter sediment transport regimes, and ultimately to increase mass wasting and channel widening with stream distance from urban areas (Shepherd et al. 2011, Paul and Meyer 2001, Piégay and Schumm 2003), all of which potentially alter availability of stream habitat for aquatic biota.

As increased flows and sediment transport continue, increased sediment load can intensify the effects of future high flow events over the long term (Booth and Jackson 1997). Deposition of sediment from agricultural land-use (Reid et al. (a) 2010) and deposition of sediment from urban sources (Kellner et al. 2014) may continue to fill interstitial spaces as sediment is moved downstream during high flow events (Larsen et al. 2011, Rabeni et al. 2005). Kellner et al. (2014) identified a difference in the size class of suspended sediment particles from agricultural and urban sources. Mean particle size of suspended sediment in water samples collected at urban stormwater sites was found to be significantly smaller ($p < 0.001$) than mean particle size in suspended sediment in water samples from two local streams (Kellner et al. 2014).

An increase in the quantity of sediment in suspension and/or deposited on the streambed has been shown to have potential effects on an aquatic ecosystem. Suspended sediment (particularly particles < 2 mm) increases turbidity of stream waters, changing the habitat available for fish and other aquatic biota. For example, suspended sediment can impair the ability of sight-feeders (including fish) to find food, may damage or impair the gills of fish or other aquatic organisms, and may affect stream productivity (Vandrocek et al. 2003, Owens et al. 2005, Campbell et al. 2005, Keyes and Radcliff 2002). Deposition of sediment on the streambed may reduce habitat for aquatic biota that require mixed gravel substrate with interstitial spaces (Richards et al. 1993).

Sediment flushed into a stream from agricultural or urban areas may also form chemical bonds with nutrients or other pollutants thereby increasing the polluting potential of the sediment. The pollutants can impair water quality altering the trait characteristic (clingers, burrowers, climbers, etc.) proportions within macroinvertebrate communities or distribution of fish species (von Bertrab et al. 2013, Mažeika et al. 2004, Rabeni et al. 2005, Jun et al. 2011, Maddock 1999). Some aquatic biota are more sensitive to certain types of pollution than others. For example, indicator species of certain macroinvertebrate taxa (Ephemeroptera, Plecoptera and Trichoptera) are known to be highly sensitive to a wide range of pollutants (at times in relatively small quantities), and an absence of these taxa from sampled stream sites can indicate water quality impairment (Rabeni et al. 2005, King et al. 2011, Reid et al. (b) 2010, Barbour et al. 1999).

In addition to sediment deposition decreasing the availability of physical habitat, increased flows may have other long term detrimental effects on in-stream biological habitat. For example, a recent study in Hinkson Creek (Boone County, Missouri) showed a negative correlation between increased discharge volumes and quantity of available riparian rootmat habitat (Nichols 2012). Submerged rootmats along the banks of a stream provide habitat for aquatic biota including some species of macroinvertebrates and fish (Rabeni et al. 1997, Pusey and Arthington 2003). For macroinvertebrates, fish and other aquatic biota, the end result of human land-use changes can be ongoing stream habitat degradation (renewed with each high flow event) resulting in a significant reduction of habitat availability and biodiversity over short and long time periods (Coleman et al. 2011).

Naturally occurring events or stream channel soil or geological features may also alter stream habitat (Allan 2004). The introduction of large woody debris due to natural tree death, for example, can either improve or degrade physical habitat and may even change the course of a low-gradient channel over time (Johnson et al. 2003). Soil composition may affect erodibility of streambanks during high flow events (Allan 2004). Sand streambanks for example do not offer much resistance to shear stress of increased stream velocities during periods of increased flow (Geyer et al. 2001). Underlying bedrock geology can also impact the availability of diverse stream habitats (Allan 2004). Limestone bedrock is more likely to be dissolved than other types of bedrock (sandstone for example) due to naturally occurring chemical reactions in regions with Karst topography, and may be broken down into thick clay, impacting heterogeneity of streambed habitat over time (Springer et al. 2003, MDNR/MGS 2015).

Many other variables may operate simultaneously with human land-use changes to affect stream physical habitat (Allan 2004). For example, legacy effects may persist from land-use changes (deforestation and/or agricultural) early in the history of human activities in a given watershed (Allan 2004). Potential legacy effects from land-use changes made long ago make it difficult to connect current land-use practices with current stream habitat conditions, as it is unclear how long it takes a stream to return to an equilibrium state after human terrestrial disturbance (Allan 2004). Land-use effects may also vary by season, particularly the amount and timing of precipitation events as water inputs into a stream will vary depending upon local climate conditions and scale (Carlson et al. 2013).

Scale is a significant factor for stream physical habitat, given that the effects of land-use vary spatially and temporally, and many aquatic organisms have the ability to move from an impaired section of a stream (Sponseller et al. 2001, Allan et al. 1997, Richards et al. 1997, Lamouroux et al. 2004). Typically the most relevant scale for macroinvertebrates is microhabitat (Rabeni et al. 2005), defined as "patches within pool/riffle systems that have relatively homogeneous substrate type, water depth, and velocity" (Frissell et al. 1986). Microhabitat requirements of aquatic biota may differ by species, and requirements may vary over life history stages for individual species of macroinvertebrate or fish, therefore a range of habitat types are required to fully support aquatic communities (Rabeni et al. 2005, Reid et al. (b) 2010, Schiemer et al. 2002). Microhabitat degradation can be observed beginning at relatively short distances of 200 to 500 meters downstream of land-use changes, as well as at the reach and catchment scales (Sponseller et al. 2001, Larsen et al. 2009), and in some cases may extend to the river basin scale. Processes at different spatial scales are simultaneous and interconnected, at times making it difficult to identify potential cause and effect relationships at a specific point in a stream (Allan 2004).

1.2 Physical Habitat Assessment

The various effects of land-use on stream physical habitat can be characterized by observation and measurement of habitat features in the field at predetermined intervals along the length of the stream, and quantified by means of a physical habitat assessment (PHA) (Peck et al. 2006). Longitudinal variation of stream physical conditions controls how much the channel can migrate or adjust to stresses or restoration activities (Piégay and Schumm, 2003, Elliott et al. 2009). Variation in characteristics such as channel morphology, riparian vegetation, and sedimentological characteristics of the streambed can affect medium-term channel change and indicate where specific management or restoration actions will be most effective (Jacobson and Gran 1999, Jacobson et al. 2004). A physical habitat assessment provides information about the condition of the streambed and streambanks and sources of microhabitats for macroinvertebrates and other aquatic biota (Rabeni et al. 2005, Nichols 2012). For example, quantification of substrate types during a physical habitat assessment can be used to identify potential areas of sediment deposition, or homogenization of habitat due to vertical embedding (depth of fine substrate such as sand, silt or clay vertically around larger particles) of gravel. Analysis of physical habitat assessment data may indicate specific types of degradation, whether land-use changes have contributed to the degradation and potential restoration sites for stream physical habitat (Peck et al. 2006).

An aquatic physical habitat assessment can provide quantitative evidence of predictable changes in specific hydrologic functions with stream distance and human land-use changes. A recent study by Jacobson and Faust (2013) noted decreased hydrologic connectivity between the stream and the floodplain at larger drainage areas downstream in northern Missouri. Reduced hydrologic connectivity was associated with channel incision and higher volume of discharge from increased overland flows (Jacobson and Faust 2013). Increased channel incision is characterized by increasing bank height from headwaters to mouth in a stream, and although channel incision is expected to increase naturally with increased drainage area into receiving waters it can be greatly influenced by deforestation and agricultural activities or increased urbanization in a watershed (Allan 2004, Booth and Jackson 1997).

An understanding of longitudinal variation in physical habitat characteristics provided by a PHA is necessary to formulate potential restoration plans for land-use impaired stream systems, and to monitor restoration efforts after improvements have been made (Thomson et al. 2001, Resop et al. 2014). Longitudinal variation can be used to identify areas with habitat homogeneity or other features that prevent colonization by biodiverse aquatic communities, although restoration of physical habitat heterogeneity is generally an oversimplification of the processes required for stream restoration (Palmer et al. 2010). A PHA can be useful both before and after implementation of stream restoration measures (Miller et al. 2010).

Recent technology has advanced the use of geographic information systems (GIS) and models to complement observed physical habitat measurements (Bockelmann et al. 2004). The geomorphic data generated by the use of models may not be directly representative of the ecological condition of a stream (Mažeika et al. 2004), indicating a need for collection of observed data in combination with models. The ability to compare directly observed data with data generated for the same watershed using GIS and other methods could provide a significant opportunity to understand how data generated from the different methods may differ.

1.3 Objectives

The objectives of the following research were to 1) identify longitudinal variations in physical habitat in a representative mixed-land-use watershed of the central U.S. by collecting various physical data (e.g. bank height, channel width, thalweg depth, etc.) every 100 meters along the entire length of a stream; 2) determine whether various land-use practices in a mixed-land-use watershed can be linked to stream physical habitat metrics at the kilometer scale; and 3) validate GIS generated data with complimentary observed PHA data.

1.4 Hypotheses

1. H_o: Longitudinal variation in physical habitat will increase as a function of drainage area, and is not controlled by physiographic framework of the stream channel and human land-use alterations.

   H_a: Longitudinal variation in physical habitat will not increase as a function of drainage area, and is controlled by physiographic framework of the stream channel and human land-use alterations.

2. H_o: Land-use practices will not affect stream physical habitat metrics at the kilometer scale.

   H_a: Land-use practices will affect stream physical habitat metrics at the kilometer scale.

3. H_o: Observed PHA data will not be statistically different from GIS generated data for the location of the stream centerline and bankfull width.

   H_a: Observed PHA data will be statistically different from GIS generated data for the location of the stream center and bankfull width.

CHAPTER II

MATERIALS AND METHODS

Background information about the hydrogeomorphology and climate of Hinkson Creek Watershed (section *2.1.1*), surficial and bedrock geology and topography (section *2.1.2*), and an overview of land-use and land cover (section *2.1.3*) are presented in this Chapter.

2.1 Study Site

This study was conducted in Hinkson Creek located in Boone County, central Missouri, USA. Hinkson Creek is the main channel of Hinkson Creek Watershed (HCW), a mixed-land-use watershed in the central United States. In 1998, the Missouri Department of Natural Resources (MDNR) placed Hinkson Creek on the state's list of impaired streams under section 303(d) of the Clean Water Act (CWA). The cause of impairment was listed as unknown (EPA 2011). Subsequent bioassessment studies of Hinkson Creek indicated that sections of the creek were not fully supporting aquatic life, but water quality analyses and follow-up studies were unable to determine a specific cause of impairment (MDNR 2002, 2004, 2005, 2006). In 2011 a Total Maximum Daily Load (TMDL) was proposed that would have required reduction of stormwater runoff from the stream's surrounding area as a surrogate for unidentified pollutants (Hubbart et al. 2010, EPA 2011). After the TMDL was proposed, the City of Columbia, Missouri, Boone County, Missouri, and the Curators of University of Missouri (joint permittees under a municipal storm sewer National Pollution Discharge Elimination System permit) sued the EPA because a

TMDL for stormwater would not resolve impairment issues, and there was not an adequate legal basis for the use of stormwater as a surrogate for a pollutant. In order to settle the lawsuit, an agreement was reached between all interested parties and a Collaborative Adaptive Management (CAM) process was initiated in the watershed in the spring of 2012. The CAM process is a science-guided approach led by a local stakeholder committee to implement management actions and learn from them how to remove impairment of Hinkson Creek. The CAM committees are charged with providing science-based solutions that simultaneously lead to removal of Hinkson Creek from the 303(d) list and provide ongoing preservation of water quality and biological health of aquatic biota living in the stream.

Upon recommendation by the Hinkson Creek CAM Science Team in 2012, the Stakeholder Committee commissioned a two-phase PHA project to quantify stream physical habitat in Hinkson Creek which was funded by the Hinkson Creek CAM team partners (Boone County, City of Columbia, and the Curators of University of Missouri) for work to begin in 2013. GIS compilation of HCW was performed by the Missouri Resource Assessment Partnership (MoRAP) at the direction of the CAM Science Committee during Phase I of the PHA (see Appendix A), mapping stream, channel and valley parameters using DEM models and aerial photographs. The final report to conclude this work was submitted by MoRAP to the Hinkson Creek CAM Stakeholder Committee in September of 2013 and is attached hereto as Appendix A. Phase II of the PHA (i.e. the current study) provides observed data to complement data generated by the GIS modeling during Phase I. A final report for Phase II of the PHA was submitted to the Hinkson Creek CAM Stakeholder Committee in March of 2015 (Appendix B).

2.1.1 Hydrogeomorphology and Climate of HCW

HCW covers approximately 231 km^2 (MDNR 2006) and Hinkson Creek is approximately 56 km long (as determined by MoRAP during Phase I of the PHA – see report Appendix A). Hinkson Creek Watershed is comprised of Hinkson Creek, and 8 major tributary basins (moving from headwaters to mouth): Varnon Branch, Nelson Creek, Hominy Branch, Grindstone Creek, Flat Branch, County House Branch, Mill Creek, and Meredith Branch (Figure 1).

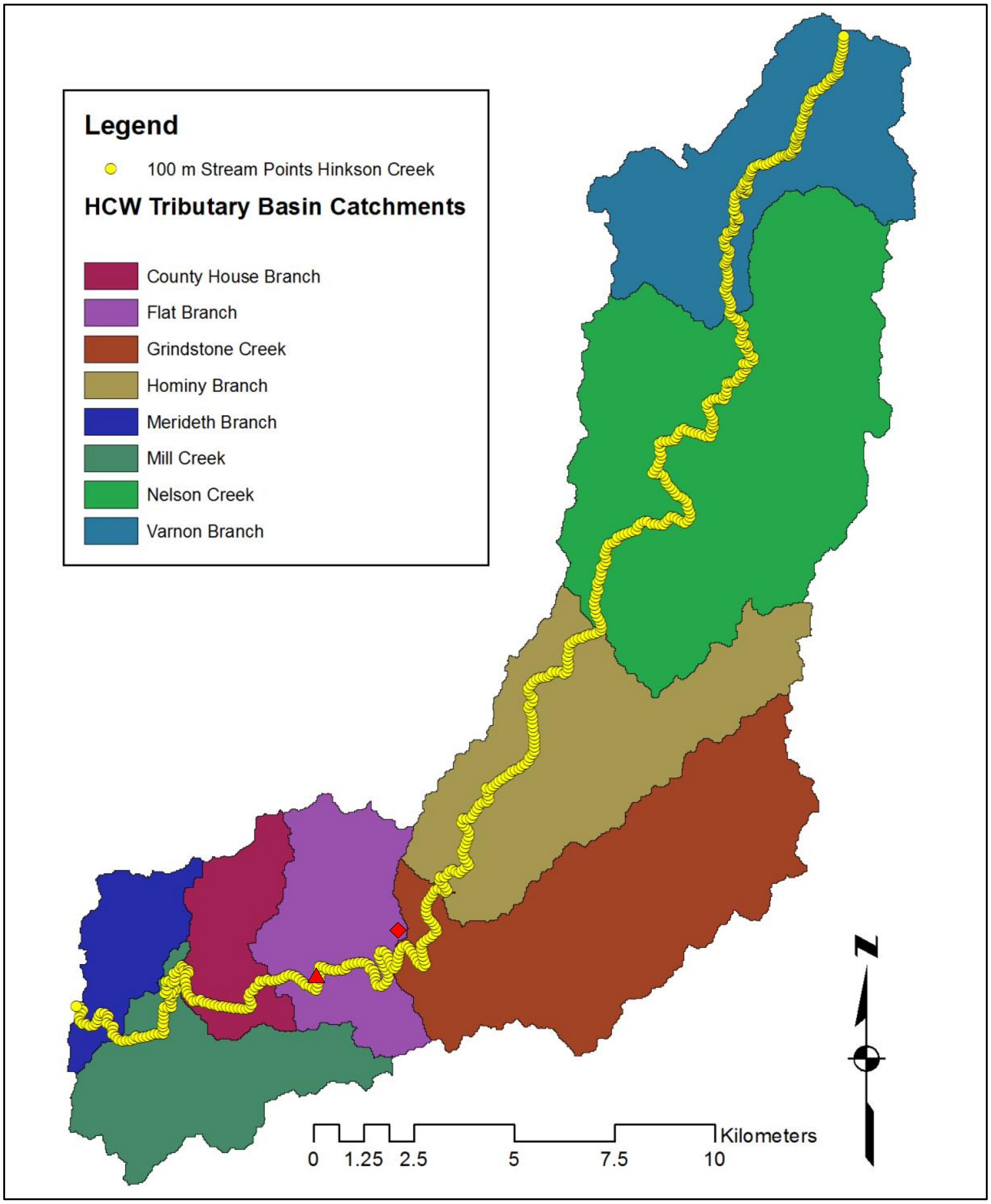

Figure 1. Hinkson Creek Watershed in Boone County, Missouri, including Hinkson Creek and 8 major tributary basins (see color legend). The yellow circles represent the survey points along Hinkson Creek. The red diamond marks the approximate location of Sanborn Field on the University of Missouri campus in Columbia, Missouri (lat. 38.942306, long. - 92.320389). The red triangle marks the approximate location of the USGS gauging station site on Hinkson Creek in Columbia, Missouri (lat. 38.92775, long. - 92.339944).

The average annual temperature in Missouri is 12.5 °C, ranging between average winter (December 21 to March 20) temperature of 0.2°C and an average summer (June 21 to September 22) temperature of 24.2°C (1895 to 2010, Missouri Climate Center). The average annual temperature in Columbia, Missouri is 13.3°C, ranging between average winter (December 21 to March 20, 2000-2015) temperature of 1.6°C and an average summer (June 21 to September 22, 2000-2014) temperature of 24.5°C (Sanborn Field). Average annual precipitation in Missouri is 104.4 cm (1895 to 2010, Missouri Climate Center), while average annual precipitation in Columbia, Missouri is 103.6 cm (2000 to 2014, Sanborn Field). A recent study indicated that climate in HCW (particularly temperature and precipitation) is influenced by an urban heat island effect in and around Columbia, Missouri (Hubbart et al. 2014).

The local climate was variable in HCW during the study period (July, 2013 through August, 2014). The statistics presented in Table 1 show calendar years 2013, 2014, and combined climate for 2013 and 2014. Climate data for Table 1 were downloaded from the Sanborn Field (Columbia, Missouri) website (Sanborn Field) (Figure 1). Total daily precipitation ranged from a minimum of 0 mm to a maximum of 66.0 mm in 2013, and a minimum of 0 mm to a maximum of 130.8 mm in 2014 (maximum total daily precipitation was 49.5% greater in 2014). The total annual precipitation for 2013 was 98.2 cm, and total annual precipitation for 2014 was 101.7 cm (maximum annual precipitation was 3.4% greater in 2014). Average daily temperature in 2013 ranged from a low of -10.7°C to a high of 30.9°C, with a mean temperature of 12.4°C, median temperature 12.8°C, and standard deviation 10.8°C. Average daily temperature in 2014 ranged from a low of -20.1°C to a high of 29.9°C (mean 12.1°C, median 13.7°C, standard deviation 11.4°C). Overall the difference in daily temperatures in 2014 as compared to 2013 was as follows: low temperature was 46.8% lower than 2013; average temperature was 3.1% higher than 2013; high temperature was 3.3% lower than 2013. During the 2013-2014 study period, relative humidity ranged from a low of 32.9% to a high of 99.2% (mean 67.0%, median 65.9%, standard deviation 13.8%). All discharge data in Table 1 were obtained from the United States Geological Survey (USGS) website for gauging station 06910230 located on Hinkson Creek in Columbia, Missouri (Figure 1). Discharge in Hinkson Creek during the combined 2013-2014 period ranged from a minimum of 0.01 m^3/s (flows were below 0.02 m^3/s from September 25, 2014 through September 30, 2014) to a maximum of 143.3 m^3/s (the maximum discharge was recorded on May 31, 2013 during a two day rain event May 30-31 with 11.2 cm of rain falling during antecedent wet conditions) (USGS).

Table 1. Climate data for the study period in Hinkson Creek Watershed: Total Daily Precipitation (mm), Average Daily Discharge of Hinkson Creek (m^3/s), Average Daily Temperature (°C), and Relative Humidity (%) for 2013, 2014, and 2013-2014.

2013 Climate variable	Maximum	Minimum	Mean	Median	Standard Deviation
Total Daily Precipitation (mm)	66.04	0.00	2.69	0.00	7.78
Discharge * (m^3/s)	143.30	0.02	2.51	0.22	11.12
Average Daily Temperature (°C)	30.90	-10.70	12.40	12.80	10.82
Relative Humidity (%)	98.13	36.90	67.45	66.41	13.35
2014 **Climate variable**	**Maximum**	**Minimum**	**Mean**	**Median**	**Standard Deviation**
Total Daily Precipitation (mm)	130.80	0.00	2.79	0.00	11.32
Discharge * (m^3/s)	117.53	0.01	2.19	0.27	9.66
Average Daily Temperature (°C)	29.90	-20.10	12.10	13.70	11.35
Relative Humidity (%)	99.18	32.85	66.57	65.51	14.22
2013-2014 **Climate variable**	**Maximum**	**Minimum**	**Mean**	**Median**	**Standard Deviation**
Total Daily Precipitation (mm)	130.80	0.00	2.74	0.00	9.70
Discharge * (m^3/s)	143.30	0.01	2.35	0.25	10.41
Average Daily Temperature (°C)	30.90	-20.10	12.25	13.20	11.08
Relative Humidity (%)	99.18	32.85	67.01	65.93	13.79

Climate data for the study period (precipitation, discharge in Hinkson Creek, temperature, and relative humidity) are presented in Figure 2. Discharge data from Hinkson Creek are presented on a logarithmic scale for ease of comparison with precipitation. A negative relationship is observed between temperature and relative humidity.

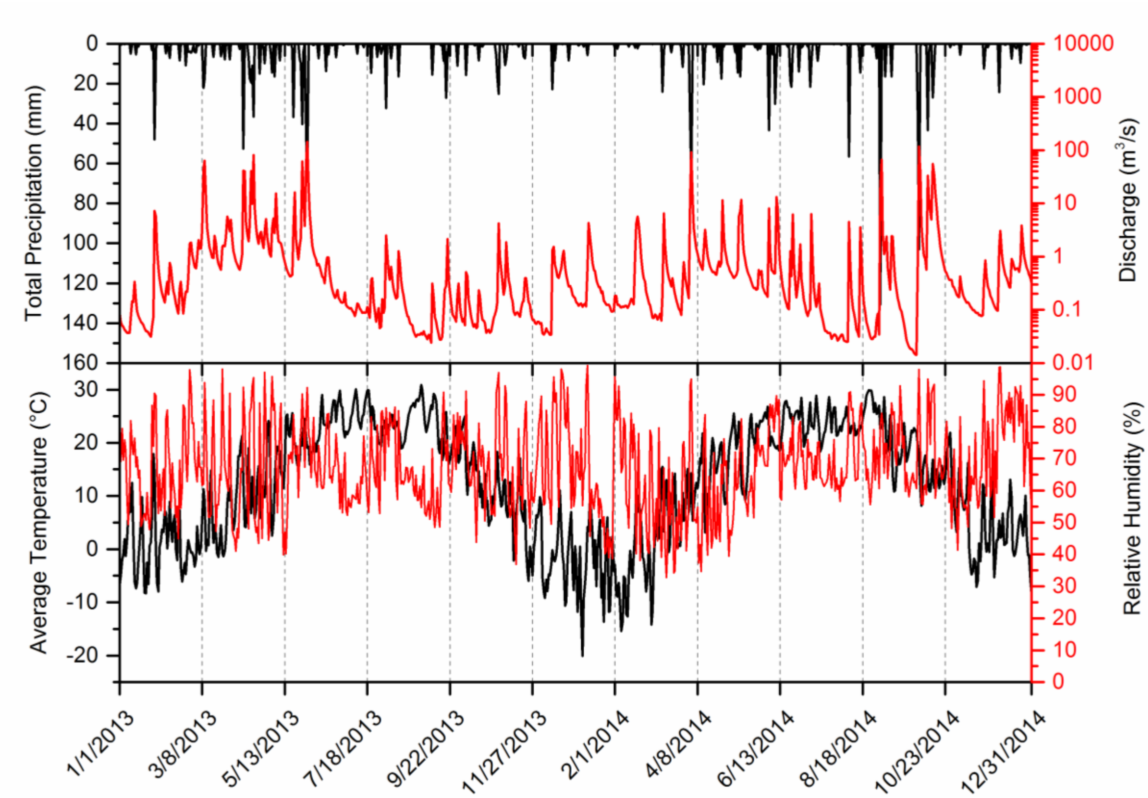

Figure 2. Total daily precipitation, average daily discharge rate in Hinkson Creek, average daily temperature, and daily relative humidity are presented for the period January 1, 2013 through December 31, 2014, and include the study period from July 18, 2013 through August 15, 2014.

Field work for PHA data collection was contingent on the field crew being able to safely work in the stream. At times there were interruptions in field work lasting several days during and after precipitation events to allow time for stream flow to return to levels within low to median baseflow conditions. Even in the upper reaches of the watershed with relatively small drainage areas, a precipitation event of 10 or 20 mm could increase flow and turbulence in the stream to the point where field work became dangerous. Bank storage of water after high flow events created slippery banks that were difficult to navigate for many days. Hinkson Creek started to periodically ice over in November of 2013, and ice presented another safety concern for field crew members. Field work was discontinued from December 5, 2013 until March 6, 2014 when ice cover was reduced to the point where PHA work could resume.

2.1.2 Geology of Hinkson Creek Watershed

The bedrock composition of HCW is comprised of four types of rock: chert, limestone, sandstone, and shale, in various combinations throughout the watershed (MDNR/MGS 2015) (Figure 3). Bedrock formations in streambanks may provide geologic constraints that impede or prevent movement of the channel, which in alluvial sediments help the stream compensate for physical stress including increased flow volume and/or velocity (Piégay and Schumm 2003, Elliott et al. 2009, Turowski et al. 2008). Karst hydrogeological features are common in the midwestern United States (Weary and Doctor 2014) including areas of Boone County, which includes limestone bedrock (including numerous sinkholes) (MDNR/MGS 2015).

While Karst topography is relatively widespread in the United States, the presence of carbonate rock (including limestone) at or near the surface is a regional geological feature that occurs in only a few areas (Weary and Doctor 2014). The largest area of carbonate rock at or near the surface in the midwest occurs in Missouri beginning north of the Missouri River (including the lower reaches of HCW) extending south into the northern part of Arkansas and west into the eastern portions of Kansas and Oklahoma (Weary and Doctor 2014). Limestone is one component of the bedrock formation in the lower reaches of HCW (Figure 3). This is an important observation since limestone bedrock is soluble via natural chemical reactions (limestone is typically eroded in the formation of Karst caves and sinkholes) which could more easily allow for channel incision into the bedrock substrate than other bedrock composition such as sandstone (Springer et al. 2003). Karst (Figure 4) and sandstone (Figure 5) formations were visible at various points along Hinkson Creek during the PHA.

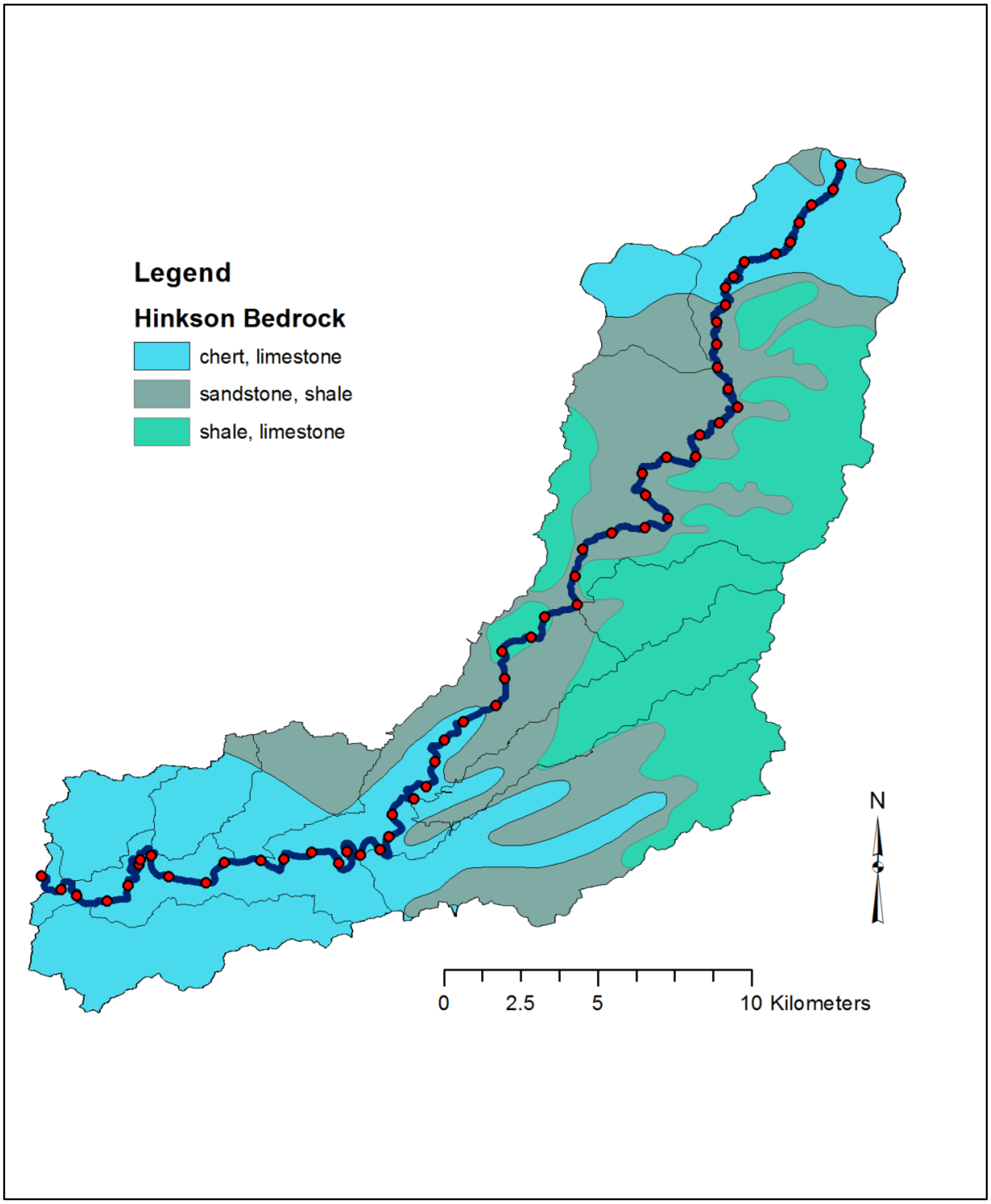

Figure 3. Bedrock geology of Hinkson Creek watershed with color legend. Projection is NAD 1927 rather than NAD 1983 as with other maps of HCW in this thesis. (Source of bedrock geology map layer: Missouri Department of Natural Resources, Geological Survey and Assessment Division, 2005, via USGS http://mrdata.usgs.gov/geology/state/state.php?state=MO; source of stream center line and points: MoRAP in conjunction with Phase I PHA report, Appendix A). The blue line is center of Hinkson Creek, and the red dots mark 1 km intervals along the length of the stream.

Figure 4. Karst (limestone) formation on left descending bank of Hinkson Creek approximately 1.4 km upstream of Rogers Road, 05-29-2014, 14:17 (lat. 39.023698, long. -92.240008).

Figure 5. Sandstone bluff formation approximately 2.7 km upstream of Rogers Road on left descending bank of Hinkson Creek, 06-02-2014, 09:38 (lat. 39.02401, long. -92.232383). Field crew members at the lower right of the photograph give an idea of the scale of the formation.

Surficial geology in HCW consists of three principal domain types: F-Glacial Drift, I-Residuum, and J-Residuum (MDNR/GIS 2015**)** (Figure 6). Explanations of the domain types below were copied verbatim from the Missouri Department of Natural Resources website (MDNR/GIS 2015**)** as follows:

> **Enumerated Domain Value:** F-Glacial Drift
> **Enumerated Domain Value Definition:** Silty clay and clay, 10-300 ft (3-91 m) thick; color ranges from light tan to dark grey. Drift varies laterally and vertically but is predominantly a silty clay mixed with pebbles of limestone, chert and quartzite. Locally, pockets, lenses and channels contain glacially derived sand, cobbles and boulders. Drift usually covered by 1-5 ft (<1-2 m) of loess, but in some areas thickness may exceed 20 ft (6 m). Generally at depths of 6-8 ft (2-2.4 m) a clay-rich Sangamon and/or Yarmouth paleosol is present. Thickness of the

clay ranges from 5-10 ft (1.5-3 m) but in local areas exceeds 25 ft (8 m). In northwest Missouri, deep preglacial stream valleys filled with pre-Illinoian tills, sands and gravels. Glacial erratics reported as far south as Miller and Ste. Genevieve Counties and lacustrine deposits in Johnson and Pettis Counties.

Enumerated Domain Value: I-Residuum
Enumerated Domain Value Definition: Sandy clay and clay, brownish yellow to dark gray, 1-10 ft (<1-3 m) thick; developed as residuum from cyclic sequences of shale, limestone, sandstone, coal and clay. Shale beds dominant, but thick limestone beds and channel sandstones also present. Unit includes many producing coal strip mines. Residuum very clayey, containing limestone and sandstone fragments; covered by thin layer of colluvium and loess. In northern Missouri, residuum may be covered by thin mantle of drift and/or loess. In Mississippi Embayment, residuum is dark-gray Tertiary clay, 0-200 ft (0-61 m) thick, capped by thin layer of loess and Quaternary gravel.

Enumerated Domain Value: J-Residuum
Enumerated Domain Value Definition: Cherty clay, dark red to reddish brown, 1-40 ft (<1-12 m) thick, developed as residuum from limestone and cherty limestone containing cherty layers and nodules. In southwest Missouri, residuum is blocky-structure, light-density cherty clay containing relict chert beds, 1-3 ft (<1-1 m) thick. Karst fields present over wide areas within this unit. Underlying bedrock pinnacled and contains numerous solution openings. In northern Missouri, residuum developed from limestone and subordinate shale beds; consists of tan to reddish-brown gravelly clay and silty clay, 1-20 ft (<1-6 m) thick, usually covered by thin mantle of loess and/or drift. Clay is fine textured. In places residuum covered by 30 ft (9 m) of loess.

A map of the surficial geology of HCW shows a large area of J-Residuum in the lower reaches of the watershed, consisting of clay with a high chert and limestone content (MDNR/GIS 2015) (Figure 6). The J-Residuum composition corresponds with the presence of a thick clay layer as the substrate in the lower reaches of Hinkson Creek. A thick clay substrate was observed in the lower reaches of the watershed during the current work (Figure 7), presumably alluvium consisting of sand, clay and silt transported from within the basin. The limestone and chert composition of the J-Residuum also suggests chemical weathering and channel incision into what was formerly limestone below the clay and silt layers of the substrate (Springer et al. 2003).

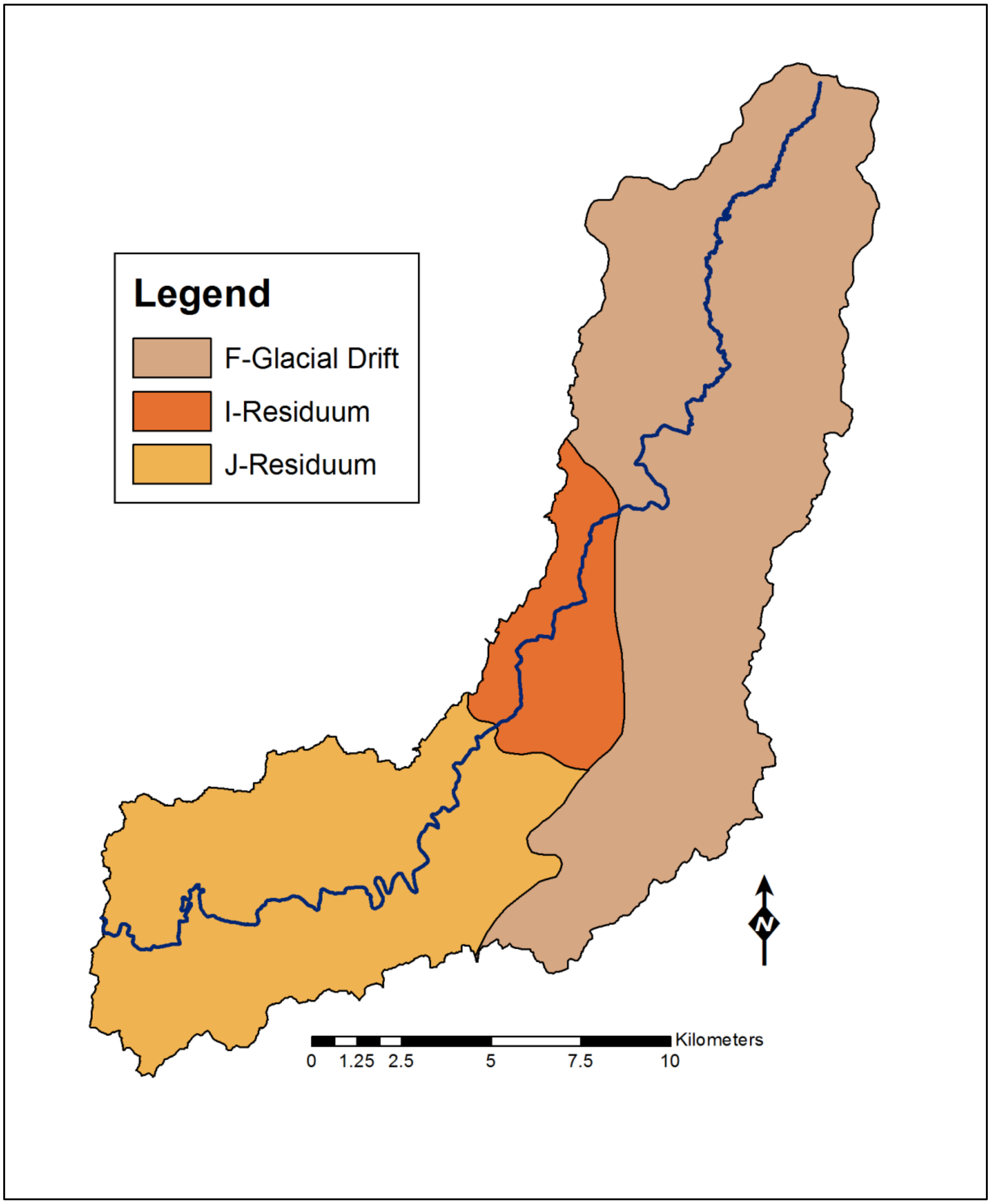

Figure 6. Surficial geology of Hinkson Creek watershed. (Source of surficial geology map layer: Missouri Department of Natural Resources, Missouri Geological Survey; source of stream center line: MoRAP in conjunction with Phase I PHA report - Appendix A).

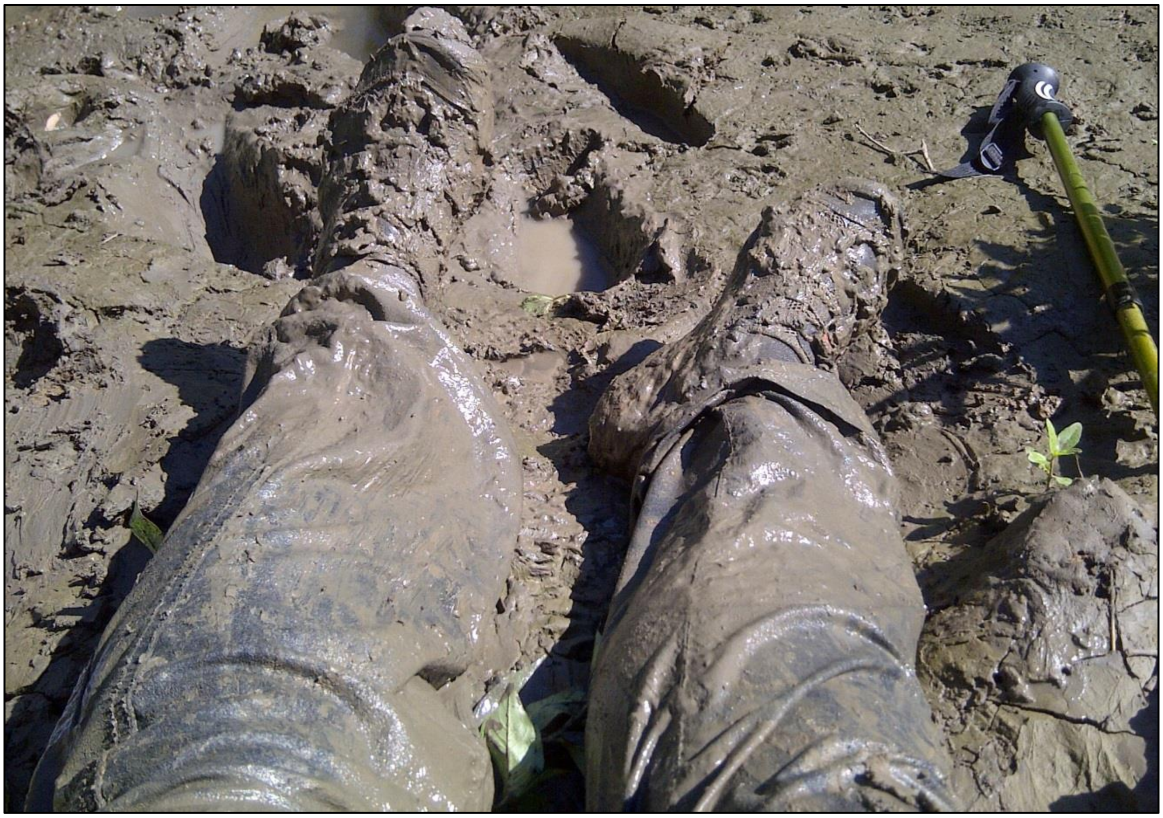

Figure 7. A view of the author's legs after walking through a deep clay substrate in Hinkson Creek 3 km downstream of Twin Lakes Recreation Area, 07-15-2014, 09:59 (coordinates not available).

HCW straddles two ecoregions. To the northeast, HCW lies in Central Irregular Plains ecoregion and to the southwest, HCW lies in the River Hills (Missouri Ozark Border) ecoregion (USEPA 2015). Differences in geology or topography in HCW between the regions are expected due to the influence of ecoregion characteristics. In particular, the presence of bedrock formations in streambanks during the PHA was associated with the Missouri Ozark Border ecoregion.

The topography of HCW is presented in three panels in Figures 8 through 10. The shape of the watershed is long and narrow. Hinkson Creek (approximately 56 km) begins near Hallsville, Missouri, and flows in a south-southwest direction making a more westerly bend in the city of Columbia on to the mouth at Perche Creek ("J"-shape – see Figure 6). The drainage area of HCW is approximately 231 km^2, and HCW is a mixed-land-use watershed meaning that Hinkson Creek flows through various dominant land-use types (e.g. agricultural, urban). Because of the length of Hinkson Creek (56 km) and the large drainage area (231 km^2), time of concentration to the outlet is longer than in smaller or more round-shaped watersheds (it takes a relatively longer time for water to travel from the furthermost point in the watershed to the mouth at Perche Creek). Runoff from the urban areas enters the stream, and the flows increase as water from the upper reaches arrives downstream and mixes with the urban runoff amplifying the urban effects on stream physical habitat in the area below the city of Columbia. Adding to the complexity of the topography in HCW, the flows of Hinkson Creek have been cutting through (both lateral cutting and channel incision) soil and bedrock since the last ice age as the channel of the Missouri River has likewise lowered in elevation (Tarr 1924). Additionally, during spring months to early summer the Missouri River backs up Perche Creek to the mouth of Hinkson Creek, and then upstream in Hinkson Creek for a distance of approximately 5 or 6 km (see *4.1 Bank and Channel Measurements*). The backwater from the Missouri River increases sediment deposition on the floodplain in HCW, potentially increasing the height of streambanks in a similar manner to what has been observed in the Upper Mississippi River system by Knox (2006).

The figures below divide HCW into approximately 3 equal segments, with some overlap between panels for continuity. Figure 8 shows approximately the lower one-third of HCW, including the majority of the City of Columbia, Missouri (urban land-use is the dominant land-use type in the lower reaches of HCW). Figure 9 shows the more central reaches of HCW, including the urban areas at the left of the panel, the rural/urban interface in the center of the panel, and the more rural area to the right side of the figure. Figure 10 illustrates the upper reaches of HCW which is primarily rural and land-use is agricultural: either pasture/ grazing or cropland.

Several examples of areas along the length of Hinkson Creek which are bordered by bedrock bluffs (bedrock constraints to channel movement) have been designated by yellow circles. The yellow circle in Figure 9 is of particular importance as the bedrock just downstream of the Grindstone confluence (see Figure 1) is quite extensive and constrains not only the left descending bank (bluff) but the substrate of Hinkson Creek. The bluff is a sandstone formation, which has been found to be more resistant to weathering than limestone bedrock (Springer et al. 2003) which is also found in HCW. Bedrock constraints to channel movement will become relevant in the discussion of channel incision (see *4.2 Thalweg Measurements*).

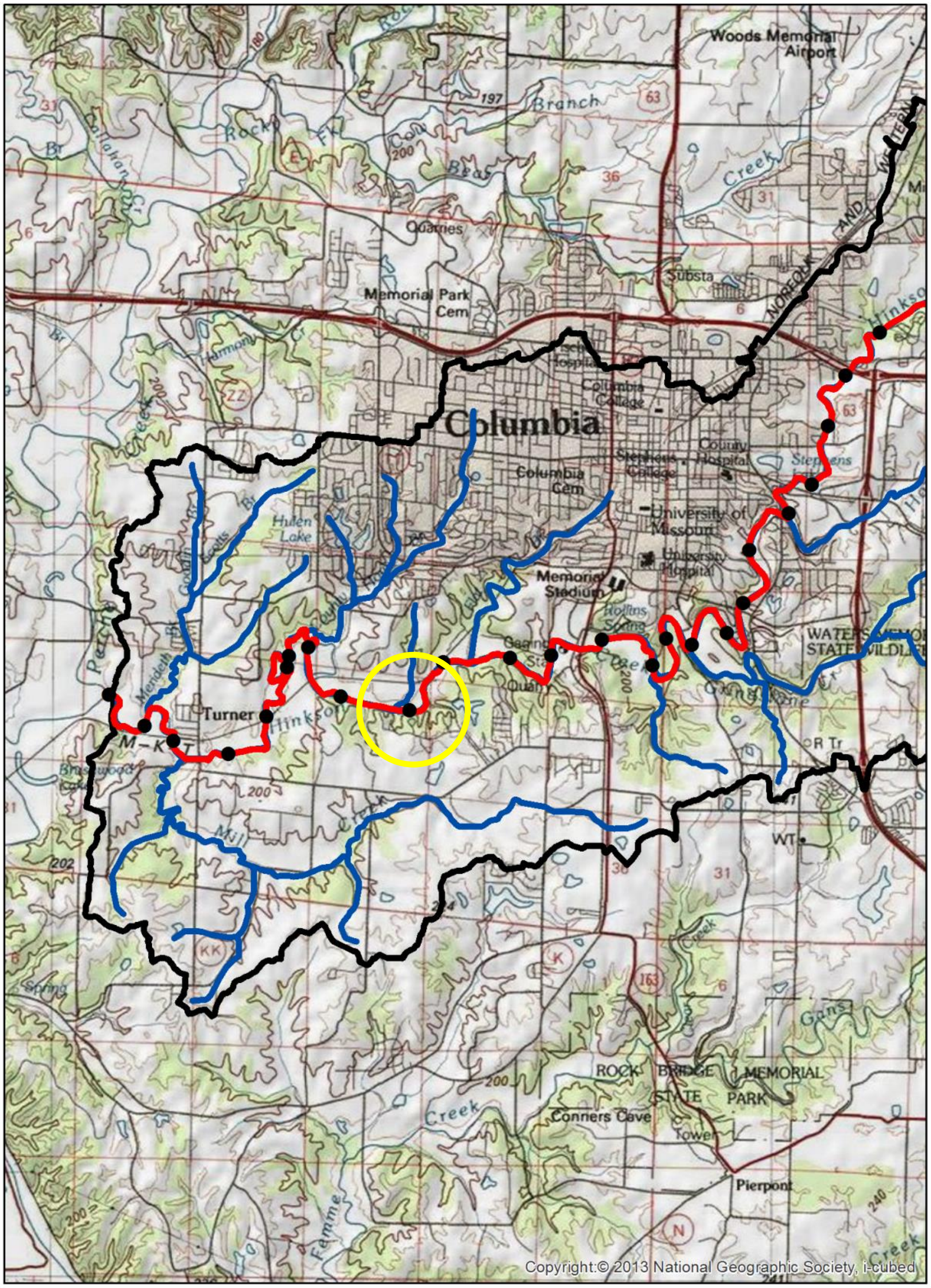

Figure 8. Topographic map of HCW by National Geographic Society (2013), accessed online (http://www.esri.com/software/arcgis/arcgisonline), lower reaches of Hinkson Creek. The red line represents Hinkson Creek, and the black dots represent 1 km intervals along the stream length. The yellow circle shows an example of an area where bedrock cliffs border Hinkson Creek.

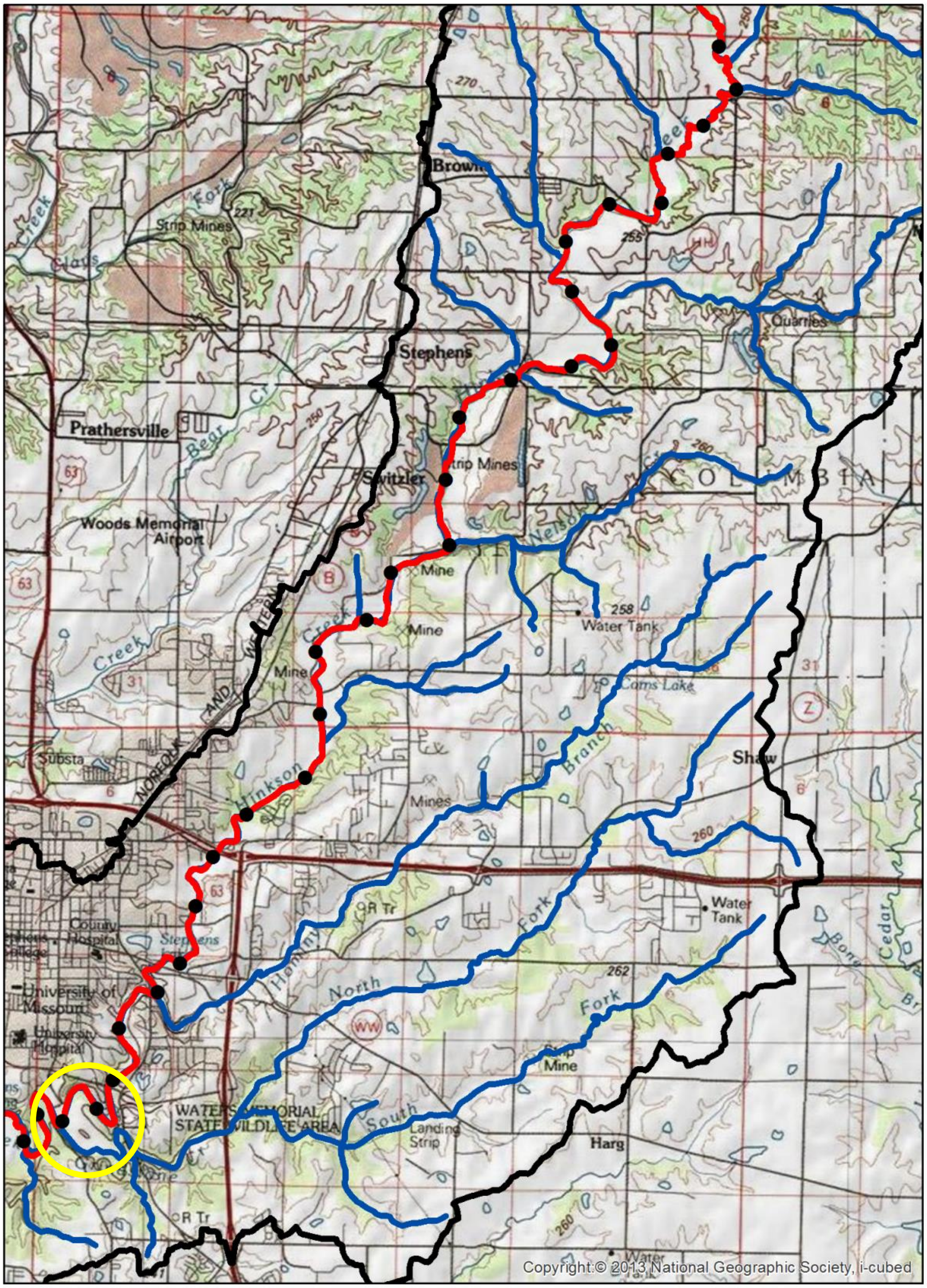

Figure 9. Topographic map of HCW by National Geographic Society (2013), accessed online (http://www.esri.com/software/arcgis/arcgisonline), middle reaches of Hinkson Creek. The red line represents Hinkson Creek, and the black dots represent 1 km intervals along the stream length. The yellow circle shows an example of an area where bedrock cliffs border Hinkson Creek.

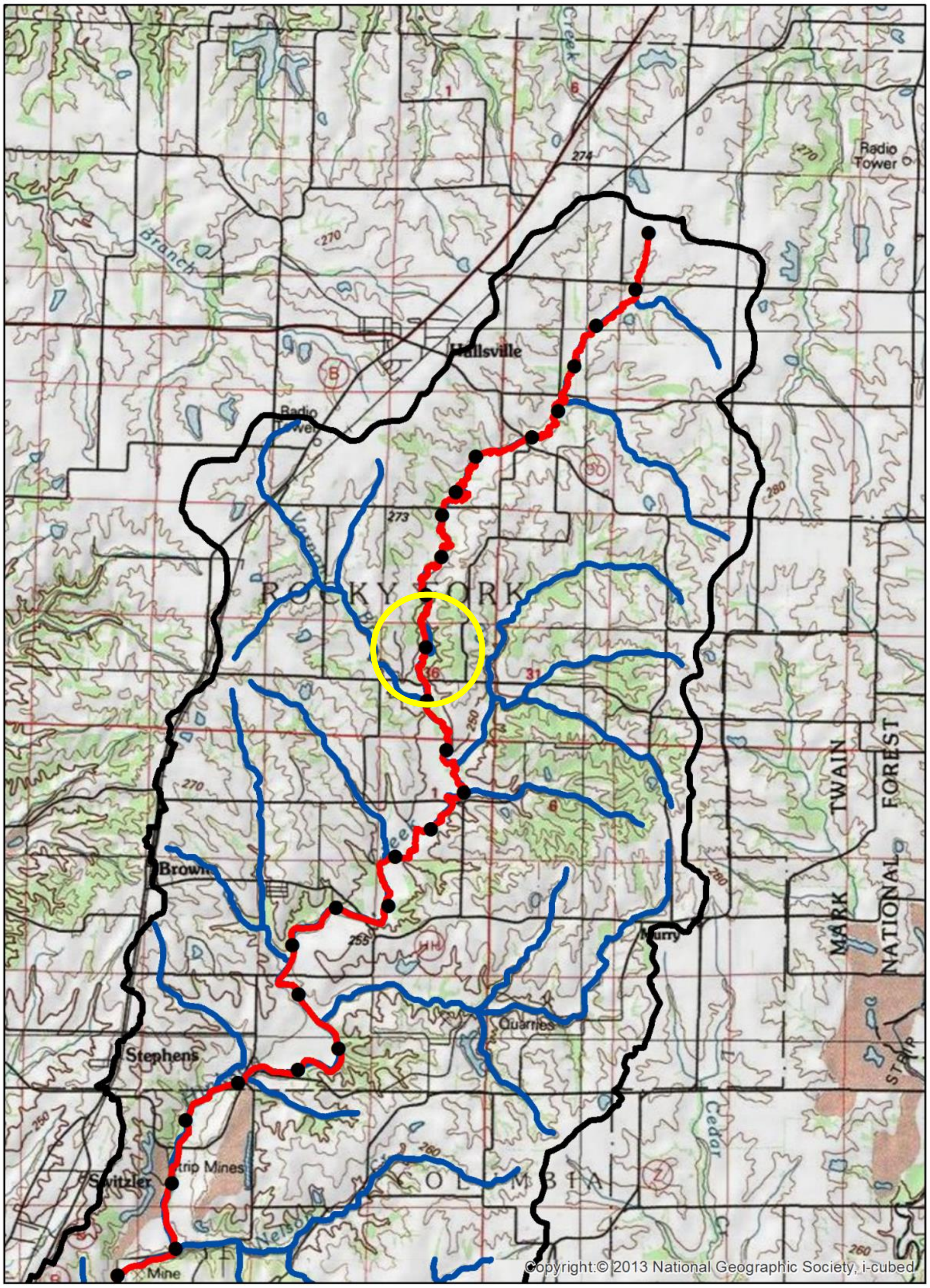

Figure 10. Figure 10. Topographic map of HCW by National Geographic Society (2013), accessed online (http://www.esri.com/software/arcgis/arcgisonline), upper reaches of Hinkson Creek. The red line represents Hinkson Creek, and the black dots represent 1 km intervals along the stream length. The yellow circle shows an example of an area where bedrock cliffs border Hinkson Creek.

2.1.3 Overview of Land-Use and Land Cover in Hinkson Creek Watershed

The data submitted in conjunction with the MoRAP report from Phase I of the PHA (see Appendix A) included land-use and land cover (LULC) data for the catchments of each of the 8 major tributaries of Hinkson Creek (Figure 1). The LULC percentages for the land-use categories used by MoRAP are provided for each catchment in Table 2 below. The highest percentage of crop (agricultural) land-use (30.14%) is in the catchment for Varnon Branch, the tributary closest to the headwaters. The percentage of crop land-use continues to decrease moving downstream from the headwaters to a low of 0.01% in the Flat Branch catchment, and then increases again in the Mill Creek and Merideth Branch catchments (the field team observed some agricultural land-use close to the confluence of Hinkson and Perche Creeks). The percent impervious surface generally increases from a low of 1.79% in Varnon Branch catchment near the headwaters, with some variability moving downstream (Hominy Branch catchment has a higher percentage of impervious surface area than Grindstone Creek catchment, although it is higher up in the watershed). The Flat Branch catchment (Flat Branch Creek begins underground in downtown Columbia) has the highest percentage of impervious surface area (corresponding to urban land-use) of the 8 catchments at 28%. Moving downstream from the Flat Branch catchment, the percentage of impervious surface area drops to 17.55% in the County House Branch catchment, drops again to 15.12% in Mill Creek catchment, and increases to 19.77% in Merideth Branch catchment.

Table 2. LULC calculated by MoRAP during Phase I of PHA in the catchments of the eight major tributary basins of Hinkson Creek Watershed, moving downstream from headwaters to the mouth.

CATCHMENT	Area (km^2)	% Forest	% Crop	% Impervious	% Water	% Sparse	% Grass
Varnon Branch	26.78	33.65	30.14	1.79	1.13	0.15	33.14
Nelson Creek	66.40	45.44	11.23	2.22	2.16	1.27	37.68
Hominy Branch	36.29	39.68	7.83	14.98	1.90	2.92	32.69
Grindstone Creek	41.23	41.52	6.81	9.90	1.48	4.67	35.62
Flat Branch	17.80	40.04	2.48	28.47	0.45	2.69	25.86
County House Branch	10.29	53.58	0.01	17.55	3.53	0.60	24.72
Mill Creek	19.49	36.14	1.00	15.12	1.66	4.50	41.56
Merideth Branch	8.77	35.33	4.26	19.77	0.67	1.80	38.17

2.1.4 Synthesis of Work to Date in Hinkson Creek

Subsequent to the placement of Hinkson Creek on the Clean Water Act 303(d) list of impaired waters in 1998, numerous studies have been conducted to identify the pollutant causing the impairment which prevents the stream from fully supporting aquatic life. Some studies have been performed by the Missouri Department of Natural Resources, including tests for heavy metals and various toxins (no source of impairment identified), and fecal coliform testing (MDNR 2006). In spite of improvements in sewer connectivity along the Hinkson Creek corridor, fecal coliform levels continue to exceed water quality standards during particularly at baseflow conditions (summer months / recreational season) (MDNR 2006).

In November of 2008 permanent gauging stations were installed at 5 locations along Hinkson Creek using a nested scale experimental watershed study design (Hubbart et al. 2010). The location of the gauging stations corresponded to different land-use types along the length of Hinkson Creek, as follows: site 1 – forested rural (but with upstream agricultural and pastureland/grazing land-uses); site 2 – agricultural and pastureland/grazing; site 3 – suburban; sites 4 and 5 – urban. The nested scale design allows for scalable and transferable comparison between this watershed and others of data collected at sites with various primary land-use practices (Hubbart et al. 2010).

A number of studies have been performed in Hinkson Creek since the gauging stations were installed 2008-2009 that are relevant to a discussion of the effects of human land-use change in HCW. Sediment as a stream pollutant has been the subject of multiple studies in Hinkson Creek, including work by Hubbart and Freeman (2010) who collected and analyzed water samples for particle size class distribution during March, 2010 (spring rains). Hubbart and Freeman (2010) identified an urban land-use effect in Hinkson Creek post-precipitation event with a 450% increase in the concentration of the smallest particle size class (2.06 µm) in the urban reaches of the stream. Thus, with a doubling of streamflow (1.4 m^3/s to 2.9 m^3/s) during a precipitation event, the concentration of fine sediment was more than quadrupled. This relationship could be attributed to a number of natural in-stream or overland processes; however, urban land-use was indicated to potentially impact their results (Hubbart and Freeman 2010). Freeman (2011) showed that suspended sediment concentrations were greater at urban sites relative to rural sites but that the difference was not statistically significant. His results also showed smaller mean particle sizes of the suspended sediment at urban sites which was attributed to both in-stream weathering processes and land-use (Freeman 2011). Kellner et al. (2014) followed up on the work of Hubbart and Freeman (2010) and Freeman (2011) by analyzing terrestrial stormwater samples for suspended sediment size class distribution comparing 17 urban stormwater monitoring sites (n = 272) to 3rd and 4th order receiving water bodies. Urban stormwater samples had lower total concentration (205.11 µl/l) relative to receiving water bodies (3rd order = 318.77 µl/l, 4th order = 323.26 µl/l), containing approximately 35% less total suspended sediment. In other research conducted in a Hinkson Creek floodplain, Huang (2012) conducted a study of streambank erosion and found that bank erosion can contribute as much as 67% of suspended sediment material in the reach of Hinkson Creek that was investigated. These studies showed the effects of land-use and implications for erosion, sediment transport and suspended sediment as well as hydrogeomorphological alteration, and ultimately potential impact on aquatic habitat.

Recent work in a floodplain of Hinkson Creek with both bottomland hardwood forest (BHF) and former agricultural sites suggests that forested floodplains attenuate flood waters during high flow events. Kellner et al. (2015) determined that floodwaters infiltrate BHF soils (great depth to water than former agricultural sites) and the groundwater moves in the opposite direction to Hinkson Creek, attenuating the flood wave which is then transported out the watershed via evapotranspiration in the BHF. Kellner et al. (2015) also found that floodplain groundwater acted as both a source and a sink for nutrients and chloride depending upon seasonal conditions and stage. For example, during periods of low flow, the agricultural sites on the floodplain pull water out of Hinkson Creek and store nutrients and chloride in groundwater. This work suggests that some mitigation of the deleterious effects of high flow events might be obtained by reforesting the floodplains of Hinkson Creek.

A stream temperature study performed by Zeiger (2014) showed a statistically significant correlation between terrestrial land-use and stream temperature at the 5 gauging stations installed on Hinkson Creek. Additionally, Zeiger (2014) found that heat was transferred from heated urban (concrete) surfaces in the City of Columbia to Hinkson Creek during precipitation events that caused overland flow into the stream, and that the temperature spike from the heated concrete surfaces could be tracked down Hinkson Creek over time.

Nutrient loading in Hinkson Creek has been tied to terrestrial land-use practices in HCW. Work by Hubbart and Zeiger (articles in prep) found that a spike in nitrogen loading was seasonally correlated with the timing of fertilization of agricultural lands in the upper reaches of the watershed in the spring. Similarly, a spike in phosphorus loading was seasonally correlated with fertilization of agricultural lands in the agricultural portion of HCW, but another phosphorus spike was associated with lawn fertilization by residential homeowners in the City of Columbia in summer months.

Chloride is another stream contaminant which has recently been tied to land-use practices in HCW. The work of Hubbart et al. (article in prep) found an increase in daily chloride loading during winter months moving downstream from the first gauging site in the upper reaches of the watershed, to the fifth gauging site below the City of Columbia (movement from rural forested, to agricultural, to suburban, and then urban land-use types in the watershed), as follows: 1620, 4350, 9470, 12800 and 19400 kg/day. Additionally, chloride levels were found to be at or above chronic levels (USEPA 1988) at various times during the year, and a few times at or above acute levels (USEPA 1988), over the course of a 5 ½ year (6 winters) study. Hubbart et al. (article in prep) suggest that chloride may persist in the sediment of Hinkson Creek year round.

Hubbart and Zell (2013) showed that despite ongoing population growth and development in HCW (Figure 11), annual streamflow metrics did not significantly increase or decrease ($p \leq 0.05$) from 1967 to 2010. However, several streamflow metrics featured shallow insignificant ($p > 0.05$) slopes in the direction hypothesized for an urbanizing (less pervious) watershed. The results suggest that although increasing urbanization may have some impact on flow regimes in Hinkson Creek, additional analyses were needed in order to isolate and identify hydrologic changes that correspond to the effects of urbanization in the watershed. As population (particularly in combination with urbanization and increased impervious surface area) continues to grow, the magnitude of the land-use effects on stream physical habitat and water quality in Hinkson Creek are likely to grow (see Nichols 2012, Hubbart and Zell 2013).

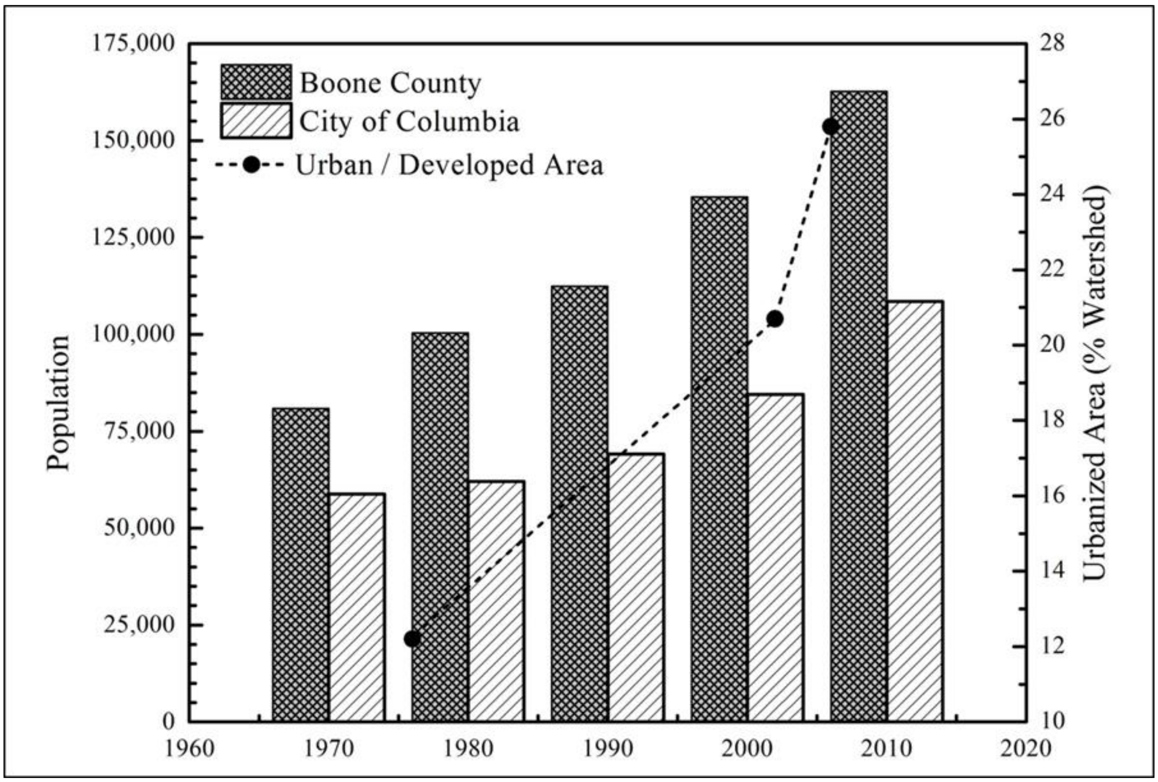

Figure 11. Population and urbanized area increase in the City of Columbia and Boone County, 1970 to 2010 (reprinted with permission: Hubbart and Zell 2013, Hubbart et al. 2014).

All of the pollutants discussed in the above research are, in one way or another, tied to human land-use in the watershed and its effects on stream physical habitat including water quality. Meyer et al. (2005) found that urban stream syndrome affects ecosystem functioning, which is intuitive when water quality and physical habitat for aquatic biota are altered by human land-use.

2.2 Physical Habitat Assessment Field Protocol

The field protocol used for the final report to the CAM stakeholder committee dated March 1, 2015, and entitled: Hinkson Creek Collaborative Adaptive Management, Physical Habitat Assessment, Phase II: Field Component, Final Report (see Appendix B), encompassed the methods set forth in sections 2.2.1 through 2.2.9. Methods in sections 2.2.10 through 2.2.12 were conducted during the PHA and analyzed for this thesis, but were not included in the final CAM report.

2.2.1 Global Positioning System Data

The PHA was conducted at pre-determined survey points at 100 m intervals that were numbered starting at the mouth of Hinkson Creek at Perche Creek and continuing upstream to the first second order confluence at the headwaters of Hinkson Creek. Coordinates for the 100 m survey points were provided by MoRAP and were pre-loaded into a Global Positioning System (GPS) handheld unit used by the field team. The field team travelled to the MoRAP coordinates of the first survey point (and every 100 m interval thereafter, not always in numerical order), and triangulated the position in the center of the stream channel closest to the MoRAP coordinate, using this position as the survey point. For each point surveyed during the PHA, the Excel datasheet includes the coordinates provided by MoRAP as well as the survey point coordinates, and a set of coordinates at the center of the stream if different from the center of the channel. In addition, coordinates were collected to mark the position of both stream banks (bottom of bank / top of streambed gravel) on either side of each survey point. Coordinates of special features including woody debris piles, public utilities, engineered structures, erosional gullies, bank failures, debris piles, and any other obvious habitat altering features were recorded in the properties of photographs taken of the special features (see *2.2.5 Special Features*). Additional survey points were established at the confluence of each of the following major tributaries as encountered on the survey path from the mouth to the first second order confluence at the headwaters of Hinkson Creek: Meredith Branch (MB), County House Branch (CH), Mill Creek (MC), Flat Branch Creek (FB), Grindstone Creek (GC), Hominy Branch (HB), Nelson Creek (NC), and Varnon Branch (VB) (Figure 1). Coordinates were collected at confluence survey points (a set of coordinates at each of 3 transects – see *2.2.3 Description of Survey Points* and *3.7 Confluences*) and recorded in the same manner as the 100 m survey points.

2.2.2 Survey Point Naming Convention

GPS waypoints were named using a code for the survey point number. For example, the waypoint for survey point one was named SP1. Each survey point was sequentially numbered from the first point at the mouth of Hinkson Creek through the final point at the headwaters. The survey point number was recorded on field data sheets, and later inputted to an electronic database and quantitatively compared with the corresponding MoRAP and survey crew GPS coordinates in a spreadsheet. For those survey points that were at the confluence with tributaries, data were collected and stored separately to avoid confusion with the 100 m survey points.

2.2.3 Description of Survey Points

Each survey point was located in the center of the stream channel of the creek and served as the center point of a study plot. The study plot consisted of a principal transect running from bank to bank through the survey point perpendicular to the direction of stream flow. Upstream and downstream transects delineated the beginning and end of the plot and were located 5 meters upstream and downstream of the principal transect. Upstream and downstream transects were parallel to the principal transect and extended from bank to bank (Figure 12). For purposes of the survey, the original field protocol called for the survey cross section of the study plot at any confluence to be set in Hinkson Creek 5 m downstream of the downstream bank of the confluence with the tributary so that the study plot was as close to the confluence as possible. This placement of the survey transect proved to be impractical in the field, as the width of the channel tended to be greater at the confluences, and the potential effects on physical habitat from the tributary flow were not evident at the 5 m distance. In order to resolve these issues, the field team set three transects for each confluence: one upstream of the confluence in Hinkson Creek, one downstream of the confluence in Hinkson Creek, and a third upstream in the tributary. Transects were located equidistant at 20 m to 50 m from the center point of the confluence (Figure 13). All bank and channel measurements described in this field protocol were collected at each of the three transects.

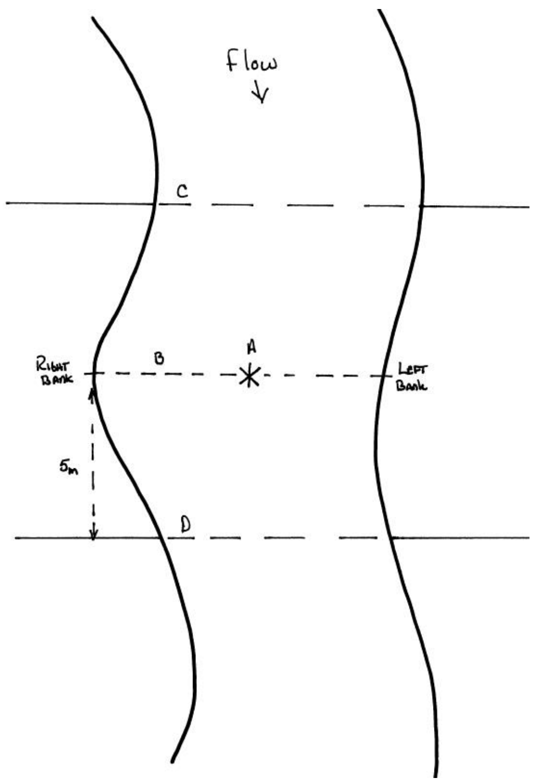

Figure 12. Layout of study plots used for habitat measurements: A) survey point, B) principal transect, C) upstream transect, and D) downstream transect.

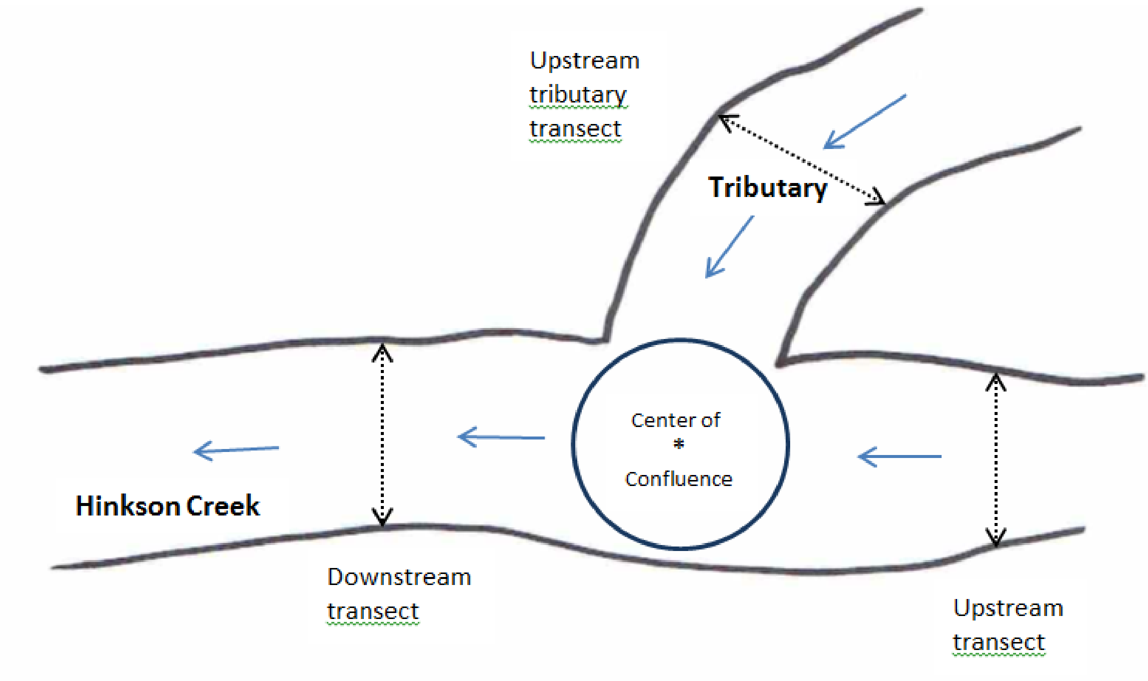

Figure 13. Layout of three measured transects at confluence sites during PHA of Hinkson Creek.

2.2.4 Photographic Database

A digital camera (Nikon Coolpix AW120, Nikon Corporation) was used to create a photographic database of each study plot. The properties of each photo included latitude and longitude of the photograph location. A standard set of photographs was taken from the survey point as follows: directly down at a distance of 1 m from the streambed (streambed composition), directly upstream (parallel with the channel), then turning clockwise a perpendicular (90 degree angle) photograph of the left bank, directly downstream (parallel with the channel), a perpendicular photograph of the right bank, and a final photo directly upwards to capture canopy cover. When possible, photographs of the stream banks captured the extent of vegetative cover present. A photograph of the survey point number (either written on a dry erase board or from the face of the GPS unit) was taken immediately before the first (streambed) photo in the series and again before photos taken at any transect between survey points (survey point – transect number, e.g. SP1-3, see *2.2.8 Longitudinal Thalweg Depth Profile*) so that the photographs could be catalogued later.

At confluence survey points, the standard channel photographs described above were taken, plus additional photographs to document physical characteristics at the confluence including a 360 degree panorama from the center of the confluence and at each of the three transects surveyed.

The mandatory set of field photographs and photographs of special features were made available to Boone County, Missouri in June of 2015, and selected photographs will be publicly available at some point in the future. Photographs selected for this thesis were chosen to illustrate certain specific discussion points or general trends in stream physical habitat with LULC and/or stream distance.

2.2.5 Special Features

GPS coordinates were embedded in the properties of the photographs taken to document the presence of any of the following special features: bank stabilization structures, including rip-rap, gabion baskets, and other engineered structures; infrastructure not adequately mapped in Geographic Information System (GIS) resources including pipes, outfalls, discharge control structures, and utilities with any related infrastructure; disturbance features including erosion gullies, debris fans, slumps, bank failures, and woody debris piles; cattle tracks found on either bank or in the substrate; large trash dumps in or near the stream. Special features photographs were named using the reference point number (as originally numbered in the MoRAP stream point file loaded into the handheld GPS unit, for ease of coordinating with an interactive map of the watershed in the future), followed by a hyphen and the distance upstream from the survey point in tens of meters (where applicable), the date, the type of feature, and the streambank. A sample file name is RP40-8_2014-07-16_erosion_and_woody_debris_rb, which would indicate a special feature located on the right bank 80 meters upstream of RP40.

2.2.6 Canopy Measurements

Canopy cover was estimated following the method described by Peck et al. (2006). A convex densiometer (Lemmon 1957) was used after modification to prevent overlap from measurements taken close together. The modification consisted of creating a "V" comprised of tape on the face of the densiometer with the vertex pointing towards the viewer such that 17 line intersections exist within the "V" (Mulvey et al. 1992) (Figure 14). The number of line intersections covered by canopy was recorded on the data sheet. During the winter months, the number of line intersections covered by branches was recorded on the data sheet, and a notation was made as to the presence or absence of leaves. Canopy cover was determined by quantifying the percentage of points covered by canopy (Peck et al. 2006).

Procedure for Canopy Cover Measurements

1. A field team member stood on the principal transect at mid channel facing upstream.

2. The densiometer was positioned 1 m above the streambed, and levelled using the bubble level. The densiometer was then positioned so that the face of the field team member was reflected just below the apex of the taped “V” (Figure 14).
3. The number of grid intersection points within the “V” that were covered by a tree, a leaf, or a high branch were counted (0 to 17) and recorded in the appropriate place on the datasheet.
4. The field team member then faced the left descending bank (left, facing downstream). Steps 2 and 3 were repeated, and the value was recorded in the appropriate place.
5. Steps 2 and 3 were repeated again facing downstream and again facing the right bank, and the values were recorded in the appropriate places.
6. Steps 2 and 3 were repeated at the channel’s edge on the left bank (while facing the center of the stream) at the end of the principal transect, and again on the right bank, and the values were recorded in the appropriate places.

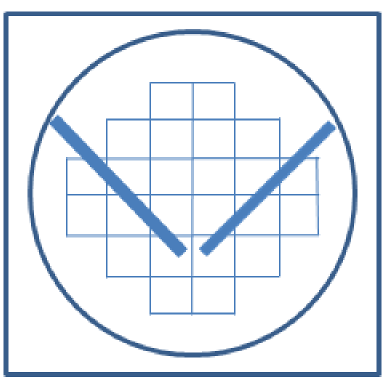

Figure 14. A diagram of the taping of the "V" on the face of the convex densiometer used in canopy cover measurements during PHA of Hinkson Creek.

2.2.7 Bank and Channel Measurements: Widths (wetted, channel, bankfull), Bank Angle, Bank Height, Channel Depth, Relative thalweg depth and thalweg position

At the principal transect running through each survey point, measurements of channel width, wetted width of the stream, bankfull width, bank angle, bank height, and channel depth were recorded (Figure 15). Bank angle was measured on both banks and calculated as the average slope of the bank extending 2 m from the bottom (top of gravel) toward the top of the bank. Normally, slope was between 0º and 90º; however, by definition undercut banks had an angle greater than 90° because the edge of the water was underneath the overhanging bank.

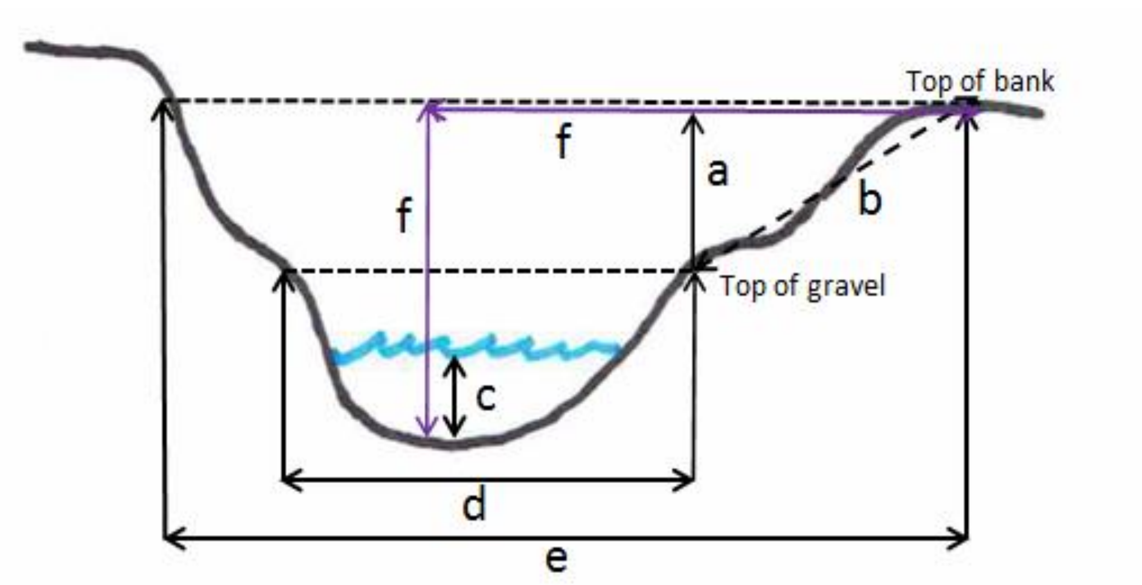

Figure 15. Cross-sectional view of channel and bank dimensions measured during PHA of Hinkson Creek: a) bank height, b) bank slope, c) thalweg depth, d) channel width, e) bankfull width, and f) relative thalweg depth (vertical) and thalweg position (horizontal). Wetted width is designated by the blue wavy line.

Bankfull flows are events large enough to erode the streambed and banks, and frequent enough to prevent substantial growth of terrestrial vegetation (Peck et al. 2006). Annual peak flows are used to compare channel morphology measurements on a consistent basis, relative to flows thought to have a consistent 1.5-2.0 year return interval (Leopold et al. 1964). Common indicators of bankfull level included the top of pointbars, changes in vegetation from aquatic to terrestrial, changes in slope, changes in bank material (e.g. from coarse gravel to sand), bank undercuts, or stain lines on bedrock or boulders (Harrelson et al. 1994). More detailed descriptions of these indicators can be found in Harrelson et al. (1994). Determination of bankfull levels at times required some discussion among crew members and if possible, multiple indicators that "agreed" with each other were used. Bankfull width was measured as the distance between banks at the bankfull level perpendicular to stream flow. Bankfull bank refers to the bank with the lowest vertical distance from the surface of the water (i.e. the first to be breached in a high flow event). All measurements in this section with the exception of bank angle and channel depth were made using a laser level and/or laser range finder.

Procedure for measuring bank angle:

1. An extension pole was laid on the bankfull bank at the end of the principal transect so that the base of the pole was at the bottom of the bank (top of the line of coarse gravel from the streambed). The extension pole was extended 2 m up toward the top of the bank. A clinometer was placed on the extension pole and the bank angle was read and recorded in degrees (0-90°). If the bank was undercut (>90°), the measurement was made from the water's edge along the underside of the undercut, and the clinometer reading was subtracted from 180° and recorded.

2. If the bank was undercut, the undercut depth was recorded by placing a meter stick horizontally parallel to the stream, and the distance from the back of undercut to the edge of the bank was measured.
3. If there was a large boulder or a log at the transect point, the measurement point was moved ($\leq$ 5 m) to a nearby point which was more representative of the slope of the bank.
4. Step 1 (and Step 2 if necessary) was repeated on the opposite bank.

Procedure for measuring Channel Width, Wetted Width, Bankfull Width, Bank Height, Channel Depth, and Relative Thalweg Depth and Thalweg Position (Figure 15):

1. Using a laser range finder, the distance from the bottom of the bank (the top of the gravel from the streambed) was measured across the stream channel from one bank to the other (channel width). Also using the laser range finder, the distance from one side of the stream to the other (wetted width) was measured. The lower end of the range of the laser rangefinder used in the field was 5 m. In the event that the width was $\leq$5 m, the width was measured manually using a meter stick. If there was a split in the channel due to a bar or island, the following wetted width values were recorded where possible and applicable: entire width of wetted portion of stream, wetted width nearest to left bank, wetted width of center stream channel, wetted width nearest to right bank. Values for channel width and wetted width(s) were recorded on the data sheet.
2. To measure bankfull width, the bankfull level on the streambank with the highest terrace was located. For a description of bankfull indicators see Harrelson et al. (1994). While squatting at the top of the streambank with the lowest terrace (bankfull bank), a field

team member used the laser range finder (visually levelled with the level inside of the device) to measure the width to the bankfull level on the opposite streambank.

3. Whether the right bank or left bank (descending) was used for bank measurements was determined at each survey point by which bank had the lower elevation (bankfull bank), and was indicated on the data sheet. Bank height was measured as the distance from the bottom of the bankfull bank (frequently determined by the top of the line of gravel from the streambed) to the top of the stream bank. A laser level (transmitter) was placed at the top of the bankfull bank and a field team member standing in the streambed extended an extension pole with a receiver attached upward (in a vertical position) from the bottom of the bankfull bank. The receiver would make intermittent beeping noises when it got close to the horizontal plane of the projection from the laser level transmitter; the beeping noises became a continuous sound once the appropriate level of the bank height was reached. Bank height measurements were adjusted in spreadsheet to subtract the height from the bottom of the laser level transmitter to the point where the laser beam was emitted.
4. Thalweg depth was measured by positioning the meter stick or extension pole on the streambed at the deepest part of the channel and reading the depth of the water. In the event that the water was more than chest deep, a float with a depth finder and battery were deployed to measure thalweg depth.
5. Relative thalweg depth and thalweg position were measured relative to the bankfull bank. Relative thalweg depth was measured in a manner similar to bank height, using the laser level as a transmitter and an extension pole with a receiver. The extension pole was set at the bottom of the stream in the thalweg, and raised or lowered in a vertical position until

the receiver was on a horizontal plane with the laser level stationed at the top of the bank (Figure 15). Relative thalweg depth measurements were adjusted in spreadsheet to subtract the height from the bottom of the laser level transmitter to the point where the laser beam was emitted. Thalweg position was measured using a laser rangefinder to measure the distance between the top of the bankfull bank and the laser receiver on the extension pole. In water deeper than chest deep, an innertube was used to float near the thalweg of the stream to obtain the measurements.

2.2.8 Longitudinal Thalweg Depth Profile

The thalweg is the path of the stream that follows the deepest point of the channel (Armantrout 1998). This is also the last part of the channel to become dry during low flow conditions. Although this is not a topographic profile, a longitudinal profile of thalweg depth yields information about potential habitat complexity and channel form variability. The thalweg was measured at each survey point and every 10 m between survey points. At the location of each thalweg measurement (including position 1, the survey point) a field crew member recorded the thalweg depth and the channel unit (Table 3). More detailed descriptions of the channel form can be found in Table 7.3 in Peck et al. (2006). At each thalweg measurement after the survey point (i.e. positions 2 through 10), the substrate size classification of a randomly selected particle was recorded (Table 4), as well as the presence or absence of periphyton on the selected particle. Periphyton on rock surfaces can provide habitat for micro-organisms and some macroinvertebrates, and can provide refugia for these organisms from high velocity flows

(Dodds and Biggs 2002). Periphyton presence is also an indicator of stream productivity (Lamberti et al. 1989; Rosemond et al. 2000).

Table 3. Channel unit types and codes used in data recording during PHA of Hinkson Creek. Adapted from Peck et al. (2006).

Channel Unit	Code	Description
Plunge pool	PP	Pool at base of plunging cascade or falls
Trench pool	PT	Pool-like trench in the center of the stream
Lateral scour pool	PL	Pool scoured along a bank
Impoundment pool	PD	Pool formed by impoundment above dam or constriction
Pool	P	Pool (unspecified type)
Glide	GL	Water moving slowly, with smooth unbroken surface and low turbulence
Riffle	RI	Water moving with small ripples, waves and eddies – waves not breaking, surface tension not broken; sound of babbling, gurgling
Dry channel	DR	No water in the channel or flow is under the substrate (hyporheic)

* Due to the local topography of Hinkson Creek, cascades are unlikely to occur, and thus this category was omitted from the Channel Unit Code on the data sheet in order to conserve space.

Procedure for Measuring Thalweg Profile

1. Using a string line marked at 10 m intervals and run for 90 m from the survey point, the field team continued upstream following the thalweg.
2. At each 10 m interval, the depth of the water was measured at the deepest part of the channel in the same manner that thalweg depth was measured at the survey points. This depth (cm) was recorded under the appropriate station number on the data sheet. The

survey point was station "1" on the data sheet (0 m, the beginning of the string line), and stations 2 through 10 continued along the string line (10 m, 20 m, 30 m... 90 m).

3. At each 10 m point, the channel unit was identified and the channel unit code was recorded on the data sheet.
4. At each 10 m point, the size classification of a particle randomly selected at the thalweg was determined and the appropriate code from Table 4 was recorded.
5. Where possible (it was difficult to select a particle from deep pools and to determine the presence of periphyton on sand or silt substrate), the presence or absence of periphyton on the substrate particle at the thalweg was determined and noted on the data sheet.
6. After the appropriate data were recorded at each 10 m point along the string line, the field team moved to the next coordinate provided by MoRAP and started a new data sheet.

2.2.9 Substrate Characterization (Pebble Count)

The method for substrate particle size characterization described here was adapted from Peck et al. (2006) and Wolman (1954). The procedure required estimation of the diameter size class of 15 substrate particles at each study plot. Five particles were sampled from the principal transect, the upstream transect, and the downstream transect (Figure 12). On each transect, particles were sampled from the left and right banks, and from 25, 50, and 75% of the distance across the width of the channel. Particle size was estimated according to the size classes listed in Table 4.

Table 4. Particle size classes and codes used on data sheets for substrate particles sampled during PHA of Hinkson Creek.

Diameter (mm)	Size Equivalent	Code	Substrate Type
>4000	Larger than a car	RS	Bedrock(Smooth)
>4000	Larger than a car	RR	Bedrock (Rough)
>4000	Larger than a car	RC	Concrete/asphalt
1000 to 4000	Meterstick to car	XB	Large boulder
256 to 1000	Basketball to meterstick	SB	Small boulder
64 to 256	Tennis ball to basketball	CB	Cobble
16 to 64	Marble to tennis ball	GC	Coarse gravel
2 to 16	Ladybug to marble	GF	Fine gravel
0.06 to 2	Gritty - up to ladybug	SA	Sand
<0.06	Smooth, not gritty	FN	Silt/clay/muck
Any size	NA	HP	Hardpan (firm, consolidated fine substrate)
Any size	NA	WD	Wood
Any size	NA	OT	Other - (write comment)

Procedure for measuring substrate:

1. Beginning on a bank of the principal transect, a field team member randomly pointed to a spot on the channel bed using a meter stick. The first particle that the meter stick came into contact with was selected. If the substrate was sand or finer material, multiple particles were picked up and size class was determined by texture.
2. The size of the selected particle was estimated (or particles for finer material) according to Table 4, and the size class was recorded on the data sheet.
3. The percent vertical embeddedness of the particle in the substrate (what percentage of the particle is not visible) was estimated to the nearest 5%. Sand and silt are by definition 100% embedded, and bedrock or claypan are 0% embedded. The percent vertical embeddedness was recorded on the data sheet.

4. The field team member moved to the next station along the principal transect (streambank, 25% across channel width, 50% across channel width, 75% across channel width, streambank) and repeated Steps 1 to 3, recording the data in the appropriate locations on the data sheet. Five particles were sampled on the principal transect.
5. Steps 1 to 3 were repeated on the upstream transect and the downstream transect (Figure 12), for a total of 15 particles per study plot.

2.2.10 Rootmat Survey

Submerged woody rootmats are important habitat for aquatic macroinvertebrates (Rabeni et al. 1997). However, there are currently no established protocols to quantify availability and quality of submerged woody root habitat in streams. The following method quantified the volume and structure of root habitat and described the composition of riparian vegetation which may be important to rootmat availability (after Nichols 2012).

1. Any submerged woody rootmats within the study plot were located. The following procedures were repeated separately for each separate contiguous area of rootmat within the study plot (Figure 12). A single tree may have had more than one separate rootmat. Likewise, a single contiguous rootmat was sometimes composed of the roots from multiple trees. The position of each rootmat relative to the principal transect was recorded and the stream bank was noted by checking the box next to the appropriate category on the data sheet. (e.g. “Up-Lft” referred to the left bank upstream of the principal transect, and “Dn-Rt” referred to the right bank downstream of the principal transect.)

2. Measurements were taken in order to calculate the volume of submerged rootmats. Each contiguous area of rootmat was measured in three dimensions (parallel to bank, perpendicular to bank, and vertical) (Nichols 2012). Each of the 3 measurements was recorded on the data sheet.
3. The percent by volume of fine roots was visually estimated (< 2 mm diameter) to the nearest 10%. The value was recorded on the data sheet.
4. The parent species of tree or shrub was recorded. In cases where there were multiple parent trees or shrubs, each species was recorded. In cases where the exact parent tree could not be determined, the dominant or most abundant species within a 2 m radius was recorded, and noted accordingly.
5. The diameter at breast height (DBH) of each parent tree was estimated according to predetermined size classes. Size classes were <10 cm, 11-30 cm, 31-60 cm, >60 cm. The appropriate DBH value was circled on the datasheet. If the parent tree could not be determined, "N/A" was circled.
6. Linear distance from base of tree to the edge of the top of the bank was estimated according to predetermined ranges. The ranges were < 0.5 m, 0.5-1 m, 1-2 m, and > 2 m. The appropriate value was circled on the datasheet. If the parent tree could not be determined, "N/A" was circled.

2.2.11 Riparian Zone Assessment and Determination of Dominant Vegetation Type

The width of the riparian corridor and the dominant vegetation type may be used to assess what areas of Hinkson Creek might be subject to excessive runoff, bank erosion and/or sedimentation during high flow events. This information, in combination with other quantitative assessments can be used to assist in future decisions regarding re-vegetation, bank stabilization or other management projects.

A visual estimation was made of the width of the riparian zone on each bank, and the width was placed into one of several classes: 0-5 m, 5-10 m, 10-20 m, > 20 m. Riparian vegetation included trees, grasses, and sparse vegetation, but did not include vegetation identifiable as crops or lawn grass. The presence of any fencing, roads or buildings in the riparian zone was noted, and at what approximate distance from the stream bank. A visual estimation of the mix of woody and herbaceous vegetation types in the riparian zone was made, and classified as a percent mix of the two classes, e.g. 60% woody, 40% herbaceous.

2.2.12 Wildlife and Cattle

Wildlife and cattle use of Hinkson Creek was documented during this study. The use of Hinkson Creek by cattle (and potentially wildlife) may impact the suspended sediment load (Trimble and Mendel 1995), and levels of bacteria such as *Escherichia coli* (*E. coli*) (Collins and Rutherford 2004).

A visual survey was conducted within the study plot in the creek and for the distance between survey points. Presence or absence of wildlife use was recorded. If wildlife was observed, the type of wildlife was noted (including species, if known). If animal tracks were present, they were identified using an animal track field guide prepared using images from the Missouri Department of Conservation website, and the type of tracks were recorded. In the event that tracks made by cattle were observed in the study plot or between study plots, this information was recorded on the data sheet.

2.3 PHA Data Analysis

Data from the PHA were analyzed using a variety of methods, as appropriate for each dataset. Analyses performed included line smoothing (100pt moving average) (Origin© software, OriginLab© Corporation, 2015) in the graphs of stream metrics with stream distance (Chapter IV) as an alternative to standard linear regression as the data were highly variable and not modelled well using linear regression. The analysis of resurveys (section *3.12* and *4.12*) was performed using Student's T-test (Origin© software, OriginLab© Corporation, 2015) (CI = 0.05) (Sokal and Rohlf 1981, Zar 1996). One-kilometer cumulative drainage area and land-use and land cover data (Table 19) were calculated in ArcGIS 10.3 (Environmental Systems Research, Inc., 2014) using watershed polygons developed using the ArcHydro toolset in combination with the MoRAP data from the PHA Phase I to delineate drainage area above each one-kilometer point.

In order to compare the GIS data from Phase I (Appendix A) with the observed data from Phase II (the current study), a version of ArcGIS (version 9 series, Environmental Research

Institute, Inc.) was used. To compare the position of stream center point from the modelled and observed data, a point file of observed stream center point coordinates was opened in ArcMap and compared to a point file of stream center points (the survey points) generated by MoRAP. Using ArcGIS tools, the distance between the modelled and observed points was calculated at each survey point. The maximum distance between stream points was 93.44 m. This maximum was a very extreme outlier, and was presumably influenced by the presence of two bridges side by side immediately upstream of the survey point that may have blocked satellite signals to the handheld GPS unit used by the field team. On this basis, the extreme outlier was removed from the data comparison pool.

Bankfull width data generated by MoRAP were copied as a column from the attribute table of the Hinkson Creek 100 m survey points file (data supplied by MoRAP with Appendix A), and pasted into a Microsoft Excel (2010) spreadsheet side by side with a column of the observed bankfull width measurements. The MoRAP bankfull width data corresponding to the 100 m survey points were converted to meters (data were in feet) for comparability with the observed data.

CHAPTER III

RESULTS

For ease of presentation, some of the results from PHA analyses have been grouped based upon similarity in types or location of measurements. For example, bank and channel measurements were grouped together for presentation in Section 3.1. As a result of the data grouping, the data may appear in a slightly different order than in the Field Protocol presented in the Methods.

All data collected during the PHA are presented in this section with the exception of the following: presence/absence of periphyton on substrate particles sampled at all thalweg profile locations, the number of rootmats per survey site (however a figure is presented in section *4.8 Rootmat Survey*), percent fines in each rootmat measured, and the distance of structures or roads in the riparian zone.

3.1 Bank and Channel Measurements

At every 100 m survey point, measurements of bank and channel variables were collected including bank angle (left and right banks), channel width, wetted width, bankfull width, and bank height (bankfull bank only). Bank angle exhibited the greatest range of measurements, with a maximum of 100°, minimum of 0°, mean of 35.0°, median of 34.0°, and standard deviation of 16.1°. Mean bank angle was very similar for the left and right banks, measuring 34.6° and 35.5°, respectively. Channel width and bankfull width varied from a maximum of 70.0 m and 74.0 m respectively (both at a survey point approximately 3 km upstream of Mexico Gravel Road in northern Columbia, right descending bank pictured in Figure 50), to a minimum of 0.8 m and 1.8

m respectively near the Hinkson Creek headwaters. Bank height reached a maximum of 5.7 m near the mouth of Hinkson Creek at Perche Creek, with a minimum of 0.2 m, mean of 2.6 m, median of 2.4 m, and standard deviation of 1.0 m. The bank height statistics shown (Table 5) were adjusted for the height of the laser level, so that they are slightly lower than the statistics shown in the report to the CAM Stakeholder Committee on the results of the PHA Phase II (attached as Appendix B).

Table 5. Descriptive statistics of bank and channel measurements recorded for entire length of Hinkson Creek during PHA.

Statistic	Left bank (°)	Right bank (°)	Channel width (m)	Wetted width (m)	Bankfull width (m)	Bank height (m)
Maximum	100.0	96.0	70.0	24.9	74.0	5.7
Minimum	2.0	0.0	0.8	0.0	1.8	0.2
Mean	34.6	35.5	15.4	9.8	24.2	2.6
Median	34.0	32.0	15.3	9.9	25.1	2.4
Standard deviation	15.8	16.4	8.2	5.5	9.4	1.0

Individual r^2 values and equations were determined for selected stream distances from the headwaters for channel width, bankfull width, and bank height. The relevant parameter and section of the stream are listed in Table 6, along with the corresponding r^2 value and the linear equation for the regression. The highest r^2 value (0.79) observed upon examination of these curves was for bank height from 0 to 5 km downstream of the headwaters. Bankfull width from 0 to 27 km downstream of the headwaters exhibited a slightly less positive trend ($r^2 = 0.659$), and channel width from 0 to 27 km downstream of the headwaters tied for third place with bank height from 38.1 to 56 km downstream of the headwaters ($r^2 = 0.616$).

Table 6. Equations and r^2 values corresponding to trendlines of graphs made of sections of Hinkson Creek for channel width, bankfull width and bank height with stream distance during the PHA.

Parameter	Stream distance from headwaters	r^2 value	Equation
Channel width	0 to 27 km	0.616	$y = 0.7325x + 1.0732$
Channel width	45 to 46	0.293	$y = 9.1545x - 389.45$
Bankfull width	0 to 27 km	0.659	$y = 0.8916x + 6.4103$
Bankfull width	38.1 to 42 km	0.215	$y = 3.2213x - 97.95$
Bankfull width	42.1 to 50 km	0.013	$y = 0.2916x + 17.541$
Bankfull width	50.1 to 56 km	0.2	$y = 1.1736x - 32.863$
Bank height	0 to 5 km	0.79	$y = 0.0163x^3 - 0.228x^2 + 1.1574x + 0.3652$
Bank height	38.1 to 56 km	0.616	$y = 0.1715x - 4.6141$

3.2 Thalweg Measurements

The thalweg is the deepest point in the stream channel (Armantrout 1998). The thalweg does not maintain a consistent position laterally across the stream, but varies due to stream geomorphology and shifting substrate moved by stream flows. Thalweg depth is simply a point measurement of the deepest point in the stream channel at a given moment in time. Thalweg depth was measured in Hinkson Creek at the 100 m survey points, and then approximately every 10 m between survey points. Thalweg depth varied from a maximum of 3.3 m to a minimum of 0 m near the headwaters where the channel was dry during the survey of the headwaters in August, 2014 (mean 0.5 m, median 0.4 m, standard deviation 0.4 m) (Table 7). On the days fieldwork was conducted in Hinkson Creek, flows ranged from low to median. Median annual baseflows for 2013 and 2014 were similar to Hubbart and Zell (2013) estimated median annual baseflows in Hinkson Creek over a 22 year study period (< 85 mm).

Measurements during the PHA also included relative thalweg depth and thalweg position. Relative thalweg depth is a measurement of the vertical distance from the thalweg of the stream to the top of the bankfull bank. Thalweg position is the distance from the thalweg (top of relative thalweg depth) to the top of the bankfull bank on a horizontal plane (Figure 15). Descriptive statistics for relative thalweg depth and thalweg position are listed in Table 7, along with the percentage of survey points where the presumed bankfull bank was the right or left bank. The general trend was an increase in relative thalweg depth with stream distance, such that the minimum of 0.2 m was found near the headwaters, and the maximum of 8.6 m was at the survey point at the mouth of Hinkson Creek at Perche Creek (mean 3.4 m, median 3.1 m, standard deviation 1.2 m).

Table 7. Descriptive statistics of thalweg measurements taken at each principal transect during the PHA of Hinkson Creek.

Statistic	**Thalweg depth (m) ***	**Relative thalweg depth (m)**	**Thalweg position (m)**	**Bankfull bank**	**Percentage of sites**
Maximum	3.30	8.60	68.30	Right bank	52.90%
Minimum	0.00	0.20	0.20	Left bank	46.20%
Mean	0.50	3.40	13.70	No record	0.90%
Median	0.40	3.10	12.50		
Standard deviation	0.40	1.20	7.80		

*Descriptive statistics are for all thalweg depths measured as part of the thalweg profile.

3.3 Channel Geometry

Metrics collected during the PHA were used to calculate features of channel geometry. Bankfull width measurements along the length of Hinkson Creek were used in combination with relative thalweg depth measurements to generate a width: depth ratio (Table 23, Appendix C). Sinuosity measurements were calculated by MoRAP during Phase I of the PHA, and were available for each of the 100 m survey points from Phase II of the PHA (Appendix A, Appendix C). Descriptive statistics of width: depth ratio and sinuosity are presented in Table 8 below. Width: depth ratio ranged from a maximum of 29.60 to a minimum of 2.39 (mean 7.17, median 6.68, standard deviation 3.30). Sinuosity ranged from a maximum of 3.67 to a minimum of 0, mean 1.12, median 1.04, standard deviation 0.25).

Table 8. Descriptive statistics of width: depth ratio and sinuosity in Hinkson Creek.

Statistic	**Width:Depth**	**Sinuosity**
Maximum	29.60	3.67
Minimum	2.39	0.00
Mean	7.17	1.12
Median	6.68	1.04
Standard deviation	3.30	0.25

Bedrock constraints were observed in Hinkson Creek at many survey points in the River Hills (Missouri Ozark Border) ecoregion. Bedrock constraints with stream distance are shown in Table 23 (Appendix C).

3.4 Canopy Cover

Average canopy cover was calculated for each 100 m survey point by averaging the six canopy cover measurements (at left bank, at center of stream: facing upstream, facing left bank, facing downstream, facing right bank, and at right bank) and dividing that average number by 17 (the maximum number of points that could be covered by canopy on the modified convex densiometer, see Figure 14) to calculate average percent canopy cover per site. The percent canopy cover at the 100 m survey points ranged from a maximum of 100% to a minimum of 0%, with a mean of 59.5%, median of 63%, and standard deviation of 27.4%.

3.5 Pebble Count

Substrate particles were collected during pebble count procedures (15 particles per 100 m survey plot), and then one additional particle was collected at the thalweg approximately every 10 m between survey points. For ease of presentation, the particles were grouped into size classes. Small particles consist of fines (silt, clay), sand, and fine gravel (2 to 16 mm). Intermediate particles ranged from 16 to 1000 mm, and also included vegetation (e.g. leaves, coarse particulate organic matter) and wood (e.g. logs, roots). The large size class included particles larger than 1000 mm, along with rough and smooth bedrock.

Particle size composition grouped by size classes is presented in Table 9. The small size class was represented in 58.4% of the particles sampled, with 28% fines (silt or clay), 25.6% sand, and 4.8% small gravel. The intermediate size class was represented in 33.6% of particles sampled, with 16.5% coarse gravel, 11.2% cobble, 3.3% small boulder, 1.8% vegetation (usually tree leaves in some state of decomposition on the streambed), and 0.8% wood. The large size class was observed in 7.8% of the particles sampled, with 4.8% rough bedrock, 1.7% smooth bedrock, 0.8% extra-large boulders, 0.4% riprap, and 0.04% large chunks of concrete. Particles not otherwise classified fell into the "other" category (one example was items of trash in the streambed), making up the remaining 0.2% of particles sampled.

Table 9. Percent particle sizes collected from substrate samples during PHA of Hinkson Creek grouped by size class.

Small		**Intermediate**		**Large**		**Other**
Sand	25.60%	Coarse gravel	16.50%	R bedrock**	4.80%	0.24%
Fines*	28.00%	Cobble	11.20%	S bedrock**	1.70%	
Sm gravel	4.80%	Sm boulder	3.30%	Xl boulder	0.80%	
		Vegetation	1.80%	Riprap	0.40%	
		Wood	0.80%	Lg concrete	0.06%	
Totals	58.40%		33.60%		7.76%	0.24%

*silt and clay; **rough and smooth bedrock

As an additional metric of physical habitat in the streambed, average percent vertical embeddednesss at each survey transect was calculated using visually estimated percent vertical embeddedness of each of the 15 particles collected during the pebble count. Average percent vertical embeddedness at survey transects ranged from a maximum of 100% to a minimum of 10%, with a mean of 72%, median of 75%, and standard deviation of 21%.

3.6 Channel Unit Classification

The results of the PHA showed that trench pools are the dominant form of channel unit and occur at 70% of sites where channel unit types were recorded (survey point, and then every ten meters between survey points along the thalweg profile), while riffles were recorded at 15% of the ten stations along the longitudinal thalweg profile (including survey point, spaced at 10 m intervals between survey points). The lengths of riffle and pool segments were not measured during the PHA. However, given the MDNR standard for the frequency of riffles and pools, and the average wetted width of 9.8 m in Hinkson Creek, a riffle would be expected approximately every 68.6 to 98 m. Using the average estimate (every 83.3 m), 672 riffles would be expected along the length of Hinkson Creek (12.0% of channel unit classifications given total measurements of 5,583). The ratio of trench pool to riffle channel units is 3% greater than the standard suggested by the MDNR Semi-Quantitative Macroinvertebrate Stream Bioassessment document (MDNR 2003). The breakdown of channel unit types recorded during the PHA is listed in Table 10.

Table 10. Channel unit breakdown at survey points and 10 m transects along thalweg profile during PHA of Hinkson Creek.

Channel unit	Percent of total count
Trench pool	70%
Riffle	15%
Dry channel	4%
Split channel	3%
Impoundment pool	2%
Lateral scour pool	1%
Other	4%

3.7 Confluences

The confluence measurements used in this study were collected over an eight day period between August 11 and August 18, 2014. Generally, average bank and channel measurements at the confluences were greater than the averages at the survey points along Hinkson Creek (Table 11 as compared to Tables 5 and 7). Thalweg depth at the confluences averaged 0.55 m, approximately 10% higher than the average of all thalweg depth measurements collected as part of the thalweg profile during the PHA. The average of 0.55 m was presumably affected by the maximum thalweg depth (1.34 m) at the County House Branch confluence located in a deep S-curve in Hinkson Creek near Twin Lakes Recreation area. Bank height at the confluences generally increased from the headwaters (2.14 m at Varnon Branch) to the mouth (4.92 m at Merideth Branch), with an average of 3.42 m, 31.5% higher than the 2.6 m average for the average of bank height measurements at the 100 m survey points. Wetted width was variable, with a generally negative relationship from the headwaters (15.07 m at Varnon Branch) to the Grindstone Confluence (9.10 m), increasing to 12.23 m at the Flat Branch confluence and then decreasing again to the mouth (6.21 m at Merideth Branch). Average wetted width at the confluences was 10.88 m, 11% greater than the 9.8 m average of wetted width measurements at the 100 m survey points. Bankfull width increased from the headwaters (22.8 m at Varnon Branch) to Flat Branch (37.97 m), and then decreased to the mouth (23.67 m at Merideth Branch. Average bankfull width at the confluences (26.8 m) was 11% greater than average bankfull width measured at the 100 m survey points along Hinkson Creek (average bankfull width 24.2 m). Channel width at the confluences averaged 15.57 m, which was only 1.1% higher than the 15.4 m average for the 100 m survey points along Hinkson Creek. Median channel width at the confluences was 15.07 m as compared to 15.3 m for the 100 m survey points (1.5% lower).

Table 11. Summary of bank height and channel measurements for average of three transects at each major confluence of Hinkson Creek during PHA.

	Confluence*							
Measurement (m)	**MB**	**MC**	**CH**	**FB**	**GC**	**HB**	**NC**	**VB**
Thalweg depth	0.43	0.49	1.34	0.41	0.44	0.60	0.35	0.35
Bank height	4.92	4.28	4.30	3.72	2.55	2.78	2.70	2.14
Wetted width	6.21	8.33	11.30	12.23	9.10	12.60	12.21	15.07
Bankfull width	23.67	24.80	27.90	37.97	35.83	26.60	23.87	22.80
Channel width	9.18	8.77	13.57	24.17	21.80	16.90	14.40	15.73

*MB=Merideth Branch, MC=Mill Creek, CH=County House Branch, FB=Flat Branch, GC=Grindstone Creek, HB=Hominy Branch, NC=Nelson Creek, VB=Varnon Branch

While the measurements averaged for three transects at the eight major confluences as discussed above demonstrate the variability of physical habitat characteristics at the confluences, they do not provide a basis for comparing the relative impact of each confluence on the surrounding physical habitat in Hinkson Creek. In order to better illustrate the potential impact of the influx of confluence drainage into Hinkson Creek, impact factors were computed for three components of stream physical habitat: channel width, bank height, and thalweg depth, to show how effective the tributary was at affecting the mainstem (a dependent variable). Impact factors were computed using the following formula:

$$\frac{(Downstream\ Hinkson\ Creek\ metric)}{(Upstream\ Hinkson\ Creek\ metric\ +\ Upstream\ tributary\ metric)}$$

A prediction as to how effective the tributary would be at affecting the mainstem could have been calculated if additional information was available about the drainage area of each tributary at the confluence with Hinkson Creek (tributary drainage area/ mainstem drainage area).

Impact factors of confluences did not appear to correspond with stream distance (Table 12). The greatest impact factor for channel width was 2.01 at Varnon Branch, with a minimum impact factor of 0.38 at Mill Creek (average impact factor for channel width is 0.83). Mill Creek had the highest impact factor (0.68) for bank height, while the lowest impact factor was at County House Branch (0.38), as compared to the average impact factor for bank height which was 0.53. The greatest impact factor for thalweg depth was at Nelson Creek (1.19), and Varnon Branch had the lowest impact factor for thalweg depth (0.25). The average impact factor for all confluences for thalweg depth was 0.58. Varnon Branch had the highest impact factor for channel width, and simultaneously the lowest impact factor for thalweg depth.

Table 12. Impact factors of confluences on channel width, bank height, and thalweg depth, including average confluence impact factors for each measurement along entire length of Hinkson Creek during PHA.

CONFLUENCE	**Channel Width**	**Bank Height**	**Thalweg Depth**
Varnon Branch	2.01	0.61	0.25
Nelson Creek	0.41	0.61	1.19
Hominy Branch	0.71	0.40	0.52
Grindstone Creek	0.48	0.50	0.31
Flat Branch Creek	1.29	0.52	0.28
County House Branch	0.63	0.38	
Mill Creek	0.38	0.68	0.84
Meredith Branch	0.72	0.54	0.68
Average Impact Factor	0.83	0.53	0.58

* Thalweg depth data for County House Branch is missing from the dataset.

3.8 Rootmat Survey

A wide variety of tree species provided the rootmats sampled at survey sites in Hinkson Creek. Only the rootmats that were in the water at the time of the survey were measured so more or less habitat was potentially available during different flow conditions. Table 13 lists the types of trees observed and recorded during the rootmat survey, and the number of rootmats in which the various tree genus and species were found. As discussed in the Field Protocol (section *2.2.10*), one tree could have more than one rootmat, and a rootmat could be comprised of roots from more than one tree. Overall, 41 different types of woody vegetation were observed in rootmats along Hinkson Creek, including 7 species of oak, and some invasive species such as honeysuckle and multiflora rose. Descriptive statistics of rootmat tree composition are provided in Table 14, with a maximum of 101 rootmats which contained roots from maple trees, four trees that were observed in just 1 rootmat (minimum) along Hinkson Creek (ironwood, juniper, Kentucky coffee, mulberry), and the Ohio buckeye falling at the median with contribution to 8 rootmats measured during the PHA.

Table 13. Woody vegetation composition of rootmats measured at survey points in Hinkson Creek during the PHA. The rootmats column indicates the number of rootmats corresponding to the listed genus. The species column indicates the number of rootmats corresponding to the listed species.

Woody vegetation type	Rootmats	Species	Woody vegetation type	Rootmats	Species
American sycamore	45		Maple (genus *Acer*)	101	
(Platanus occidentalis)			*(Acer nigrum)*		1
Ash (genus *Fraxinus*)	22		*(Acer saccharinum)*		79
(Fraxinus americana)		5	*(Acer saccharum)*		5
Autumn olive	3		Mulberry	1	
(Elaeagnus umbellata)			(genus *Broussanetia)*		
Basswood	4		Multiflora rose	3	
(Tilia americana)			*(Rosa multiflora)*		
Boxelder	14		Oak (genus *Quercus*)	49	
(Acer negundo)			*(Quercus velutina)*		1
Buttonbush	5		*(Quercus macrocarpa)*		16
(Cephalanthus occidentalis)			*(Quercus palustris)*		1
Catalpa	4		*(Quercus rubra)*		21
(Catalpa speciosa)			*(Quercus imbricaria)*		4
Cottonwood	5		*(Quercus shumardii)*		1
(Populus deltoides)			*(Quercus alba)*		5
Dogwood	4		Ohio buckeye	8	
(Cornus florida)			*(Aesculus glabra)*		
Elm (genus *Ulmus*)	55		Pawpaw	12	
(Ulmus rubra)		3	*(Asimina triloba)*		
Hackberry	26		Red bud	5	
(Celtis occidentalis)			*(Cercis canadensis)*		
Hickory (genus *Carya*)	57		Red cedar	2	
(Carya ovata)		3	*(Juniperus virginiana)*		
Honeysuckle	21		River birch	88	
(Lonicera maackii)			*(Betula nigra)*		
Ironwood	1		Sumac (genus *Rhus*)	2	
(genus unknown*)*			Walnut	16	
Juniper	1		*(Juglans nigra)*		
(genus *Juniperus)*			Willow	25	
Kentucky coffee	1		(genus *Salix)*		
(Gymnocladus dioicus)					
Locust	16				
(Robinia pseudoacacia)					

Table 14. Descriptive statistics of trees included in rootmats measured along length of Hinkson Creek during PHA.

Number of Rootmats		**Trees identified**
Maximum	101	Maples (genus *Acer*)
Minimum	1	Ironwood, juniper (genus *Juniperus*), Kentucky coffeetree (*Gymnocladus dioicus)*, mulberry *(*genus *Broussanetia)*
Mean	20.6	
Median	8	Ohio buckeye *(Aesculus glabra)*
Standard deviation	26.5	

For each rootmat, measurements of width, height and depth were recorded so that rootmat volume could later be calculated in-spreadsheet. Some rootmats were particularly large, and the width of the rootmat was measured using a laser rangefinder. Calculation of rootmat volume provided a more informative representation of the quantity of habitat available for aquatic biota than identification of the number of rootmats at a survey site. An examination of the descriptive statistics of rootmat volume shows a maximum of 20.2 m^3 for one survey site during the PHA, a minimum of 0 m^3, with a mean of 0.7 m^3, median of 0 m^3, and standard deviation of 2.2 m^3 (Table 15).

Table 15. Descriptive statistics of total rootmat volume calculated at survey sites during PHA of Hinkson Creek.

Statistic	**Volume (m^3)**
Maximum	20.2
Minimum	0
Mean	0.7
Median	0
Standard deviation	2.2

3.9 Riparian Zone Survey

At each survey point, a visual estimation was made of the percent woody versus percent herbaceous cover in the riparian zone on both the left and right banks. Riparian vegetation surveyed did not include row crops or lawn grasses. A frequency distribution of the percent woody riparian cover (percent woody plus percent herbaceous equals 100%) is presented in Table 16. For both the left and right banks, the highest frequency of woody riparian cover was in the 0 to 10% range. Overall for both the left and right banks more than one-half of the survey sites had woody riparian cover less than 30%.

Table 16. Frequency distribution of percent woody riparian cover observed at survey points in Hinkson Creek during the PHA.

% Woody Riparian Cover	Frequency (left bank)	Frequency (right bank)
0 to 10	177	179
>10 to 20	106	91
>20 to 30	91	110
>30 to 40	64	65
>40 to 50	15	13
>50 to 60	19	21
>60 to 70	21	18
>70 to 80	23	23
>80 to 90	17	12
>90 to 100	25	27

During the PHA, a visual estimation of the width of the riparian zone was made at the survey points for the both the left and right banks. The width estimates did not include areas with row crops or lawn grasses. A frequency distribution of the width size classes (<5 m, 5 to 10 m, 10 to 20 m, >20 m) observed at the survey points in presented in Table 17. A relatively low number of survey sites had riparian corridor widths less than 5 m (33 for both the left and right banks). The number of sites having riparian corridor widths between 5 and 10 m was 30 on the left bank, and 34 on the right bank. The left bank had a lower number of sites (38) than the right bank (57) in the 10 to 20 m width range. A high percentage of sites (82% left bank, 79% right bank) had riparian corridors wider than 20 m, although the riparian corridor vegetation was primarily herbaceous (Table 16).

Table 17. Frequency distribution of riparian zone widths observed at PHA survey points in Hinkson Creek, left and right banks.

Width size class (m)	Frequency (left bank)	Frequency (right bank)
<5	33	33
5 to 10	30	34
10 to 20	38	57
>20	459	435

3.10 Wildlife and Cattle

For ease of presentation of the wildlife and cattle use survey data, some wildlife observed during the PHA were grouped into categories (e.g. amphibians, mammals). Deer and raccoon were not included in wildlife categories as they were observed at more than half of the 561 survey points during the PHA (deer 59.4%, raccoon 67.6%) and including them would have skewed categorical results. Crayfish were also not included in a category as there were no other macroinvertebrates counted.

The number of sightings for each category of wildlife (Table 18) was calculated by totaling the number of sightings for each separate animal in the category, with a maximum of ten sightings per kilometer per animal. The amphibians category for example includes frogs, frog morphs (between tadpole and frog), mudpuppy (2 possible sightings were not confirmed due to turbid water), tadpoles and toads, for a total of 418 sightings of representatives from this category during the PHA. Songbird sightings were frequent, so they were not included in the birds category with the exception of gold finches because their tracks were observed in the streambanks. Birds were observed during the PHA 176 times (14 different species), bivalves or snails were observed 25 times, there were 140 crayfish sightings, 6 sites with hairworms/leeches, and 496 fish sightings. Fry and minnows were counted as separate fish "species" – fry were any small fish that could not yet be identified by appearance (generally swimming in schools) and what were identified as minnows were likely species' of darter. There were 321 sightings of fry or minnows. Other types of fish included in the fish category were Asian carp (7), spotted bass (33), smallmouth bass (4), catfish (4), gar (16), sculpin (53), and sunfish (57).

The mammal category contained 11 animals, and all but the single bat and one of the coyotes were identified by tracks left in the sandbars or streambanks. Tracks were printed from the Missouri Department of Conservation website (MDC) and carried in the field for use in mammal identification. The mammals identified were as follows: beaver (3), coyote (46), fox (54), mink (7), muskrat (32), opossum (6), otter (2), skunk (9), weasel (45), and a woodchuck (1). The animals in the reptile category were directly observed by field crew members during the PHA. Reptiles included: black snakes (2), garter snakes (5), lizard (1), northern water snakes (14), skinks (7), and turtles (25).

The final category of wildlife is cattle that were identified by tracks in the banks or streambed. Cattle tracks were observed within 19 100 m sections of Hinkson, and horse tracks were observed within 2 100 m sections. Damage to streambanks from cattle trails were observed (Figures 16 and 17), as were fecal deposits in or near the water.

Table 18. Wildlife use and cattle track data observed during PHA at 1 km intervals for length of Hinkson Creek.

KM	AMPHIBIANS	BIRDS	BIVALVE/SNAIL	CATTLE TRACKS	CRAYFISH	DEER	FISH	HAIR WORM/LEECH	MAMMALS	RACCOON	REPTILES
1	1	0	0	0	0	5	0	0	2	7	0
2	6	3	0	0	0	9	0	0	8	9	1
3	6	3	0	0	1	8	1	0	10	9	1
4	8	0	0	2	4	7	0	0	6	8	0
5	12	0	0	0	2	9	1	0	8	10	0
6	8	4	0	0	2	10	0	0	3	10	1
7	10	2	0	0	0	10	2	0	5	10	3
8	6	4	0	0	3	10	4	0	4	10	0
9	10	5	0	0	2	8	3	0	2	9	0
10	8	7	0	0	4	7	4	0	5	9	1
11	8	1	0	0	2	5	3	0	7	10	0
12	7	1	0	3	7	0	5	0	1	8	0
13	10	4	0	0	4	5	11	0	8	8	1
14	11	6	3	5	3	7	17	0	7	9	0
15	11	4	0	0	2	9	15	0	4	10	2
16	12	7	2	0	4	9	8	0	2	7	0
17	6	9	1	0	3	8	5	0	5	8	4
18	9	4	0	0	1	7	3	0	8	10	1
19	9	2	1	0	6	6	4	0	3	7	1
20	10	2	0	6	5	4	8	0	0	8	2
21	10	4	1	3	5	6	17	1	5	7	0
22	11	2	0	0	8	9	6	2	3	8	0
23	11	3	0	0	3	7	0	0	5	7	2
24	11	1	0	0	0	7	5	0	3	4	0
25	12	1	1	0	4	8	14	1	3	6	4
26	15	1	0	0	3	6	15	0	4	3	0
27	15	3	0	0	7	7	9	0	7	4	1
28	14	3	0	0	5	5	14	0	5	6	4
29	10	2	0	0	3	4	14	0	2	4	1
30	5	0	0	0	2	4	8	0	4	6	0
31	6	1	0	0	1	7	9	0	5	7	1
32	5	0	0	0	2	4	4	0	3	9	0
33	7	0	0	0	2	4	10	0	3	8	0

Table 18 (cont.)**.** Wildlife use and cattle track data observed during PHA at 1 km intervals for length of Hinkson Creek.

KM	AMPHIBIANS	BIRDS	BIVALVE/SNAIL	CATTLE TRACKS	CRAYFISH	DEER	FISH	HAIR WORM/LEECH	MAMMALS	RACCOON	REPTILES
34	1	2	0	0	1	2	7	0	0	1	1
35	1	2	0	0	0	4	12	0	10	3	0
36	1	3	0	0	0	2	6	0	1	3	1
37	3	2	0	0	0	4	14	0	0	3	0
38	7	5	0	0	4	6	23	0	1	8	1
39	9	2	1	0	4	0	20	0	3	3	0
40	3	2	0	0	9	2	11	0	1	4	1
41	11	0	0	0	3	4	11	0	0	5	1
42	3	0	0	0	1	6	5	0	0	6	1
43	0	0	0	0	0	4	0	0	2	3	0
44	6	3	0	0	1	2	17	0	3	4	0
45	8	6	0	0	0	3	21	0	0	2	1
46	12	2	0	0	0	7	18	0	4	4	2
47	3	2	3	0	1	3	13	0	1	4	4
48	4	1	0	0	1	7	3	1	3	6	0
49	7	7	1	0	1	4	8	1	0	6	2
50	8	9	2	0	3	5	5	0	4	5	5
51	4	8	3	0	1	10	13	0	3	9	1
52	7	5	3	0	5	8	18	0	3	9	0
53	5	6	0	0	1	7	17	0	3	10	0
54	4	7	0	0	2	10	16	0	3	9	1
55	4	11	3	0	1	10	17	0	5	10	0
56	7	2	0	0	1	2	1	0	6	7	1
TOTALS	**418**	**176**	**25**	**19**	**140**	**333**	**495**	**6**	**206**	**379**	**54**

Figure 16. A cattle trail in a streambank of Hinkson Creek, 06-20-2014, 08:18 (lat. 39.069505, long. -92.215825).

Figure 17. Cattle trail. Photograph taken approximately 1 km upstream of Spiva Crossing Road, 06-18-2014, 12:38 (lat. 39.062998, long. - 92.212955).

3.11 Longitudinal Variation in Stream Physical Habitat Due to Influence of LULC

In order to quantitatively analyze the effects of land-use and land cover on stream physical habitat in Hinkson Creek, drainage area and cumulative land-use in five categories (cropland, forest, grassland, impervious surface area, sparsely vegetated, and water) were estimated at 1 km intervals (Table 19). Sparsely vegetated areas have thin vegetative cover and the plants are scattered. Drainage area in HCW ranged from 2.66 km^2 at 1 km from the headwaters of Hinkson Creek, to a total drainage area of 227.87 km^2 at the mouth of Hinkson Creek where it converged with Perche Creek. The total drainage area of HCW is approximately 4 to 6 kilometers greater than the total drainage area calculated, as there were land-cover data gaps for a couple of small areas in Boone County that were not included in the tally (Figure 45). Cumulative percent cropland increased rapidly from the headwaters through the agricultural / rural portion of the watershed (kilometers 1 through 26, $y = 0.4512x + 2.6395$, $r^2 = 0.9613$), and then more slowly through the suburban and urban sections in the City of Columbia (kilometers 27 through 56, $y = 0.2653x + 8.4617$, $r^2 = 0.8726$). Cumulative percent impervious surface area exhibited the opposite trend, increasing slowly from the headwaters through the agricultural / rural portion of the watershed (kilometers 1 through 26, $y = 0.0688x - 0.2287$, $r^2 = 0.9197$), and then more rapidly through the suburban and urban sections in the City of Columbia (kilometers 27 through 56, $y = 0.7864x - 21.34$, $r^2 = 0.9794$).

Table 19. Cumulative percent increase in land-use /land cover with distance from headwaters and drainage area in km^2 along entire length of Hinkson Creek.

Distance	Cropland	Forest	Grassland	Impervious	Sparsely Veg	Water	Drainage area (km^2)
1	1.76	0.40	0.44	0.04	0.00	0.01	2.66
2	2.38	0.64	0.69	0.05	0.00	0.03	3.80
3	3.79	1.26	1.43	0.11	0.01	0.04	6.63
4	5.74	3.05	3.48	0.18	0.01	0.10	12.55
5	5.86	3.35	4.00	0.20	0.02	0.13	13.55
6	6.37	4.04	4.92	0.26	0.02	0.14	15.76
7	6.68	4.66	5.29	0.28	0.02	0.15	17.07
8	6.75	4.87	5.48	0.29	0.02	0.16	17.57
9	6.88	5.23	5.75	0.30	0.02	0.17	18.34
10	6.92	5.67	6.25	0.30	0.03	0.17	19.35
11	6.93	6.15	6.46	0.32	0.04	0.18	20.07
12	8.16	8.95	8.70	0.48	0.04	0.30	26.62
13	8.16	9.19	9.03	0.48	0.04	0.32	27.22
14	9.34	16.02	12.74	0.69	0.06	0.54	39.39
15	9.44	19.02	13.72	0.73	0.07	0.66	43.63
16	9.59	19.87	14.27	0.77	0.07	0.68	45.24
17	10.00	21.58	16.55	0.84	0.09	0.78	49.83
18	10.14	22.01	16.66	0.85	0.09	0.79	50.55
19	10.45	22.53	16.90	0.87	0.09	0.81	51.65
20	10.81	25.04	20.72	1.03	0.12	0.97	58.69
21	12.26	29.97	0.00	1.25	0.24	1.35	45.07
22	12.44	31.27	27.41	1.29	0.25	1.36	74.02
23	12.89	32.28	28.11	1.32	0.26	1.38	76.24
24	13.83	33.60	29.88	1.59	0.53	1.45	80.88
25	13.94	34.31	30.47	1.72	0.74	1.49	82.68
26	15.50	39.15	33.94	1.98	0.89	1.74	93.19

Table 19 **(cont.)**. Cumulative percent increase in land-use /land cover with distance from headwaters and drainage area in km^2 along entire length of Hinkson Creek.

Distance	**Cropland**	**Forest**	**Grassland**	**Impervious**	**Sparsely Veg**	**Water**	**Drainage area (km^2)**
27	15.72	39.89	34.19	2.04	0.90	1.78	94.53
28	15.86	40.71	34.52	2.11	0.91	1.80	95.91
29	16.09	41.26	35.08	2.22	0.93	1.82	97.40
30	16.31	41.76	35.41	2.34	1.02	1.85	98.69
31	16.51	43.94	36.84	2.95	1.18	1.89	103.30
32	16.59	44.38	37.01	3.13	1.30	1.89	104.29
33	16.59	44.88	37.51	3.62	1.36	1.92	105.89
34	16.61	45.99	38.81	4.87	1.41	1.93	109.62
35	16.67	46.56	39.35	5.31	1.42	1.95	111.25
36	16.67	46.92	39.71	5.56	1.45	2.00	112.30
37	18.42	54.21	45.95	7.72	1.94	2.43	130.68
38	18.42	54.50	46.05	7.79	1.96	2.44	131.15
39	18.42	55.29	46.51	8.22	2.02	2.48	132.94
40	18.42	55.49	46.55	8.25	2.03	2.48	133.22
41	21.24	71.03	60.69	11.78	3.89	3.04	171.67
42	21.24	71.42	60.72	11.80	3.90	3.05	172.13
43	21.53	72.61	61.39	12.52	4.24	3.07	175.35
44	21.54	72.98	61.81	13.19	4.27	3.08	176.88
45	21.56	73.49	62.11	13.46	4.30	3.09	178.01
46	21.68	78.11	65.38	16.66	4.35	3.12	189.30
47	21.68	78.69	65.67	16.87	4.37	3.16	190.44
48	21.68	79.50	66.08	17.12	4.38	3.22	191.98
49	21.68	79.87	66.28	17.19	4.38	3.30	192.69
50	21.68	83.81	67.89	18.52	4.41	3.48	199.79
51	21.68	83.96	67.98	18.54	4.42	3.49	200.07
52	21.68	84.09	68.09	18.55	4.43	3.49	200.34
53	21.72	84.86	68.72	18.76	4.44	3.54	202.04
54	21.89	90.79	76.01	21.50	5.30	3.80	219.29
55	22.11	93.38	78.78	23.13	5.40	3.82	226.62
56	22.27	93.79	79.31	23.20	5.45	3.86	227.87

The LULC data generated by MoRAP during Phase I of the PHA (see Appendix A) allowed for calculation of cumulative land-use by tributary catchment moving from the headwaters to the mouth of Hinkson Creek. The data presented in Table 20 were used to calculate cumulative land-use percentages in each of the eight major tributary catchments in Hinkson Creek. The range of survey points in each catchment was determined, so that cumulative land-use could be associated with a distinct group of points along the PHA survey. A series of photographs is presented in section *4.11 Longitudinal Variation in Stream Physical Habitat Due to Influence of LULC* to highlight some of the observed stream physical habitat effects at selected points during the PHA, and the observations are discussed in the context of terrestrial (land-use) processes going on upstream of the selected photographs. The photographs and discussion of stream physical habitat are framed by LULC in the catchments as presented in Figure 1 (section 2.1.1 Hydrogeomorphology and Climate of HCW) and Table 20.

Table 20. Cumulative drainage area and cumulative land-use percentages by catchment in Hinkson Creek based upon MoRAP Phase I PHA data. The total area of HCW is less than 231 km^2 due to small areas (approx 4 - 6 km^2) where data was not available for LULC assessment.

CATCHMENT	AREA (km^2)	% FOREST	% CROP	% IMPERVIOUS	% WATER	% SPARSE	% GRASS
Varnon Branch	26.78	33.65	30.14	1.79	1.13	0.15	33.14
Nelson Creek	93.18	42.05	16.66	2.86	1.86	0.95	36.38
Hominy Branch	129.47	41.39	14.19	5.71	1.87	1.50	35.34
Grindstone Creek	170.7	41.42	12.41	6.72	1.78	2.27	35.41
Flat Branch	188.5	41.29	11.47	8.77	1.65	2.31	34.51
County House Branch	198.79	41.92	10.88	9.23	1.75	2.22	34.00
Mill Creek	218.28	41.41	9.99	9.75	1.74	2.42	34.68
Merideth Branch	227.05	41.17	9.77	10.14	1.70	2.40	34.81

3.12 Statistical Analysis of Cross-Section Accuracy

As per the Field Protocol and to analyze accuracy of PHA measurements, on the tenth field day in a sequence one-half day was spent re-surveying every other point surveyed during the first field day of the ten day sequence. The initial survey points were not marked by flags or other means. However in the summer months, the field team trimmed back vegetation growth on the stream banks so that bank and channel measurements could be taken without obstruction. On resurveys during the summer months, the field team could visually ascertain the initial survey point (typically the vegetation had not completely grown back), but resurvey points were at all times confirmed using GPS coordinates collected during the first survey. Descriptive statistics of the initial survey metrics (labelled A under the Metric column) are presented with descriptive statistics of the resurvey metrics (labelled B under the Metric column) below (Table 21).

Based upon the Student's T-test analysis (Origin© software, OriginLab© Corporation, 2015), there were not statistically significant differences in measurements between the initial surveys (averaged for all initial survey sites) and the resurveys (averaged for all resurvey sites) (p-value 0.05). A comparison of left bank angle shows a maximum of 78° on the initial survey with a maximum of 74° on the resurveys, and minimum 5° and 4° respectively (mean 32.46° and 30.34°, median 30.00° and 29.00°, standard deviation 18.60° and 18.28°). Channel width was measured at a maximum of 41.40 m on the initial survey and 40.40 m on the resurvey, and minimum 7.60 m and 7.30 m respectively (mean 18.96 m and 18.57 m, median 19.10 m and 17.90 m, standard deviation 6.91 m and 6.63 m). Bank height measurements show a maximum of 5.30 m on the initial survey and 5.19 m on the resurvey, and minimum 1.04 m and 1.01 m respectively (mean 3.22 m and 3.07 m, median 2.90 m and 2.85 m, standard deviation 1.17 m and 1.07 m).

Table 21. Descriptive statistics from comparison of initial survey measurements (field day 1 of 10 day sequence) to resurvey measurements (field day 10 of 10 day sequence) during PHA of Hinkson Creek. In each listed pair, A is the initial survey metric and B is the resurvey metric.

Metric	Maximum	Minimum	Mean	Median	Standard Deviation
A: Bank angle (LB) (deg)	78.00	5.00	32.46	30.00	18.60
B: Bank angle (LB) (deg)	74.00	4.00	30.34	29.00	18.28
A: Bank angle (RB) (deg)	76.00	5.00	33.66	32.00	15.30
B: Bank angle (RB) (deg)	69.00	1.00	34.20	35.00	16.29
A: Channel width (m)	41.40	7.60	18.96	19.10	6.91
B: Channel width (m)	40.40	7.30	18.57	17.90	6.63
A: Wetted width (m)	23.90	3.20	11.77	10.70	5.45
B: Wetted width (m)	24.20	4.50	12.56	12.10	5.30
A: Bankfull width (m)	50.80	15.40	29.75	28.90	7.85
B: Bankfull width (m)	48.50	14.60	29.07	30.10	7.12
A: Bank height (m)	5.30	1.04	3.22	2.90	1.17
B: Bank height (m)	5.19	1.01	3.07	2.85	1.07
A: Avg canopy cover (of 17)	16.67	0.00	8.31	8.67	4.46
B: Avg canopy cover (of 17)	16.17	0.00	8.44	8.50	4.96
A: Thalweg depth (cm)	105.00	9.00	49.36	45.00	27.81
B: Thalweg depth (cm)	111.00	11.00	53.11	50.00	27.75
A: Thalweg position (m)	30.70	2.50	15.96	15.90	7.45
B: Thalweg position (m)	29.60	4.90	15.61	15.60	6.24
A: Relative thalweg depth (m)	6.50	2.17	3.94	3.64	1.11
B: Relative thalweg depth (m)	6.00	2.09	3.81	3.60	1.11

3.13 Comparison of Observed Data to GIS Data

During Phase I of the PHA, MoRAP generated GIS data of various channel and valley characteristics of Hinkson Creek and HCW. Some of these data could be directly compared to observed data collected during this study (Phase II of the PHA). The only two metrics which were directly comparable were the coordinates of the center of the stream at the survey points, and bankfull width at survey points. The coordinates of the center of the stream (observed) were compared to the center of the stream points generated during Phase I of the PHA (see Appendix A). The maximum distance between MoRAP and observed center of stream points was 39.93 m, minimum distance 0.00 m, mean distance 4.18 m, median of data set 2.99 m (data are right-skewed so median is more descriptive statistic than mean), and standard deviation 4.25 m (Table 22). Comparison of the bankfull width data at the survey points yielded a maximum difference between MoRAP and observed measurements of 55.22 m, minimum of 0.02 m, mean of 4.72 m, median of 2.76 m, and standard deviation of 6.15 m (Table 22).

Table 22. Descriptive statistics of the differences between GIS modelled (Phase I) and observed (Phase II) center of stream points and bankfull width at survey points during PHA of Hinkson Creek.

Statistic	Center of stream points (m)	Bankfull width measurements (m)
Maximum	39.93	55.22
Minimum	0	0.02
Mean	4.18	4.72
Median	2.99	2.76
Standard deviation	4.25	6.15

CHAPTER IV

DISCUSSION

For ease of presentation, some of the discussion sections have been grouped based upon similarity in types or position of measurements, or relevance of measurements to one another. For example, channel geometry and incision analyses were grouped together for presentation in Section *4.3 Channel Geometry*. Some results from PHA data analysis completed for this thesis are omitted from this chapter: thalweg position and frequency of bankfull bank being left or right. This is because thalweg position is relatively inconsistent, and depends upon the location of the thalweg in the channel and to some extent upon bankfull width at a particular location, and for the purposes of this research is a random geomorphic feature. Similarly, frequency of bankfull bank being the left or right bank is a topographical feature, and again may have less relative relevance to stream physical habitat status.

4.1 Bank and Channel Measurements

In streams that are impacted by human land-use practices, certain changes in physical parameters are observable (and expected) with stream distance. For example, while channel width is expected to increase with stream distance in natural stream systems, it may increase more rapidly or more inconsistently in impacted systems (Walsh et al. 2005, Jacobson and Gran 1999). Increased overland flow resulting from deforestation, agriculture, and increased impervious surface area (primarily urban areas) can alter the timing and quantity of in-stream flow regimes and potentially lead to channel incision of the substrate. After incision, stream banks often slump or collapse (mass wasting) and stream channels widen (Shepherd et al. 2011, Paul and Meyer 2001, Piégay and Schumm 2003). The purpose of the examination of the PHA data presented in the following text is to quantify relationships between observed bank and channel measurements and stream distance in Hinkson Creek and drainage area in HCW.

A slight positive trend of increasing channel width with stream distance from the headwaters of Hinkson Creek until approximately 27 km downstream of the headwaters (2 km downstream of the bridge on N. Hinkson Creek road) (drainage area approximately 94.53 km^2) is observed in Figure 18A ($r^2 = 0.616$; $y = 0.7325x + 1.0732$).

A similar relationship to that of channel width and stream distance from approximately 0 to 27 km downstream is observed with a comparison of channel width to increasing drainage area in HCW (Figures 18B and 18C). The slight dip in all three graphs (Figures 18A, 18B and 18C) corresponds to an area between approximately 29 km downstream of the headwaters and 38 km downstream of the headwaters (just upstream of bridge at Stadium Blvd.) (drainage areas approximately 97.40 km^2 to 131.15 km^2). This area translates approximately to the area immediately north of Mexico Gravel Road down to an area just north of Stadium Blvd in Columbia. Intermittent bedrock geologic constraints were observed along Hinkson Creek between Mexico Gravel Road and Stadium Blvd. (examples shown in Figures 54 and 55), and it is possible that the presence of bedrock in this area is sufficient to mitigate in-stream land-use effects. Bedrock constraints in a stream channel have been shown to influence channel unit and channel migration (Grant et al. 1990).

From approximately 38 km to 42 km downstream of the headwaters (almost 3 km upstream of Providence Road in Columbia) (approximate drainage areas 131.15 km^2 to 172.13

km^2), the positive trend between channel width and stream distance starts to pick up again slightly. Channel width in the area from 38 km downstream to 42 km may be a reflection of the influx of additional urban drainage from the City of Columbia. A spike in channel width (62 m) is observed in Figure 18A at approximately 42 km downstream from the headwaters at a large bend in Hinkson Creek just upstream from the Hinkson Creek Recreation Area (approximately 3 km upstream of S. Providence Road). From 42 km downstream of the headwaters (approximate drainage area 172.13 km^2) until approximately 50 km downstream (1 km downstream of Twin Lakes Recreation Area in Columbia) (approximate drainage area 199.79 km^2) the trend reverses, and a slightly negative relationship is observed between channel width and stream distance. The one exception to this relationship is observed at approximately 45 to 46 km downstream (0.4 km downstream of the Flat Branch confluence – see Figure 1) (178 to 189 km^2 cumulative drainage area) and extending to approximately 0.7 km downstream of the confluence. The influx of water at the Flat Branch confluence includes drainage of all of the impervious surface area in downtown Columbia and may increase peak discharges during high flow events.

The PHA data showed that the channel incises downward into the streambed beginning at approximately 42 to 44 km downstream of the headwaters (2-3 km upstream of Flat Branch confluence, see Figure 1) (with the of the area downstream of Flat Branch confluence as discussed above), so that the channel is deepening rather than widening until a point somewhere between 50 and 52 km downstream (3 km upstream of Scott Blvd.) (approximate drainage area 199.79 to 200.34 km^2). From that position between 50 and 52 km downstream of the headwaters until the mouth of the stream, channel width stabilizes. This may be due to the effect of backwater from the Missouri River after major high flow events that may deposit sediment on the floodplains and slow or reverse movement of water coming downstream in Hinkson Creek (for discussion of process, see Knox 2006). The sudden loss of stream competence (stream velocity) as streamflow meets the backwater could possibly cause sediment to drop out of suspension, raising the streambed. Identifying exact mechanisms of this observation in Hinkson Creek were beyond the scope of the current study.

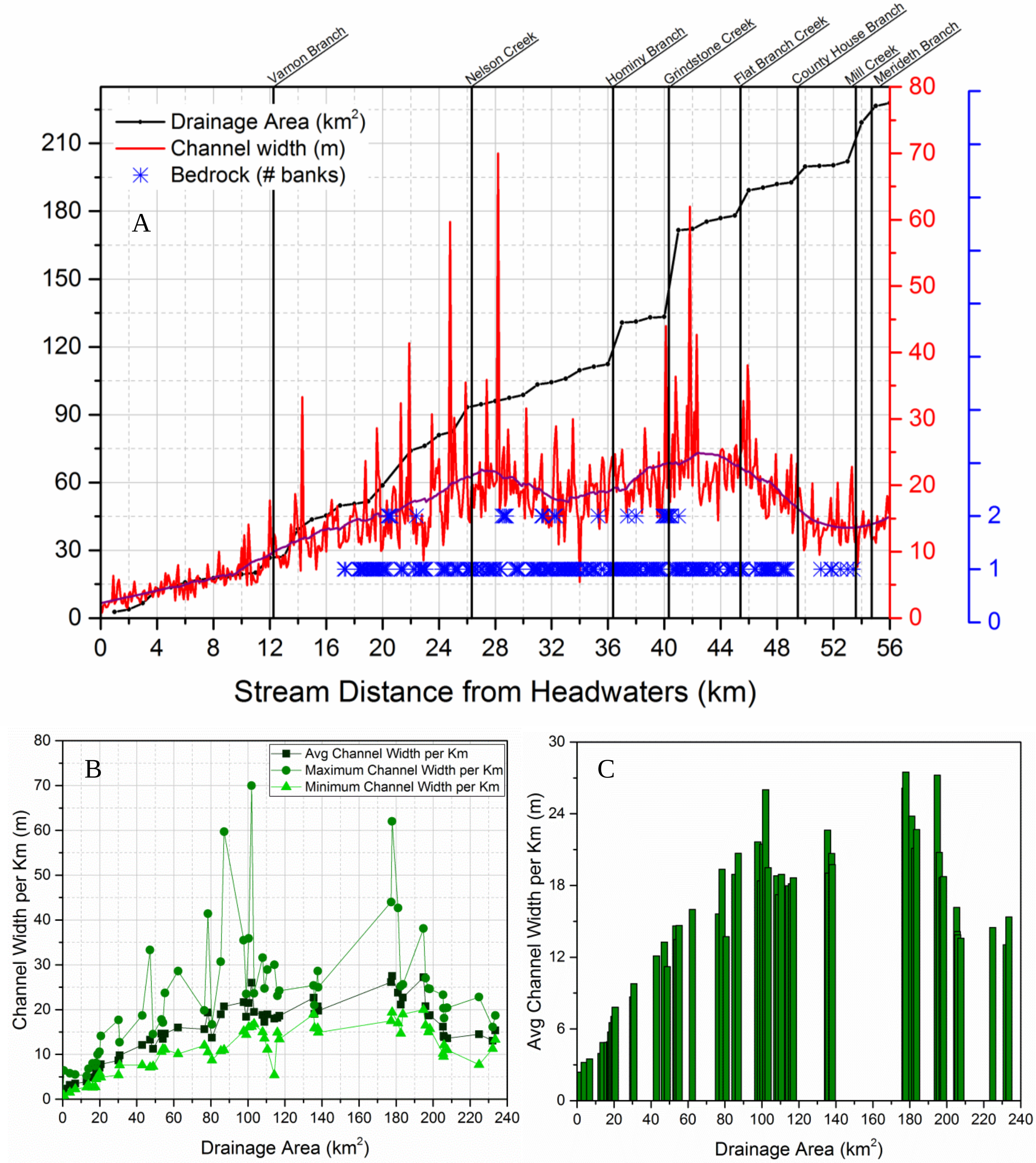

Figure 18. A. Channel width with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in dark gray, and major tributary confluences marked. Bedrock constraints are shown with blue asterisks; B. Average, maximum and minimum channel width per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements, and C. Average channel width per kilometer with drainage area in Hinkson Creek watershed.

Wetted width measurements in Hinkson Creek ranged from a minimum of 0.0 m (dry channel in some upper reaches in August, 2014) to a maximum of 24.9 m. Because wetted width is highly dependent upon prevailing streamflow and stage at the time of measurement, a strong relationship between wetted width and channel width is not expected. Channel width is dependent upon more persistent hydrologic (discharge) and geologic (bedrock constraints) conditions than wetted width (Montgomery and Gran 2001). However, a comparison of channel width and wetted width with stream distance does exhibit loosely similar curves in the graphs of the two widths with stream distance (Figure 19A). The observed relationship makes sense as channel width provides the boundary for wetted width during normal flows, and all measurements during the PHA occurred during normal flow conditions (wetted width values approximating low to median baseflow).

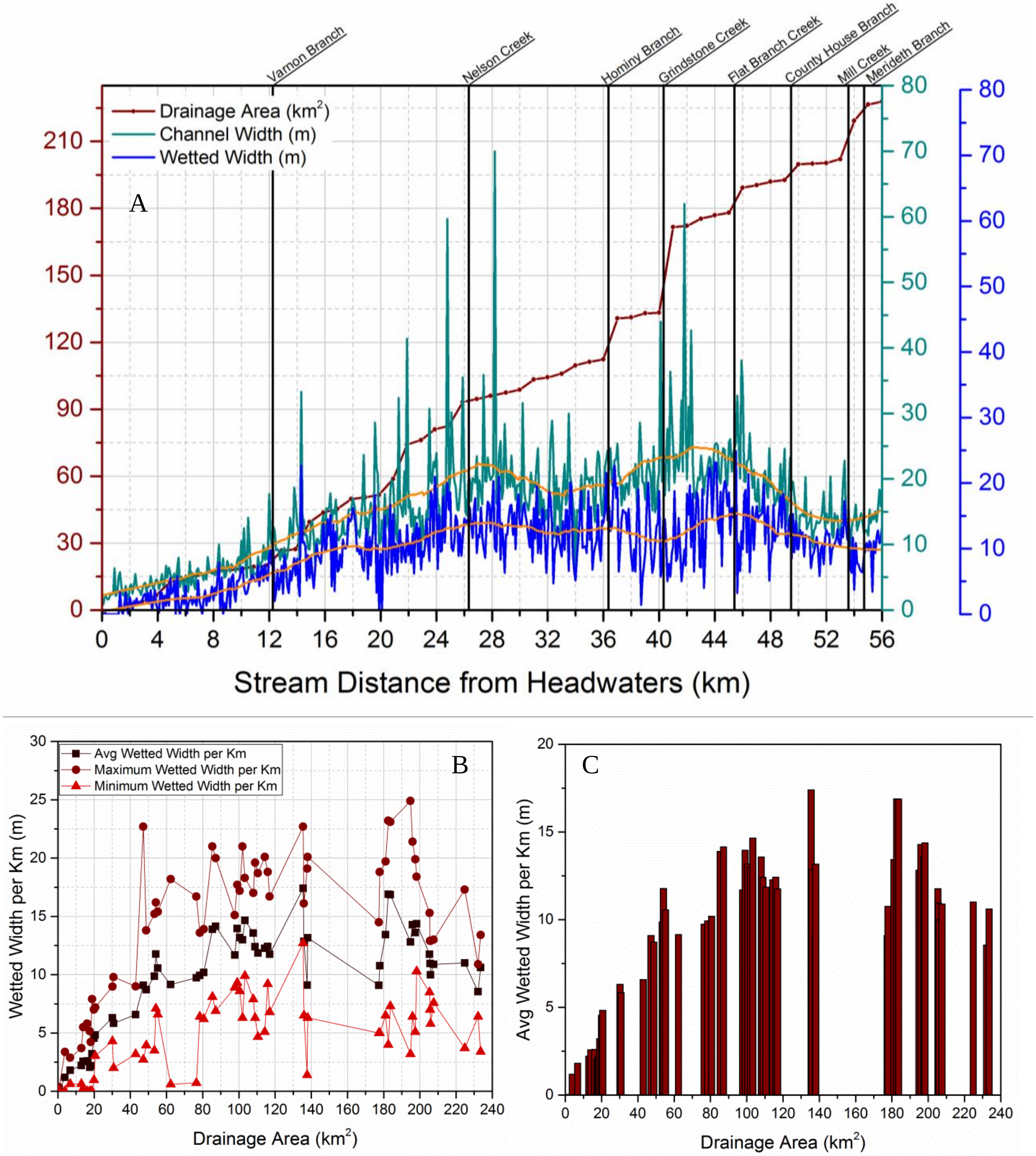

Figure 19. A. Channel width and wetted width with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving averages shown in orange, and major tributary confluences marked; B. Average, maximum and minimum wetted width per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average wetted width per kilometer with drainage area in Hinkson Creek watershed.

Bankfull width showed a slightly stronger positive relationship with stream distance than channel width ($r^2 = 0.659$; $y = 0.8916x + 6.4103$) and stream distance between the headwaters and approximately 27 km downstream (2 km downstream of the bridge on N. Hinkson Creek road) (approximately 0 to 94.53 km^2 drainage area) (Figure 18A compared to Figure 20A; Figure 18C compared to Figure 20C). A comparison of the channel width and bankfull width indicated that there is greater variability in measurements of bankfull width, as shown by the average difference between maximum and minimum every 10 survey points along the length of Hinkson Creek (15.68 m), than channel width (12.81 m, a 22.4% greater range) (Figures 18B and 20B). The velocity of flows that reached bankfull levels may have caused increased stress on streambanks, potentially leading to mass wasting of weaker banks during high flow events and greater variability in bankfull width. The curves of both channel width and bankfull width with stream distance become more horizontal (visually shown using 100 pt moving average) between 29 km and 38 km downstream of the headwaters (just upstream of bridge at Stadium Blvd.) (drainage areas approximately 97.40 km^2 to 131.15 km^2). As with channel width, bankfull width then exhibits a weakly positive relationship between approximately 38 km and 42 km downstream of the headwaters (approximately 3 km upstream of S. Providence Road) (approximate drainage areas 131.15 km^2 to 172.13 km^2). The relationships between channel width and bankfull width described above may be observed in Figures 18A and 20A (stream distance) and 18C and 20C (drainage area).

Unlike channel width, average bankfull width (as observed through the 100 pt moving average – there is still variability from the moving average from site to site) begins to level off horizontally again at approximately 42 km downstream (approximate drainage area 172.13 km^2) until approximately 50 km downstream (1 km downstream of Twin Lakes Recreation Area in

Columbia) (199.79 km^2). From 50.1 km downstream to the mouth at 56 km, bankfull width began to increase which suggests that while channel width remains fairly consistent from 50 km downstream until the mouth, the bank slumping and mass wasting observed in the last few kilometers near the mouth of the stream (Figure 62) may already be affecting bankfull width at the lowest reaches of Hinkson Creek.

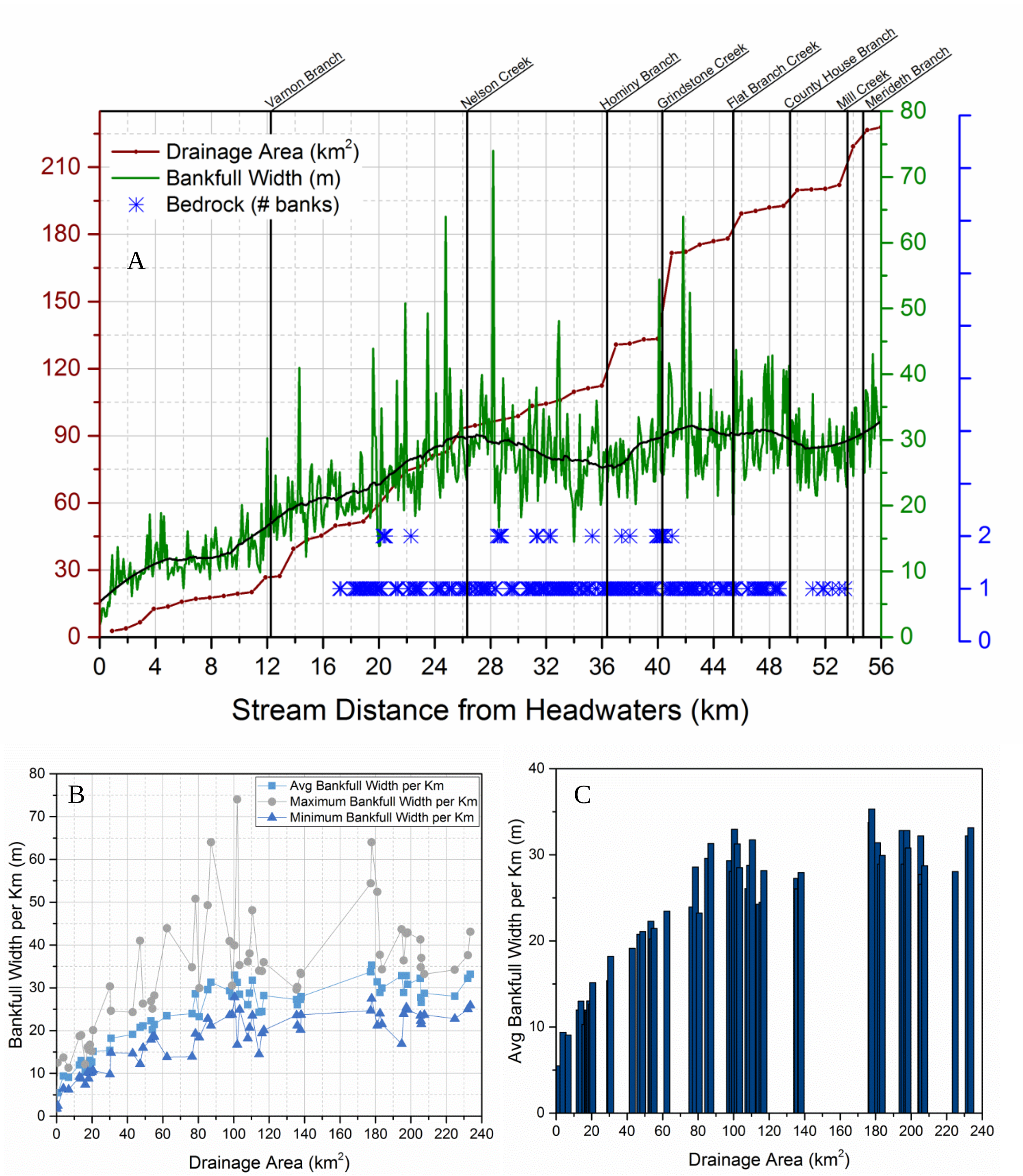

Figure 20. A. Bankfull width with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in black, and major tributary confluences marked. Bedrock constraints are shown with blue asterisks; B. Average, maximum and minimum bankfull width per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average bankfull width per kilometer with drainage area in Hinkson Creek watershed.

Bank height with stream distance is illustrated in Figure 21A. There is a comparatively sharp rise in bank height from the headwaters to approximately 5 km downstream ($r^2 = 0.79$) (drainage area accumulates rapidly from roughly 0 to 14 km^2 along this stream distance). From 5 km downstream to approximately 18 km downstream (1 km downstream of E. O'Rear Road) (approximately 50.55 km^2 drainage area) a slight negative relationship between bank height and stream distance is observed using the 100 point moving average. There is still a great deal of variability from survey point to survey point.

Between 18 km downstream and approximately 27 km downstream (2 km downstream of the bridge on N. Hinkson Creek road), bank height is highly variable with an overall very slight positive trend with stream distance. The exception is seen at approximately 23 km downstream (0.2 km downstream of Rogers Road) (approximately 76.24 km^2 drainage area) where there is a large spike in bank height. As this area is just downstream of the bridge on Rogers Road, and it is possible that the bank height was either artificially increased to accommodate the construction of the bridge, or that the county took advantage of an aberrant natural formation when choosing where to construct the bridge across the stream.

A positive relationship was observed between bank height and stream distance from approximately 27 km to 32 km downstream of the headwaters (just upstream of Highway 63 bridge over Hinkson Creek) (drainage area range approximately 94.53 km^2 to 104.29 km^2). This section of the stream falls within the area previously designated as containing a number of bedrock constraints, and it is possible that the bedrock formations play some role in the positive relationship observed. The potential role of the bedrock constraints will be addressed later in the text.

The relationship sharply reverses and becomes negative as average bank height decreases between 32 km downstream (just upstream of highway 63) and 38 km downstream (just upstream of Stadium Blvd.). However, there is still a wide range of variability in the bank height measurements through this section of Hinkson Creek (drainage area approximately 104.29 km2 to 131.15 km^2 on Figure 21B), suggesting the intermittent presence of sloping forested hillslopes underlain by bedrock (bank height increased at survey points with bedrock bank constraints) as noted in previous discussion.

The graph in Figure 21A shows a consistent long-range positive relationship ($r^2 = 0.616$; $y=0.1715x – 4.6141$) between stream distances 38 km to 56 km from the headwaters (approximately 136 km^2 to 234 km^2 cumulative drainage area). A rapid increase in bank height with stream distance in the lower reaches of the stream (from 1.54 m high at 38 km to 5.54 m high at 56 km, a 73.5% increase) is shown on Figure 21A. The positive relationship can also be observed between bank height and drainage area in Hinkson Creek in Figures 21B and 21C. Although Figure 21B shows that there is still a great deal of variability in the bank height measurements (there have been numerous urban development projects along Hinkson Creek below Stadium Blvd. which could account for variability in streambank heights), the trend of the average bank height with drainage area in Figure 21C clearly mirrors the trend of bank height with stream distance observed in Figure 21A. The observed measurements of bank height between 38 km downstream and the mouth (73.5% increase) suggest that channel incision may be ongoing in the stream channel of Hinkson Creek below the City of Columbia (Hubbart et al. 2011, Huang 2012). Due to the complexity of the in-stream processes in between 38 km downstream and the mouth, a determination cannot be made as to how much of the channel incision is potentially due to groundwork laid by geologic processes since the last glacial retreat

(Tarr 1924), or whether more recent channel incision and accompanying bank erosion may be indicative of cumulative effects of backwater from the Missouri River and/or urban stream syndrome. Urban land-use effects in this portion of the watershed include but are not limited to alteration of stream hydrologic processes, loss of bottomland hardwood forests, and increased impervious surfaces (Hubbart et al. 2011, Hubbart and Zell 2013, Meyer et al. 2005, Walsh et al. 2005).

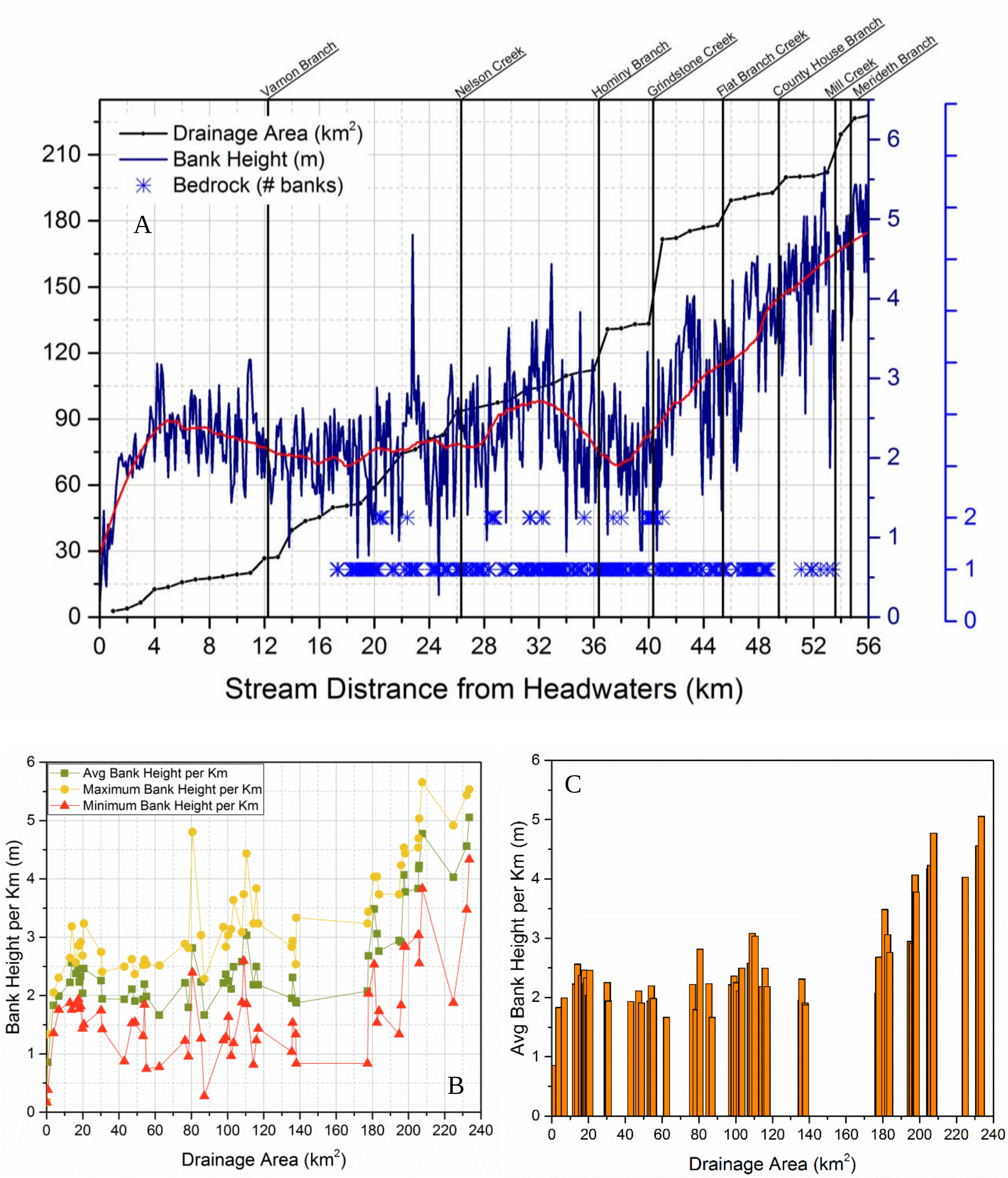

Figure 21. A. Bank height with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in red, and major tributary confluences marked. Bedrock constraints are shown with blue asterisks; B. Average, maximum and minimum bank height per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average bank height per kilometer with drainage area in Hinkson Creek watershed.

4.2 Thalweg Measurements

The relationship between relative thalweg depth (the height from the thalweg of the stream to the top of the bankfull bank) with stream distance shown in Figure 22A is very similar to the relationship observed between bank height and stream distance shown in 21A. A comparison of Figures 21A and 22A shows that there is less variability (noise in the measurements) in the relative thalweg depth with stream distance.

The relationship between bank height and drainage area (Figure 21C) and relative thalweg depth and drainage area (Figure 22C) is also quite similar. However, a comparison of Figure 21B with Figure 22B shows less overall variability in measurements of relative thalweg depth than bank height, mirroring the relationship discussed in the above paragraph with each of the metrics and stream distance.

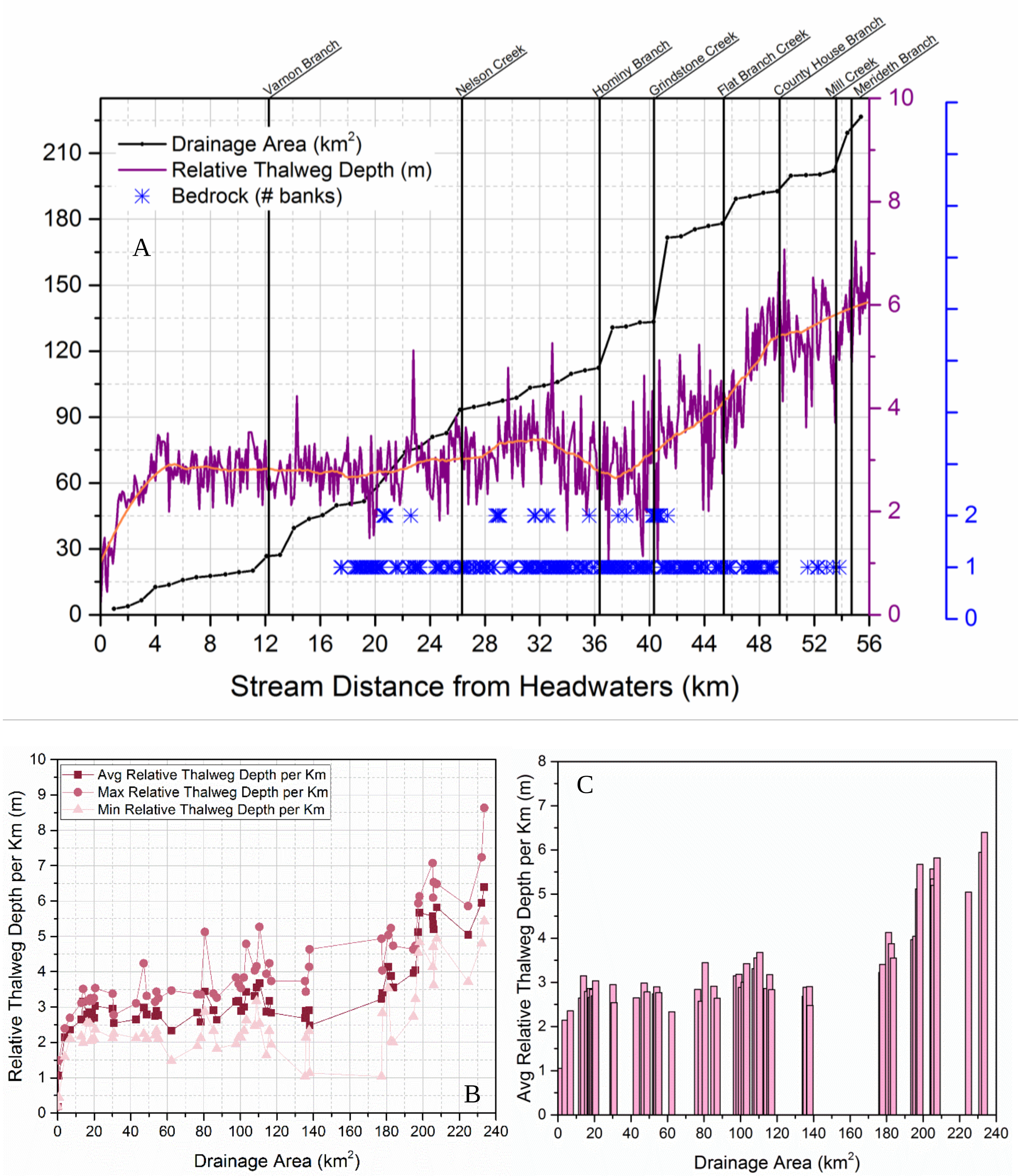

Figure 22. A. Relative thalweg depth with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in orange, and major tributary confluences marked. Bedrock constraints are shown with blue asterisks; B. Average, maximum and minimum relative thalweg depth per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average relative thalweg depth per kilometer with drainage area in Hinkson Creek watershed.

Surficial geology may affect physical habitat available in a stream by influencing the stability of the bank and streambed and hence the potential resistance to incision and widening of the channel with altered flow regimes (Schwendel et al. 2010). The stability of the banks and substrate may also affect the types of biota that can withstand the shear stress of the water flow over specific types of substrate in a stream habitat (Schwendel et al. 2010). The stability of the streambanks and streambed become more relevant with increased pressure from upstream land-use moving further downstream in Hinkson Creek. Below the City of Columbia, the cumulative land-use effects include rural, suburban and urban effects which become evident in an analysis of the next few figures. Additionally, ongoing sedimentation on the floodplain during and after high flow events may be increasing bank height in the lower reaches of Hinkson Creek.

Based on data presented in this thesis and Figures 22 and 23 (using 100 pt moving averages), the beginning of the channel incision may be located somewhere in the range between of 44 km to 46 km downstream (drainage area approximately 176.88 km^2 to 195 km^2) of the headwaters. The 44 km to 46 km downstream range coincides with an area beginning approximately 1 km downstream of Providence Road to approximately 0.8 km downstream of the confluence of Hinkson Creek and Flat Branch Creek. While an examination of the 100 pt moving average line in Figure 23 shows a sharp increase in average thalweg depth between 40 km and 42 km downstream of the headwaters, there is a much greater increase detectable between 44 km and 46 km downstream. The two separate increases in thalweg depth just described are also apparent in Figures 23B and 23C at drainage areas beginning at approximately 176.88 km^2 and 195 km^2. The location of the channel incision at this point in the watershed is consistent with both the channel incision and erosion effects resulting from urban stream syndrome (Walsh et al. 2005), and sedimentation from Missouri River backwater and flooding of Hinkson Creek increasing the height of the floodplain during and after high flow events.

One possible explanation for the channel incision not travelling any further upstream is the influence of bedrock geology (blue asterisks, Figure 23A). The PHA data and photographic database show that there are bedrock constraints just above Providence Road, and again moving downstream from the confluence with Grindstone Creek which would prevent incision of the channel into the streambed further upstream than 44 to 46 km downstream of the headwaters.

At approximately 50 km downstream of the headwaters (1 km downstream of Twin Lakes Recreation Area in Columbia), the average thalweg depth begins to decrease (again with a great deal of variability although the 100 pt moving average line shows a negative relationship). As with the previous discussion of bank height, this relationship may be due to the combination of the urban land-use effects downstream of the City of Columbia and the effects of backwater from the Missouri River.

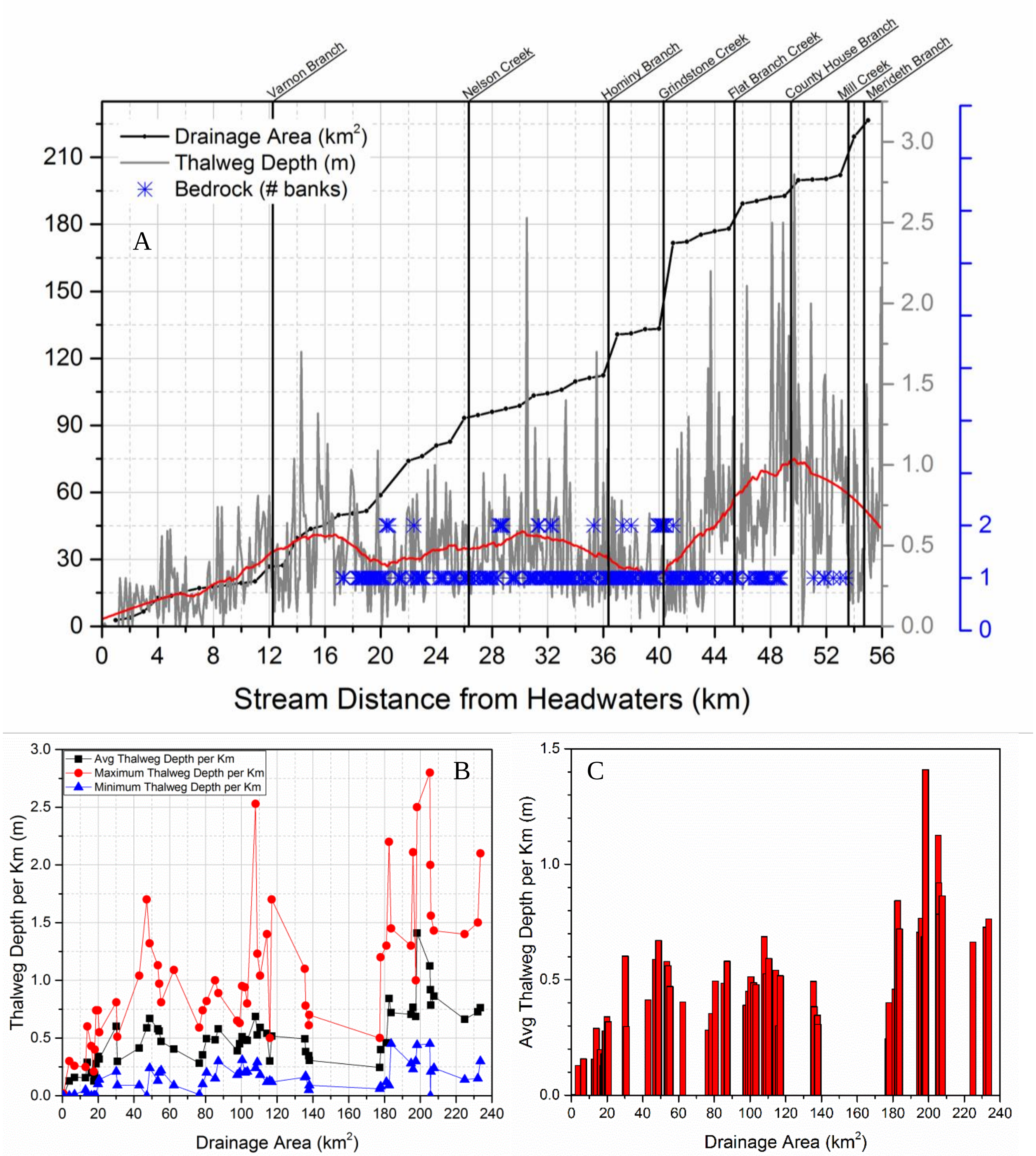

Figure 23. A. Thalweg depth with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in red, and major tributary confluences marked. Bedrock constraints are shown with blue asterisks; B. Average, maximum and minimum thalweg depth per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average thalweg depth per kilometer with drainage area in Hinkson Creek watershed.

4.3 Channel Geometry

Channel geometry of Hinkson Creek was explored using several different metrics. Width: depth ratio was calculated for the entire length of Hinkson Creek, using bankfull width (m) and relative thalweg depth (m) (Figure 24). Sinuosity was calculated by MoRAP during Phase I of the PHA. A review of Figure 24 illustrates increased width: depth ratios close to the headwaters and the mouth of Hinkson Creek. Overall, sinuosity decreased in the central portion of the watershed, although there was still a wide range of variability from the 100 pt average line. Decreased sinuosity has been associated with flashy systems with high depositional sediment loads (Piégay and Schumm 2003).

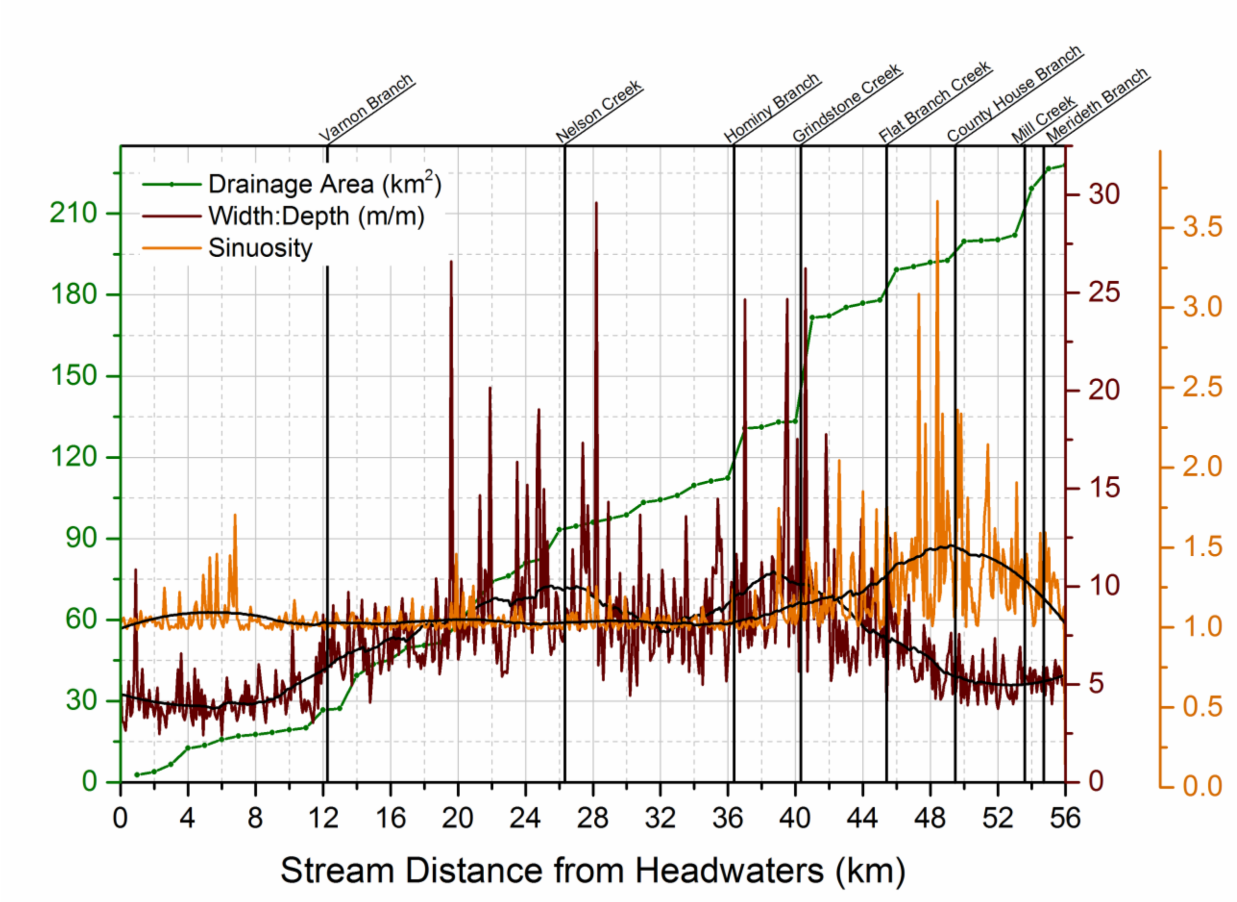

Figure 24. Width: depth ratio and sinuosity in Hinkson Creek with stream distance and drainage area. 100 pt moving averages are marked in black.

The observed relationship between relative thalweg depth and stream distance (Figure 22) in the lower reaches of Hinkson Creek is consistent with the work of Tarr (1924) who presented that lateral cutting (increased meanders followed by cutting off of meanders) and channel incision (downward cutting, increasing bank height from the channel bed) had been occurring in Hinkson Creek Watershed since the last glacial retreat. The Missouri River had filled with rocks and debris which were flushed out over time by high flows. Over geologic time, Hinkson Creek changed course and cut into the channel bed to adjust to the decreasing elevation of the Missouri River bed (Tarr 1924). This geomorphologic activity laid the foundation for more recent physiographic changes in the HCW.

The presence of channel incision in the lower reaches of Hinkson Creek can be observed in Figures 25 and 26. Figure 25 is a graphical model of thalweg depth (at low to median flows during the PHA) below a water surface drawn at 0 meters (left y-axis), and compared to the distance from the surface of the water to the top of the bank (right y-axis) computed by subtracting thalweg depth data collected during the PHA from relative thalweg depth PHA data, both with stream distance from the headwaters of Hinkson Creek. Figure 26 is a similar representation but uses drainage area on the x-axis. The 100 pt (Figure 25) and 50 pt (Figure 26) moving averages in these graphs show the sudden increase in thalweg depth observed between 44 km and 46 km downstream. Figure 26 shows very little average variability in thalweg depth per km along the entire length of the stream until a point at approximately 195 km^2 drainage area, corresponding to the observed increase in bank height. From approximately 50 km downstream (drainage area approximately 200 km^2) until the mouth, average thalweg depth decreases, again suggesting the recent dual influences of urban land-use effects (Walsh et al. 2005) and the influence of the Missouri River backwater and increased floodplain elevation due to sediment deposition (Knox 2006).

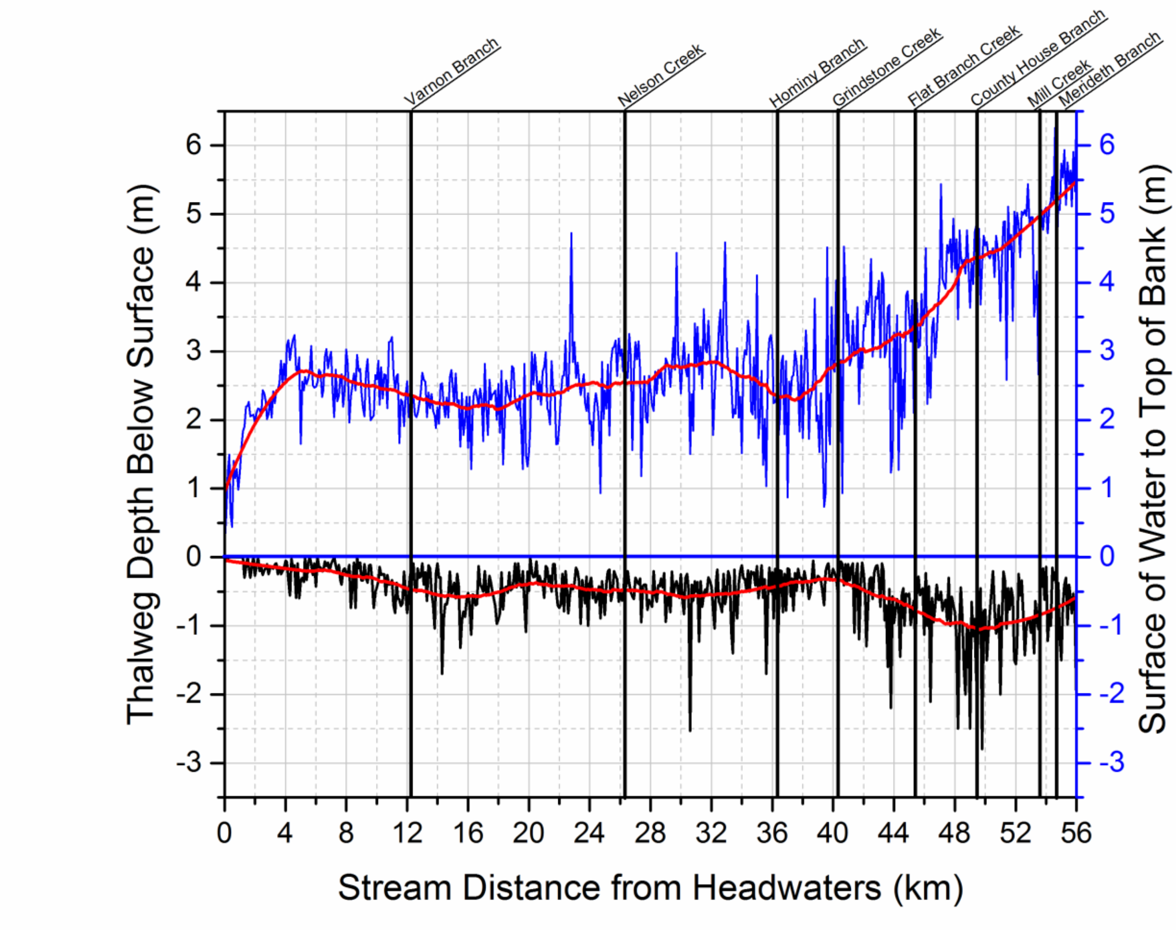

Figure 25. Thalweg depth (left y-axis, in black) and distance from surface of water to top of bank (right y-axis, in blue) with stream distance, with 100 pt moving averages in red. Confluences with the 8 major tributaries are marked.

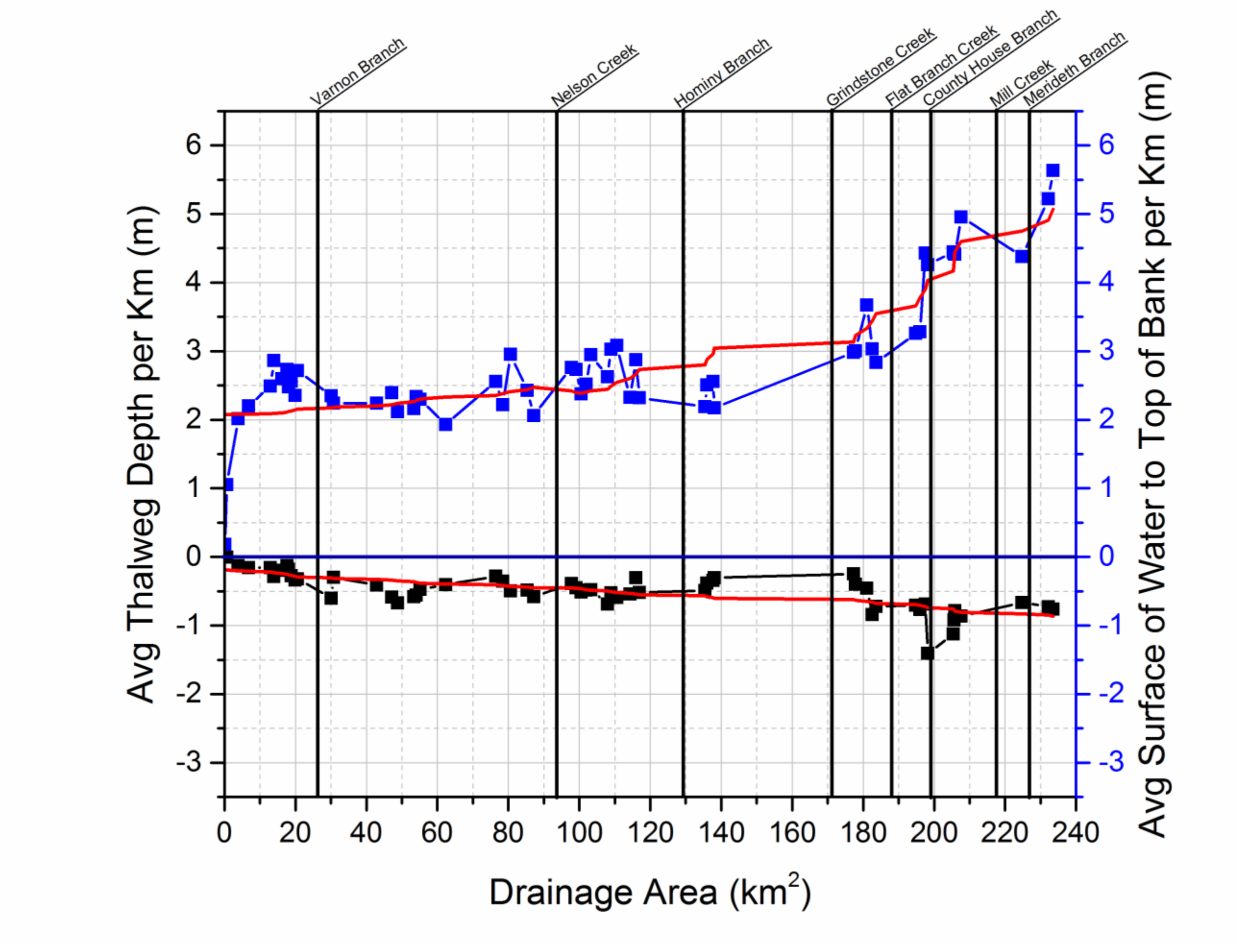

Figure 26. Average thalweg depth per km and average distance from surface of the water to the top of the bank per km with drainage area, 50 pt moving average in red. Confluences with the eight major tributaries are marked.

4.4 Canopy Cover

Canopy cover was highly variable (0% to 100%) along the length of Hinkson Creek which is consistent with the variability in the composition (woody v. herbaceous) of the riparian corridor, and the variability in the width of the riparian corridor observed during the PHA. There were a number of densely forested streambanks which provided canopy cover and shading for the stream, although the majority of the sites with a higher percentage of canopy cover occurred higher up in the watershed (Figure 27A). Canopy cover and stream shading can help to reduce water temperatures in the hot summer months (Biondi 2008), an important water quality characteristic for some aquatic biota including “shade adapted” diatoms at the base of the stream food web (Robinson and Rushforth 1987). Other aquatic biota, particularly periphyton which provides food and habitat for a variety of aquatic organisms, depend upon the absence of shade in order to thrive (Quinn et al. 1997). Several sites were observed along the Hinkson Creek with 0% average canopy cover across the stream width (Figure 27A) including a couple of agricultural sites (some of which are illustrated with photographs in section *4.11 Longitudinal Variation in Stream Physical Habitat Due to Influence of LULC*) in the upper reaches of the stream and also several in the lower half of Hinkson Creek. Various other land-uses including the golf course upstream of E. Walnut St. in Columbia involved complete removal of the riparian corridor. The implications of the absence of riparian cover are important for aquatic biota, as many fish for example require habitat that is temperature dependent (temperature and oxygen availability are linked in aquatic habitats) (Comte et al. 2013).

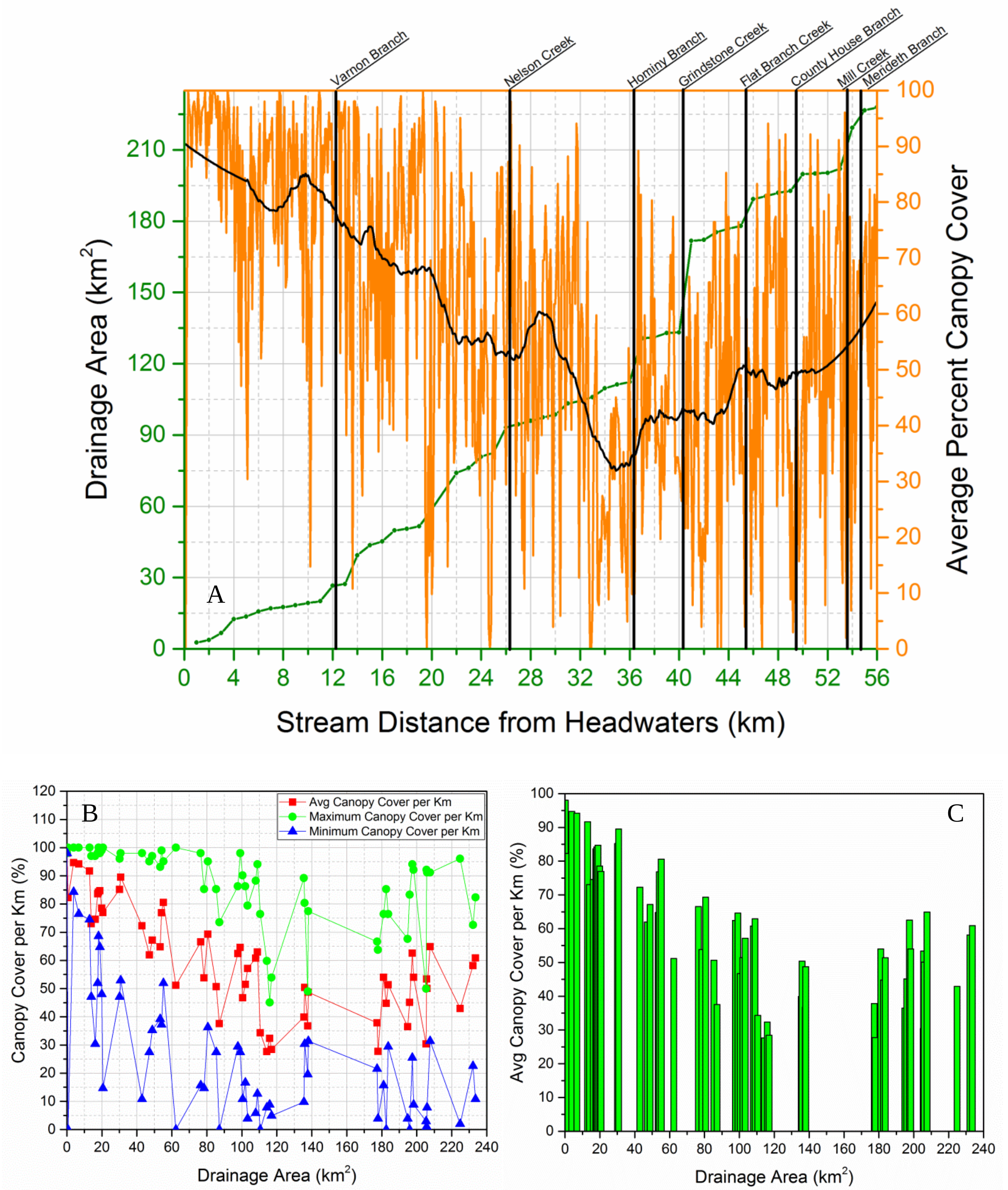

Figure 27. A. Average percent canopy cover with stream distance from headwaters in Hinkson Creek and drainage area, with 100 pt moving average shown in black, and confluences with the eight major tributaries marked; B. Average, maximum and minimum percent canopy cover per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average percent canopy cover per kilometer with drainage area in Hinkson Creek watershed.

4.5 Pebble Count

Substrate size is important for suitable microhabitat for aquatic organisms including some macroinvertebrates and small fish that require interstitial spaces between gravel particles in the substrate for habitat (Rabeni et al. 2005, Schiemer et al. 2002). The stream substrate particles in Hinkson Creek were found to be in the small size class (Table 9 – sand, silt and clay, or small gravel) 58.4% of the time. These findings are shown graphically in Figure 28. The high percentage of particles in the small size class (58.4% of particles sampled, as compared to the 33.6% in the intermediate size class, 7.76% in the large size class, and 0.24% in the other size class) suggests that gravel beds with interstitial spaces available for habitat were filled with small particles at the times that the PHA was performed in Hinkson Creek. Increased sedimentation can be an effect of deforestation and agricultural land-use (Stone et al. 2005) and altered sediment regimes have been observed with urban stream syndrome (Walsh et al. 2005). The PHA was performed across a relatively broad time span (July, 2013 through August, 2014) and it was not possible to obtain simultaneous quantification of streambed condition at all points along the stream. Resh et al. (1988) discuss dynamic equilibrium in stream systems, suggesting that sediment is continually moving downstream from the headwaters to the mouth. Due to the limitations of the measurements during the PHA, it is unknown whether sediment deposits were permanent or temporally variable. Substrate particle size with stream distance is shown in Figure 29. Larger particles and bedrock are grouped in the central portion of the watershed.

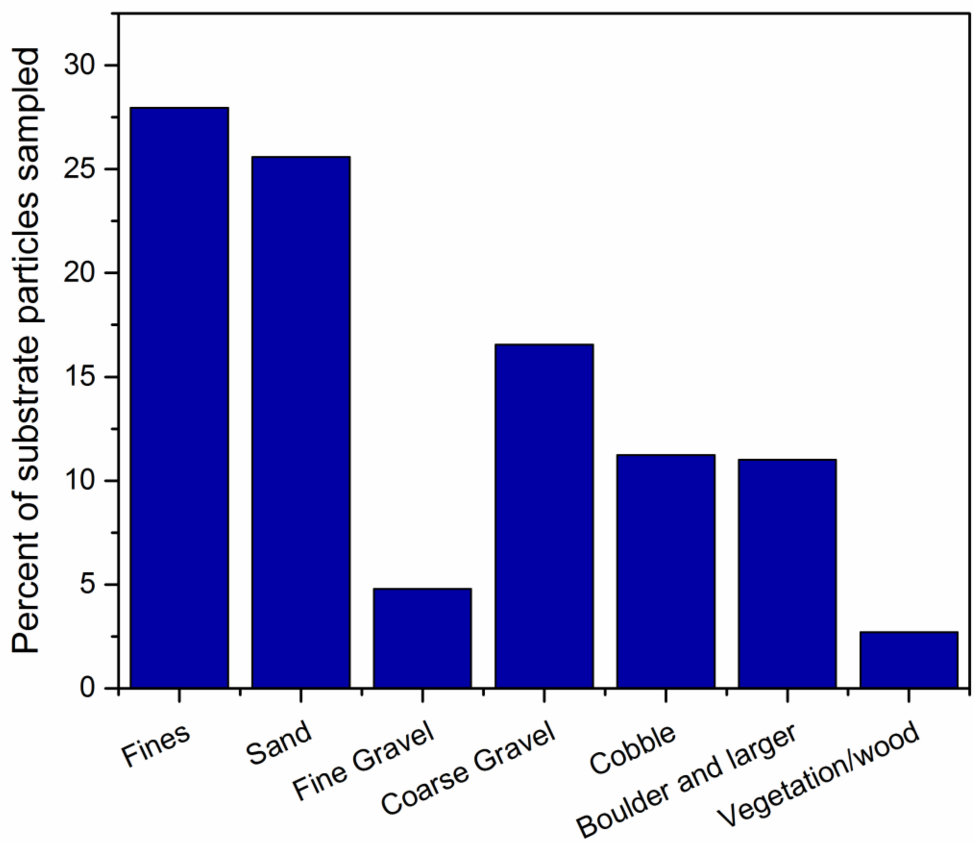

Figure 28. Percentage of substrate particle samples collected during the pebble count and thalweg profile of the PHA of Hinkson Creek, grouped by size class. Fines include both silt and clay particles.

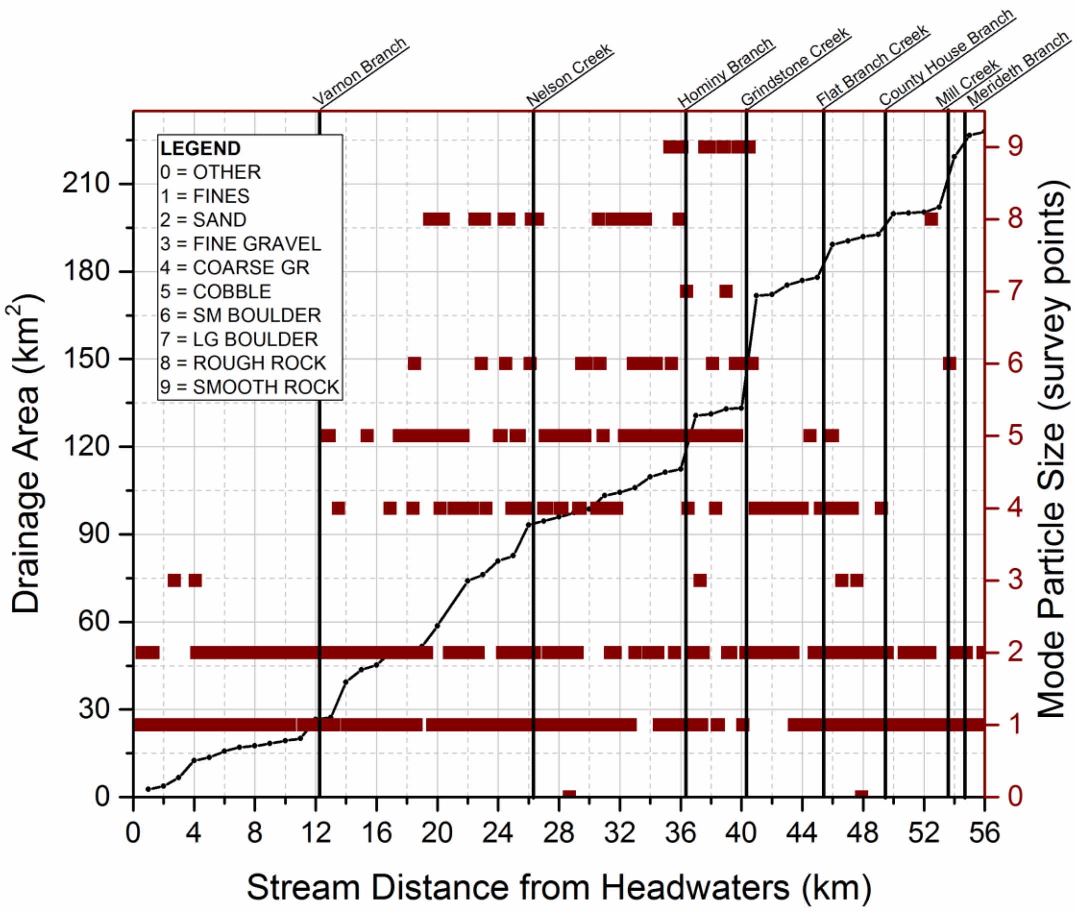

Figure 29. Mode particle size (of 15 particles per survey point) with stream distance and drainage area in Hinkson Creek during the PHA of Hinkson Creek (Phase II). Confluences with eight major tributaries are marked.

Substrate characteristics are the most significant habitat selection criteria for specific families of macroinvertebrates (Richards et al. 1993). However, substrate particle size is not the only characteristic of the streambed that is important for habitat for aquatic biota. Embeddedness of the substrate due to deposition of fine sediment (i.e. sand, silt and clay) can fill interstitial spaces regardless of the underlying particle size class composition (Rabeni et al. 2005). To further explore potential habitat relations along Hinkson Creek, the average percent embeddedness at survey transects was calculated to be 100% fifty-one times along the length of

Hinkson Creek, or approximately 9% of the survey transects (Figure 30A). These results are also illustrated by looking at average percent embeddedness with drainage area (Figures 30B and 30C). A highly embedded streambed significantly reduces habitat available for virtually all macroinvertebrates except those that are burrowers (Rabeni et al. 2005). Various fish species also require interstital spaces during their life cycles (Schiemer et al. 2002). At no point along Hinkson Creek did average percent embeddedness drop below 10%. Based solely on the results from a single PHA during a window in time, Hinkson Creek may have reduced streambed habitat heterogeneity available for aquatic biota. However, given the measurements of average percent embeddedness were not made simultaneously along the length of the stream, so further PHA work at regular intervals across a long time series is needed in Hinkson Creek to corroborate the results.

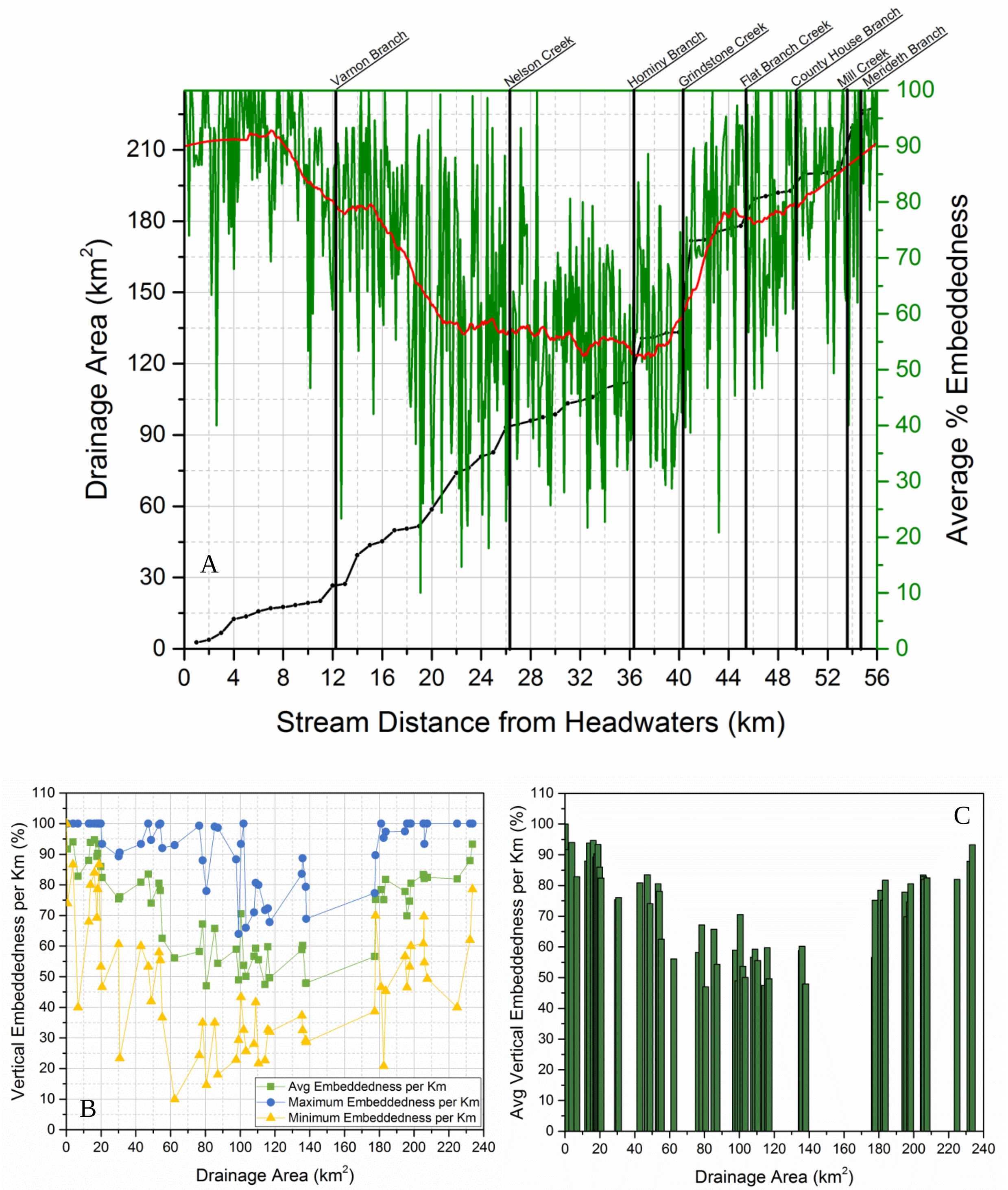

Figure 30. A. Average percent vertical embeddedness of sampled particles with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in red. Confluences with the eight major tributaries are marked; B. Average, maximum and minimum percent vertical embeddedness per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average percent vertical embeddedness per kilometer with drainage area in Hinkson Creek watershed.

Although the presence or absence of periphyton was noted on the particles sampled from the thalweg where possible as instructed in the Field Protocol, the results were not sufficiently consistent to be quantified and have been omitted from this thesis. For example, there were numerous survey points and thalweg profile stations where the substrate was silt or sand, and the presence or absence of periphyton was difficult if not impossible to determine. Additionally, presence of periphyton was presumed to be absent in deep pools due to turbidity of the water and lack of sunlight penetration, but was not verified as it was not practicable to obtain samples in the field.

The surficial geology of Hinkson Creek may be directly relevant to the availability of physical habitat available for aquatic biota. For example, Bucci (2009) showed that stable streambanks (corresponding to reduced sand content) provide burrow habitat for muskrats living in the riparian corridor (Illinois, USA). The dens observed on Hinkson Creek were constructed in streambanks near the level of the water surface at baseflow (example shown in Figure 31). Streambanks were used as habitat by wildlife in Hinkson Creek (Figures 32 and 33).

Figure 31. One of several muskrat dens found during the PHA of Hinkson Creek, 08-13-2014, 10:03 (lat. 39.115652, long. -92.19164).

Figure 32. A burrow for a bird or small mammal in the streambank more than a meter above the surface of the water of Hinkson Creek, 08-08-2013, 12:39 (lat. 38.924095, long. - 92.326942).

Figure 33. A river otter slide on a bank of Hinkson Creek, 10-01-2013, 10:35 (coordinates not available).

4.6 Channel Unit Analysis

Alluvial streams exhibit certain morphological characteristics, including a sequence of channel unit types which are variable based upon regional characteristics. For example, in mountainous regions it would be common to see cascades and step-pools (Montgomery and Buffington 1997) which do not occur in lowland areas. In streams in the central United States, streams exhibiting the riffle-pool sequence are common, and the riffle-pool sequence is expected to occur at regular intervals along the length of a stream. The Missouri Department of Natural Resources (MDNR) procedure for Semi-Quantitative Macroinvertebrate Stream Bioassessment states that riffles are expected to occur at a distance of 7 to 10 stream widths (wetted width) due to the effects of sinuosity and the influence of point bars on streamflow velocity (MDNR 2003).

Using the metric above, the ratio of riffles (15%) to pools (70%) along the length of Hinkson Creek was found to meet standards set by the MDNR (2003) (Figure 34). The ratio of riffles to pools as a count of the total channel units, however, did not address issues of riffle spacing or proportional area. Riffle lengths were not measured in Hinkson Creek as part of the PHA. Along the length of Hinkson Creek, trench pools were observed that were hundreds of meters in length. These were long entrenched drainage canals with clay or silt substrate. Some of these extended trench pools appeared in areas with forested banks and wide riparian corridor. Thus, from external appearances one might assume that habitat for aquatic biota was heterogeneous and readily available. Although dynamic equilibrium theory demonstrated that sediment is likely to continue to move downstream (Resh et al. 1988), it would take time for stream habitat to recover after embeddedness. Based upon the data collected and these observations in Hinkson Creek, it appears that the frequency and length of trench pool areas may also be a factor in reduced diversity of aquatic biota in Hinkson Creek.

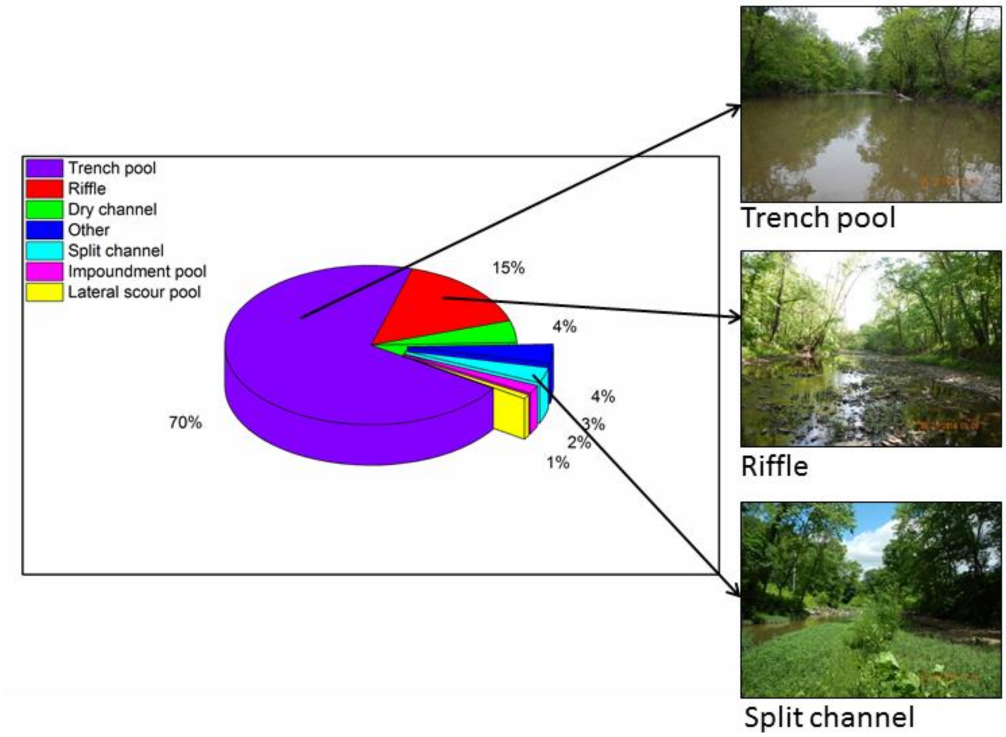

Figure 34. Percentage of channel unit types at locations sampled in Hinkson Creek during the PHA.

The distribution of physical habitat types (channel units) with stream distance in Hinkson Creek is illustrated in Figure 35. The graph illustrates that there are large gaps in the length of Hinkson Creek where there are not any riffles and appear to be dominated by trench pools. Very few glide pools were observed in Hinkson Creek. Glide pools are characterized by laminar flow, and flow was not laminar in the trench pools common in Hinkson Creek.

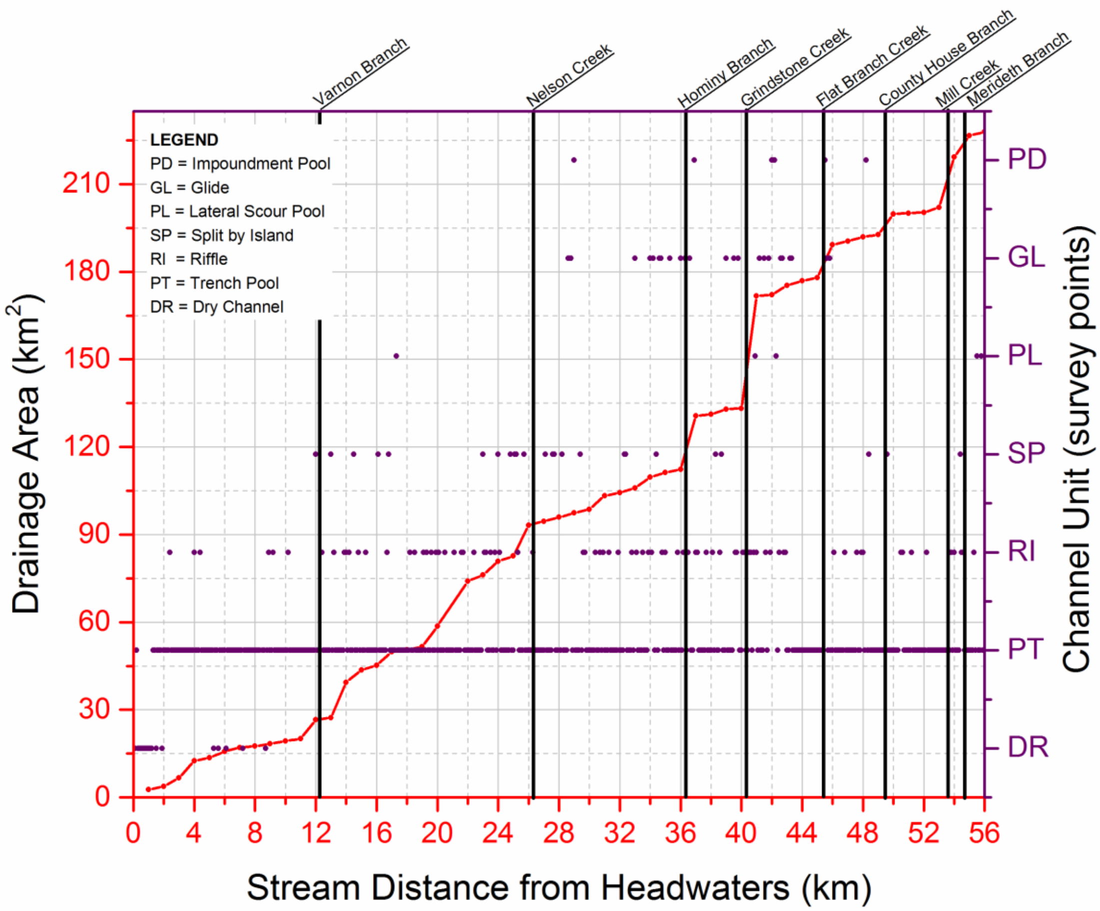

Figure 35. Channel unit types recorded during the PHA of Hinkson Creek, with stream distance and drainage area. Confluences with the eight major tributaries are marked.

4.7 Significance of Confluences as Points of Recurrent Measurement

The point along the drainage where smaller tributaries converge with larger tributaries is called a confluence. The work of Benda et al. (2004) showed that the effects of tributary convergence on stream morphology can be observed both above and below a confluence. In Hinkson Creek, detailed bank and channel measurements were made at each of the eight major tributary confluences. Three transects were used, one above and one below the confluence on Hinkson Creek, and then the last above the confluence on the tributary (Figure 13). The measurements from the three transects were averaged and confluence data are presented in Table 11. A summary of the average of the three transects measured at each of the 8 major confluences with Hinkson Creek is presented below as Figure 36. The average measurements standing alone are not particularly informative. The impact factors computed and presented in Table 12 go further to help explain the physical "state" of each confluence. For example, Varnon Branch has an impact factor of 2.01 for channel width as compared to the stream confluence average impact factor for channel width of 0.83. The relatively high impact factor of Varnon Branch at the confluence with Hinkson Creek can be explained by the relatively narrow channel width of Hinkson Creek at the confluence as compared to the relatively wide channel width of Varnon Branch compared to other small tributary streams from the headwaters to this point. As another example, Nelson Creek has an impact factor of 1.19 for thalweg depth as compared to the stream confluence average impact factor for thalweg depth which is 0.58. This can be explained by the thalweg depth of Hinkson Creek at the transect upstream of the confluence (0.62 m) compared to the thalweg depth of Hinkson Creek at the transect downstream of the confluence (1.02 m), an increase in thalweg depth of 39%.

Confluences are important for a variety of reasons. Observations along the length of Hinkson Creek showed that confluences were relative hotpots of biodiversity, with increased numbers of fish, amphibians, plant species, etc. These observations are consistent with the network dynamics hypothesis proposed by Benda et al. (2004), which suggests that frequent physical disturbance at confluences increase the presence of biodiverse flora and fauna in a riverine system. For the most part, the confluences were in undeveloped areas which is likely due to the increased incidence of flooding during high flow events (i.e. not conducive to development). The confluences were overall wider than the upstream and downstream transects on Hinkson Creek, possibly due to altered hydrology typical of stream confluences (Benda et al. 2004), the influence of human land-use changes upstream, or some complex interaction between the two. Confluences in Hinkson Creek should be considered hotspots of hydrogeomorphological and ecological variability in the stream, and resurveyed regularly for changes in impact factor and in-stream physical habitat metrics over relatively short periods of time (perhaps every three to five years) as human population increases in Boone County and the City of Columbia.

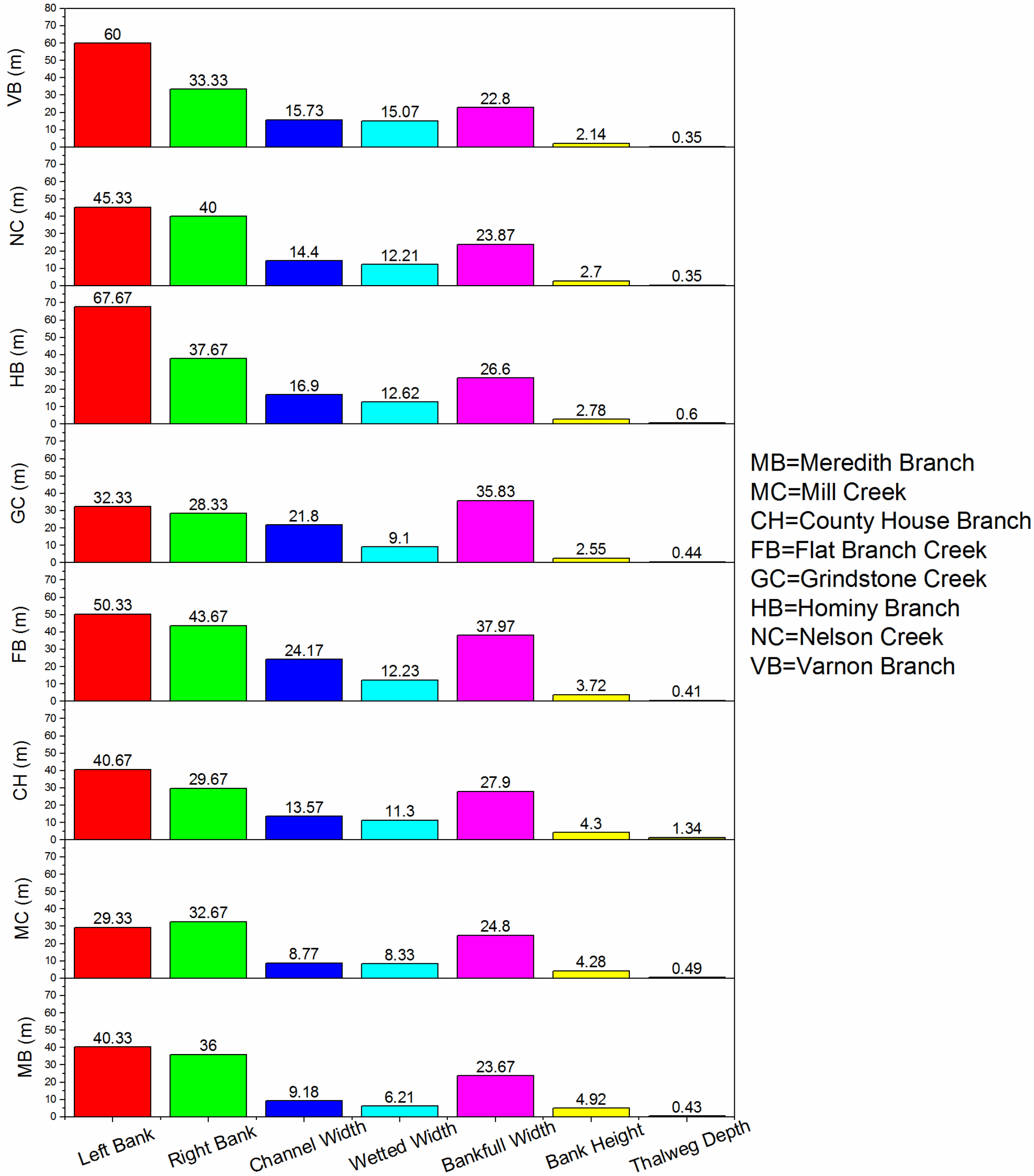

Figure 36. A comparison of averaged transect measurements (see section *2.2 Physical Habitat Assessment Field Protocol* for how metrics are calculated) at the confluence of each of the eight major tributaries of Hinkson Creek. All measurements are in meters, with the exception of the left bank and right bank angles which are in degrees.

4.8 Rootmat Survey

The work of Sedell et al. (1990) and Duehr et al. (2006) suggests that in-stream refugia for aquatic biota, including roots extending from riparian vegetation, can decrease recovery time for stream processes and aquatic biota populations after disturbance. The rootmat data collected during this work were an initial investigation of the types and number of trees which make up submerged rootmats, the relative distribution of rootmats with stream distance, and the volume of rootmats available as habitat for aquatic biota.

The results of the rootmat survey in Hinkson Creek were consistent with the findings of Nichols (2012). Rootmat habitat does not appear to be consistently available for aquatic biota along the length of Hinkson Creek. The results are similar whether looking at rootmat with stream distance (Figure 37A) or rootmat with drainage area (Figures 37B and 37C). There does seem to be a spike in the number of rootmats per survey site from approximately 8 to 14 km downstream from the headwaters (drainage area approximately 40 to 50 km^2). Observations in this area of the stream also indicate relatively high percentages of average canopy cover (Figure 27) which would make sense as trees in the riparian corridor create rootmat habitat.

Although the number of observed rootmats at survey sites was relatively low, there was a wide variety in the volume of individual rootmats (maximum 20.2 m^3, minimum 0 m^3, Table 15). Rootmat habitat is important for aquatic biota as habitat heterogeneity in the form of variable flow velocities, water depths, and types of substrate are represented in rootmats (Duehr et al. 2006). Rootmat volume does not appear to exhibit a strong relationship with either stream distance or drainage area (Figure 38). Nichols (2012) postulated that rootmat habitat was damaged or eliminated during high flow events in Hinkson Creek. Because ongoing human development has led to a reduction of forested streambanks throughout the HCW, strong relationships between the numbers of rootmats observed or the volume of rootmat habitat would not be expected with stream distance or drainage area. Contrary to expectations due to the influence of urban stream syndrome, there does appear to be an increase in the volume of rootmats in the area below the city of Columbia (Figure 38A, 43 km to 48 km downstream).

A large variety of trees contribute to rootmat habitat (Figure 39) suggesting that the loss of one species of tree in the riparian corridor (perhaps due to disease or a change in climate conditions) may not eliminate rootmat habitat in the stream. However, due to the abundance of maples and river birch in rootmats in Hinkson Creek, a loss of maple or river birch might significantly reduce rootmat habitat.

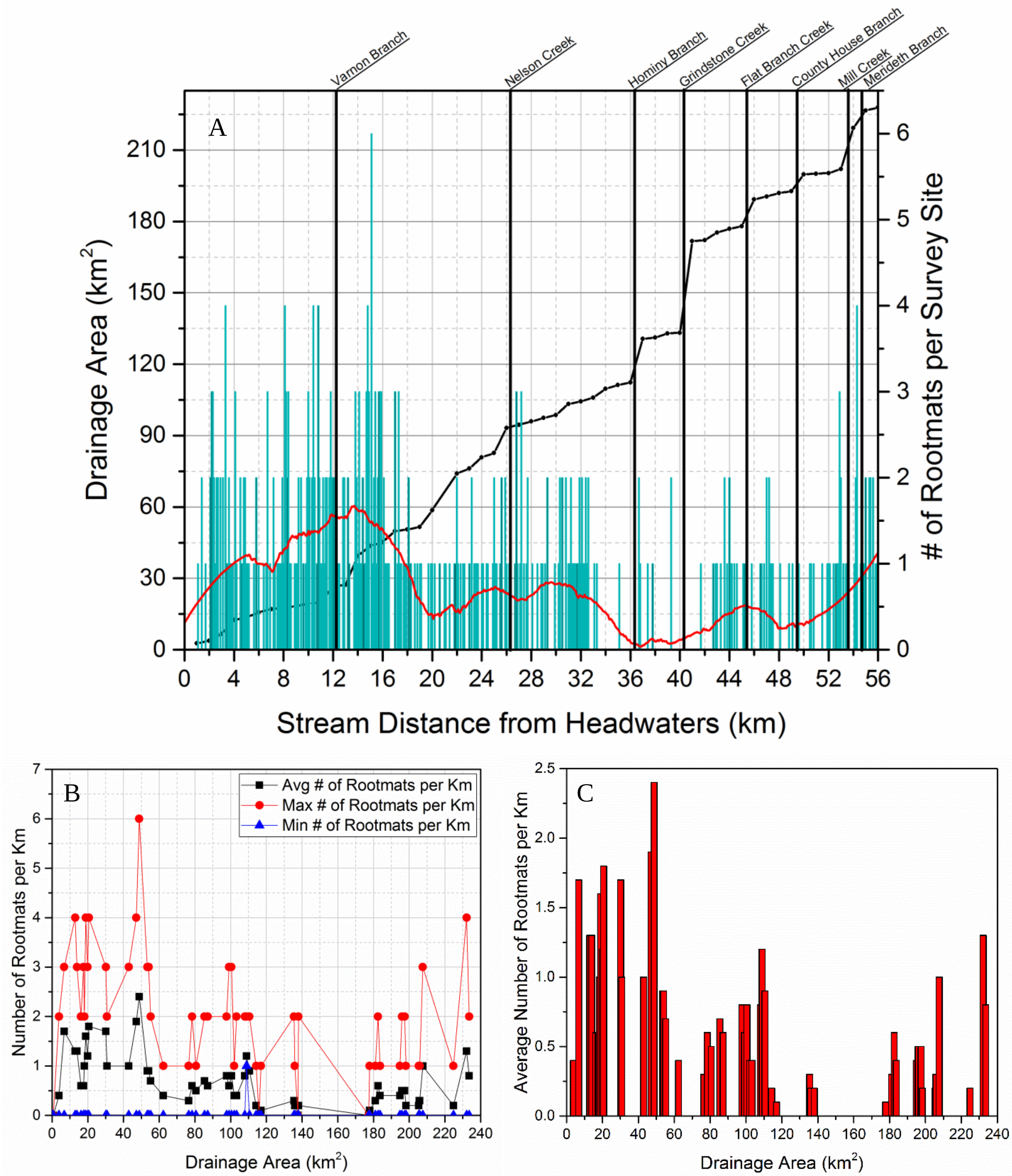

Figure 37. A. Number of rootmats per survey site with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in red. Confluences with eight major tributaries are marked; B. Average, maximum and minimum number of rootmats per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average number of rootmats per kilometer with drainage area in Hinkson Creek watershed.

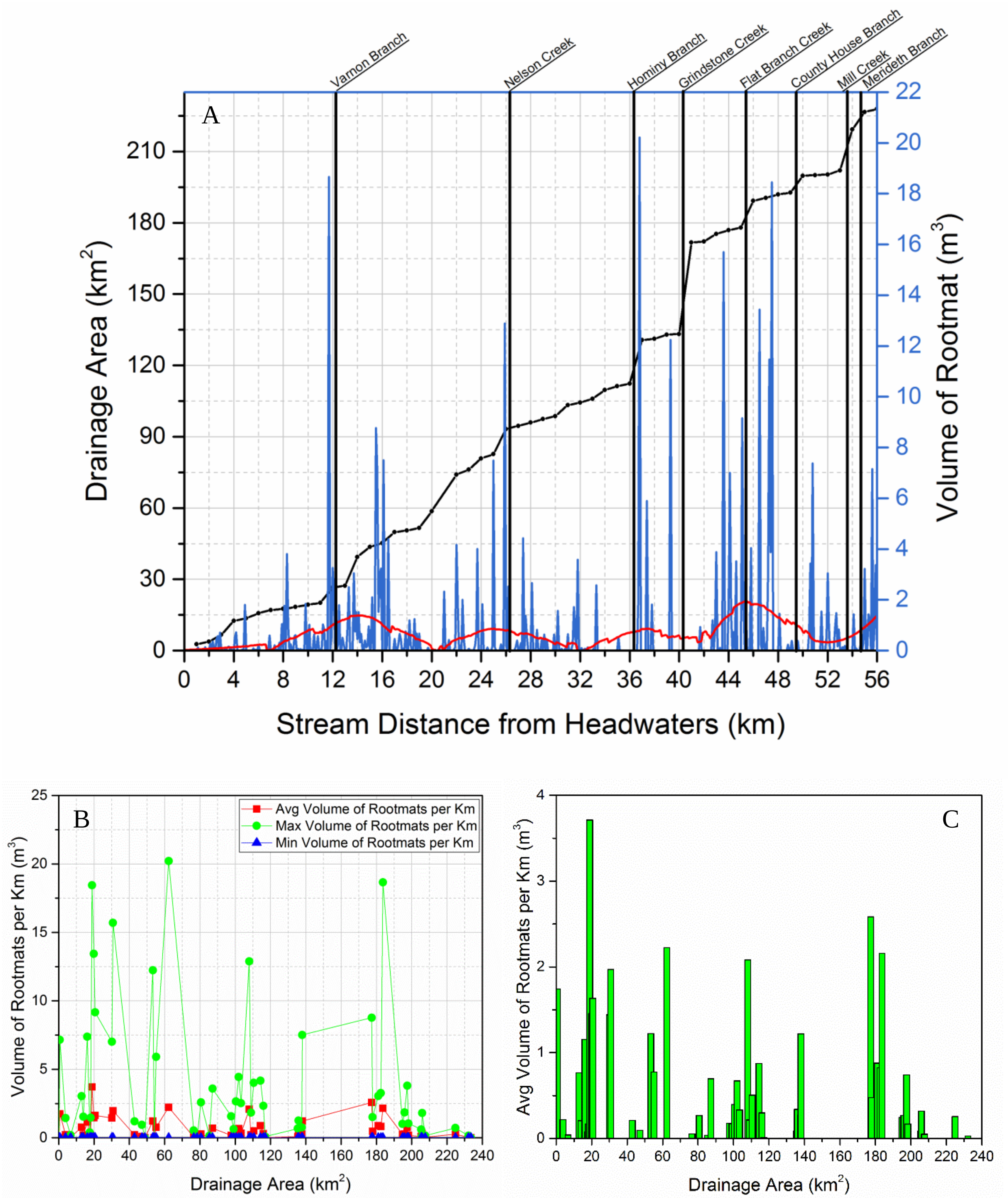

Figure 38. A. Rootmat volume at survey sites with stream distance from headwaters and drainage area in Hinkson Creek, with 100 pt moving average shown in red. Confluences with eight major tributaries are marked; B. Average, maximum and minimum rootmat volume per kilometer with drainage area in Hinkson Creek watershed to illustrate variability in measurements; and C. Average rootmat volume per kilometer with drainage area in Hinkson Creek watershed.

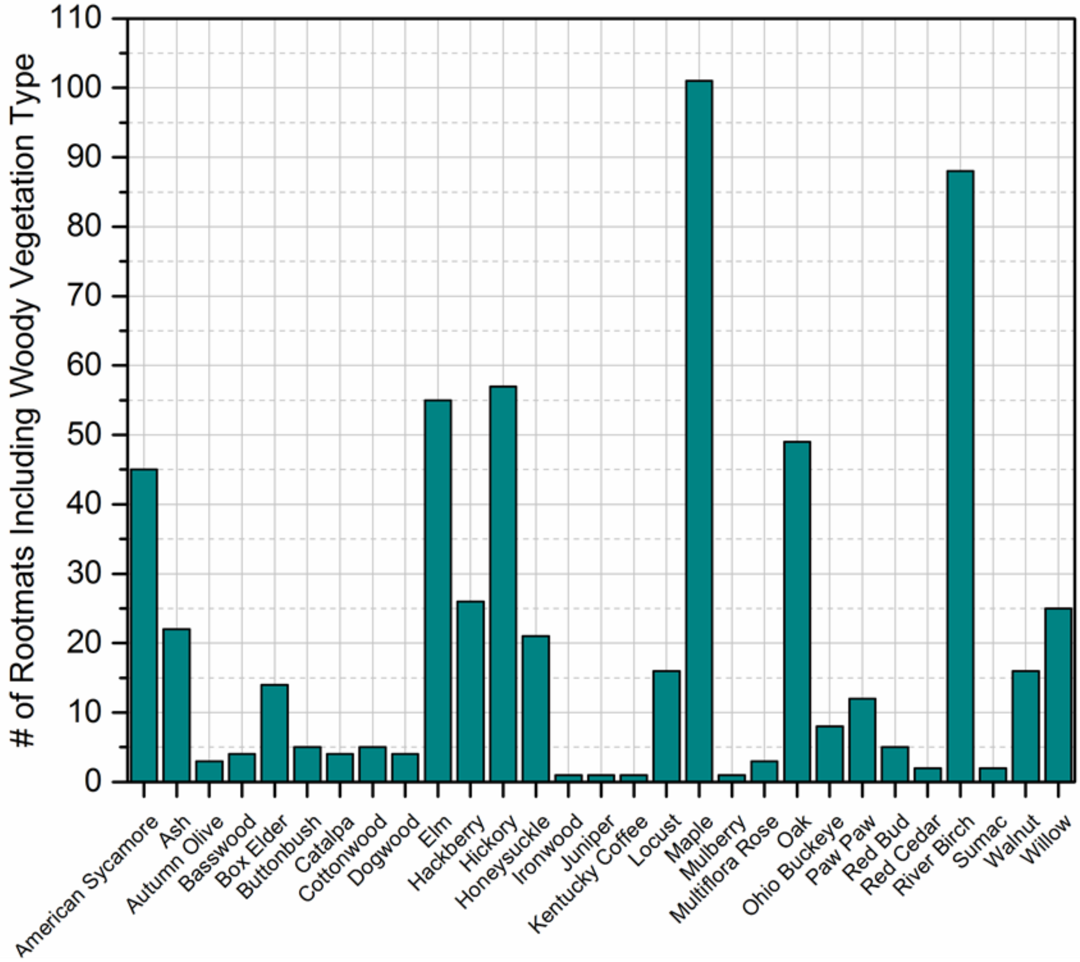

Figure 39. Trees included in rootmats measured during PHA of Hinkson Creek.

4.9 Riparian Zone Quantification and Significance of Riparian Corridor

The riparian corridor along the length of a stream serves a number of important functions with respect to aquatic biota. Stream temperature is often correlated to the condition and extent of nearby riparian corridor vegetation cover (Sponseller et al. 2001) (Figure 40). The riparian zone may provide habitat or a path for dispersal between water bodies for biota such as frogs that spend a portion of their life cycle entirely in the water (Semlitsch and Bodie 2003). As discussed in the previous section, in-stream rootmat extending from riparian vegetation can also serve as habitat and potential flow refugia for aquatic biota (Sedell et al. 1990, Duehr et al. 2006).

Figure 40. Riparian shading of Hinkson Creek a few hundred meters upstream of Forum Blvd. in the city of Columbia, September 29, 2013, 13:38 (lat. 38.924228, long. -92.362847).

Depending on tree species, tree density in forested area, and stream size, woody vegetation may contribute to streambank stabilization (Geyer et al. 2000) and provide more stream shading than herbaceous vegetation. Because of the designation of the riparian corridor as percent woody and percent herbaceous, presentation of riparian zone composition with stream distance or drainage area in a graphical manner did not produce visual results that were readily interpretable. Therefore, the data for percent woody riparian cover on the left and right descending banks of Hinkson Creek have been presented in the form of relative frequency curves in Figure 41. The shape of the relative frequency curve for each bank is similar, and it becomes apparent that the higher the percentage of woody vegetative cover, the lower the frequency of occurrence along the length of Hinkson Creek.

A similar problem was encountered when trying to graphically present the width of the riparian corridor, as the Field Protocol set width ranges for visual estimation during the PHA. Figure 42 shows the relative frequency curves for the left bank (Figure 42A) and the right bank (Figure 42B) riparian corridor width during the PHA. The riparian corridor exceeded 20 m in width approximately 37.5% of the time along the left bank, and greater than 50% of the time along the right bank. Based upon visual observation, these data do not indicate well-forested, stable riparian corridors, but rather just wide areas of undeveloped land (including at times strips of fallow farmland) adjacent to the stream. Recent work in Boone County (Brushy Creek in Ashland, Missouri) emphasized the significance of the width of riparian corridor to hydrologic connectivity between the floodplain and a stream and the functioning of groundwater systems (Chinnasamy and Hubbart 2014). Additional future analyses should identify which areas of Hinkson Creek would benefit from reforesting the riparian corridor, based upon upstream land-use and in-stream physical habitat conditions.

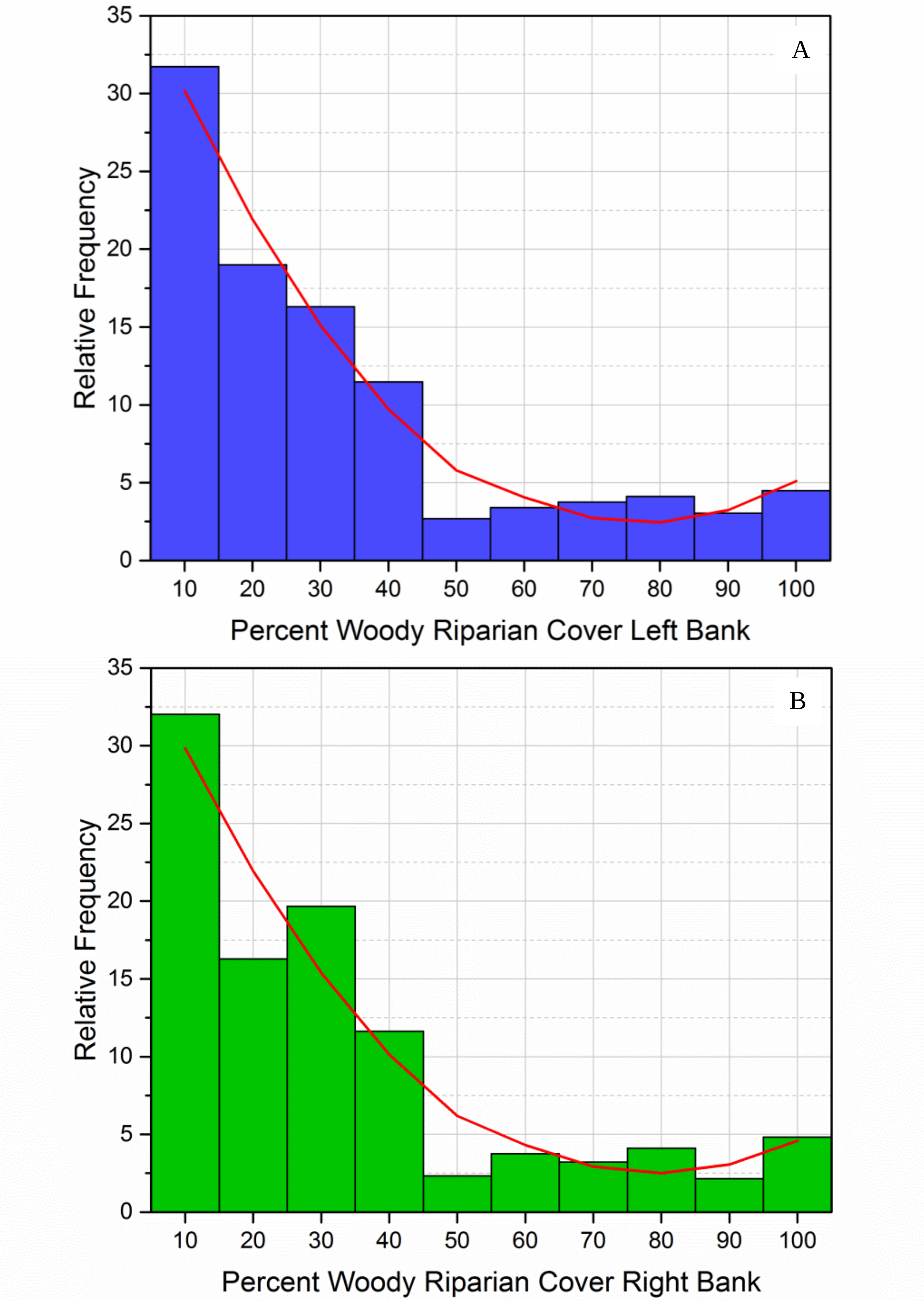

Figure 41. A. Relative frequency of percent woody riparian cover, left bank. B. Relative frequency of percent woody riparian cover, right bank.

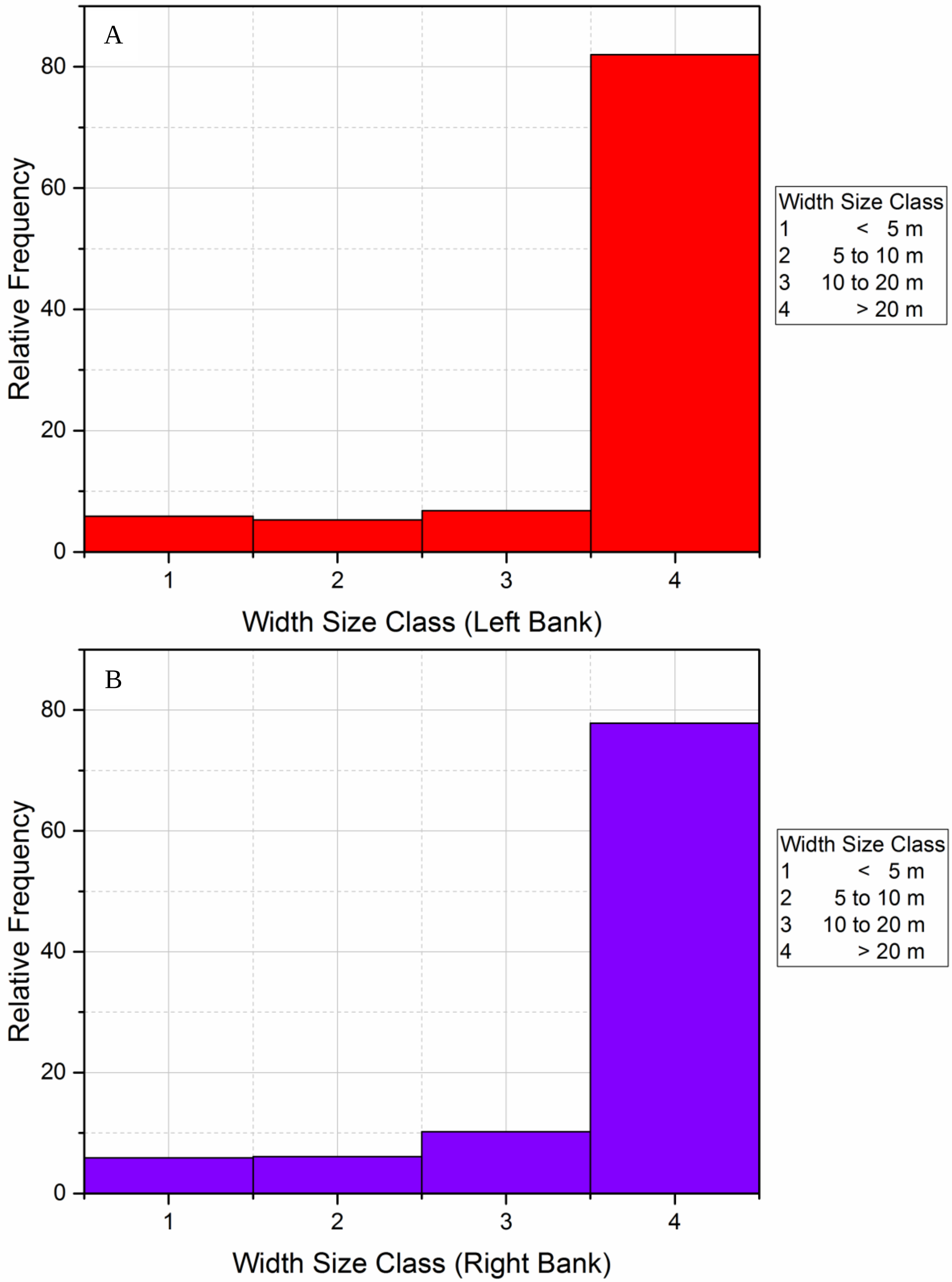

Figure 42. A. Relative frequency of width size class of riparian corridor, left bank, during PHA of Hinkson Creek. B. Relative frequency of width size class of riparian corridor, right bank, during PHA of Hinkson Creek.

The percent woody vegetation observed during the PHA on the left bank of Hinkson Creek is shown with stream distance in Figure 43. Contrary perhaps to expectations of urban land use, percent woody cover reaches a peak in the area between the confluence of Hinkson Creek with Hominy Branch and the Grindstone Creek confluence.

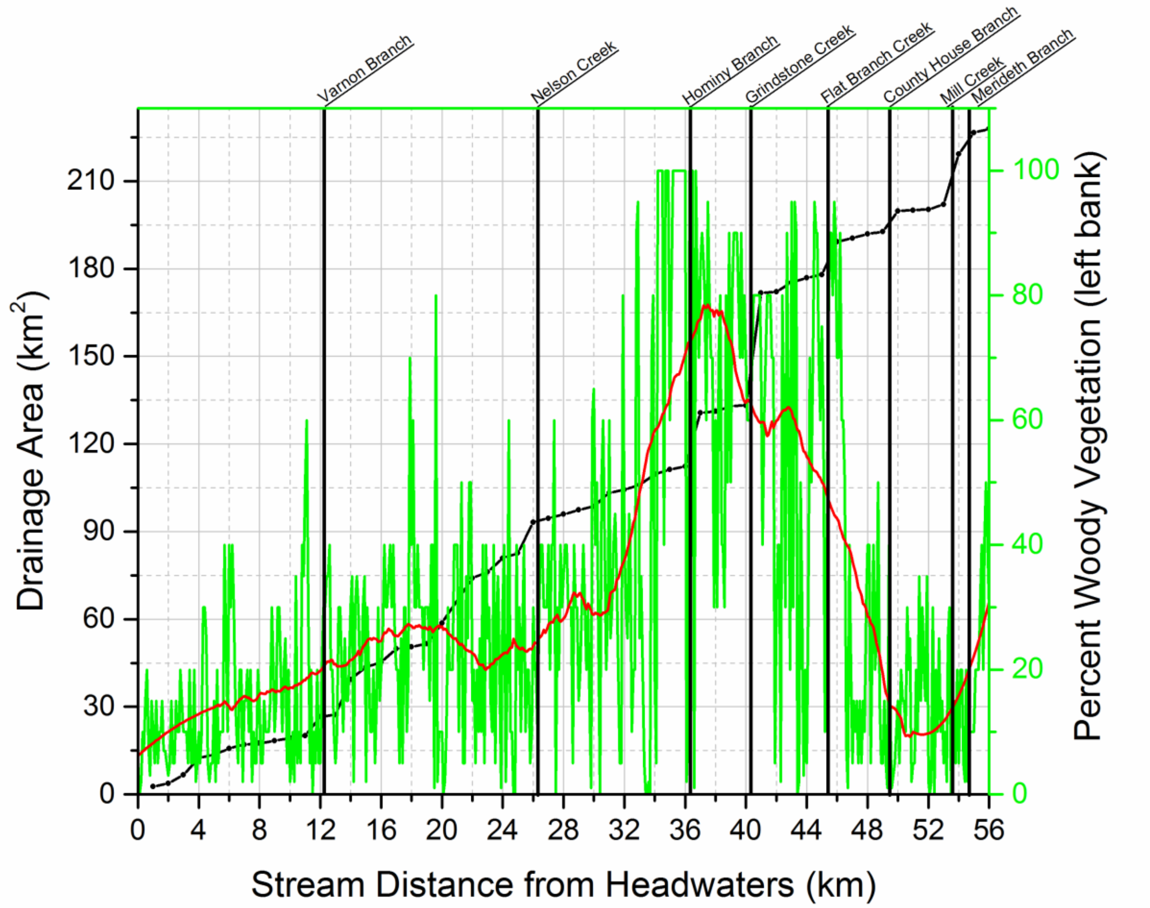

Figure 43. Percent woody vegetation on the left bank of HInkson Creek with stream distance and drainage area, as recorded during the PHA. 100 pt moving average is shown in red. Confluences with eight major tributaries are marked.

4.10 Wildlife and Cattle Presence

Given that *Escherichia coli* contamination has been an ongoing concern in Hinkson Creek (USEPA 2012) observations of the presence of wildlife or tracks of wildlife were made at the survey points and along the channel and streambanks between the survey points. The observations included the presence of cattle, cattle tracks or cattle feces. It is also known that multi-use watersheds can have a variety of sources of *E. coli* (Crim et al. 2012) so the presence of various types of wildlife was noted for future reference.

One of the major objectives of the wildlife survey was to improve quantitative understanding of the presence and variety of wildlife in or using Hinkson Creek and the adjacent riparian corridor. The data for presence of wildlife actually seen or inferred due to the presence of tracks in either the streambed or streambanks are presented in Figure 44. For the purposes of this graph, the number of sightings of a species within a category per kilometer was calculated, and then for many of the species, they were then grouped into categories presented in the figure. Deer and raccoon were left outside of other categories as the frequency of their sightings would have significantly skewed categorical results. Crayfish were not included in any category as they were the only types of macroinvertebrates sampled. Fish and amphibians sightings were numerous during the PHA of Hinkson Creek. Amphibians were observed at all life stages, but very few large fish were observed (a few gar longer than 10 inches, and several spotted bass longer than 8 inches). It is possible that the large fish were in the deep pools and were not visible due to the turbidity of the water in the pools.

Cattle tracks were observed in the upstream reaches of Hinkson Creek in the more agricultural area of HCW. Cattle were also physically observed, along with damage to streambanks from cattle migrations into the stream, cattle feces (some of which were floating in the stream). There are currently no county, state or federal regulations in place to prevent cattle ranchers who own land adjacent to Hinkson Creek from accessing the stream. To date, there have also not been any analyses of the animal origin of the *E. coli* strains found in Hinkson Creek. Identification of the origin of *E. coli* strain may be accomplished using a technique known as Microbial Source Tracking or MST (Lee et al. 2010, Lee et al. 2014).

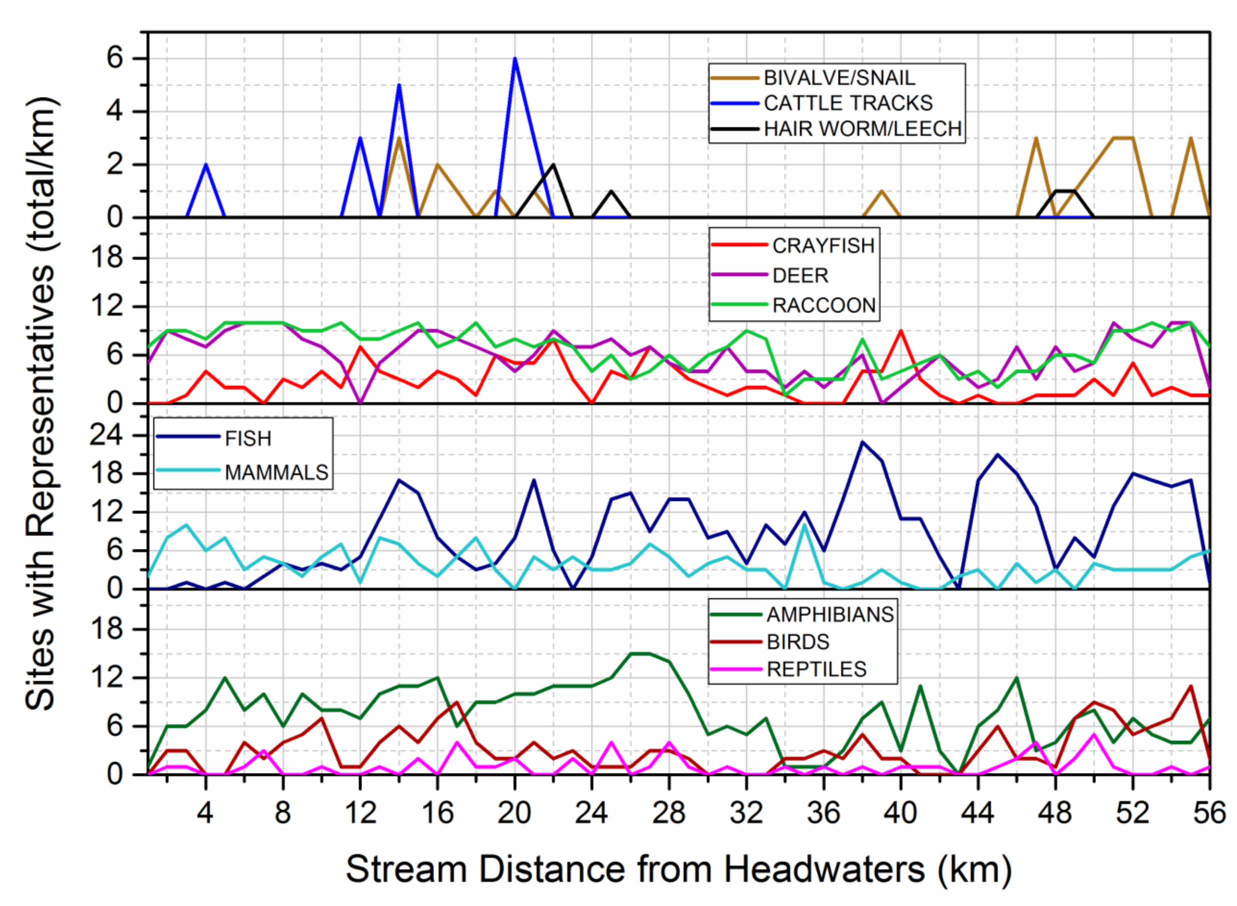

Figure 44. Categories of wildlife grouped by number of representatives sited per kilometer of stream distance along Hinkson Creek during PHA.

4.11 Longitudinal Variation in Stream Physical Habitat due to influence of LULC

During Phase I of the PHA in HCW, MoRAP conducted GIS analysis using aerial images and Digital Elevation Models to evaluate land-use and land cover in Hinkson Creek Watershed (see Phase I report, Appendix A). Data that were submitted in conjunction with the MoRAP report were used to create the LULC map shown in Figure 45. In addition, using the MoRAP data from Phase I, land-use and land cover percentages were calculated for the entire 56 km of Hinkson Creek at 1 km intervals (Table 19). Land-use and land cover data were not available for the two white spaces in Figure 45 (total area approximately 4 - 6 km^2). The land-use and land cover percentages were correlated with cumulative drainage area, making direct comparisons of physical habitat metrics with land-use difficult at a particular point in the stream (i.e. cumulative drainage area versus a static point in the stream). Additionally, attributing physical habitat characteristics at a point in the stream to the effects of upstream land-use is an oversimplification. At any given survey point, there were numerous complex interacting factors resulting in observed localized physical habitat. A calculation of the effects of land-use and land cover on stream physical habitat at the 1 km scale was not possible due to time constraints, and the second set of hypothesis were abandoned. Future analysis of the data from this study may reveal additional information about the relationship between PHA metrics and LULC with stream distance and/or drainage area.

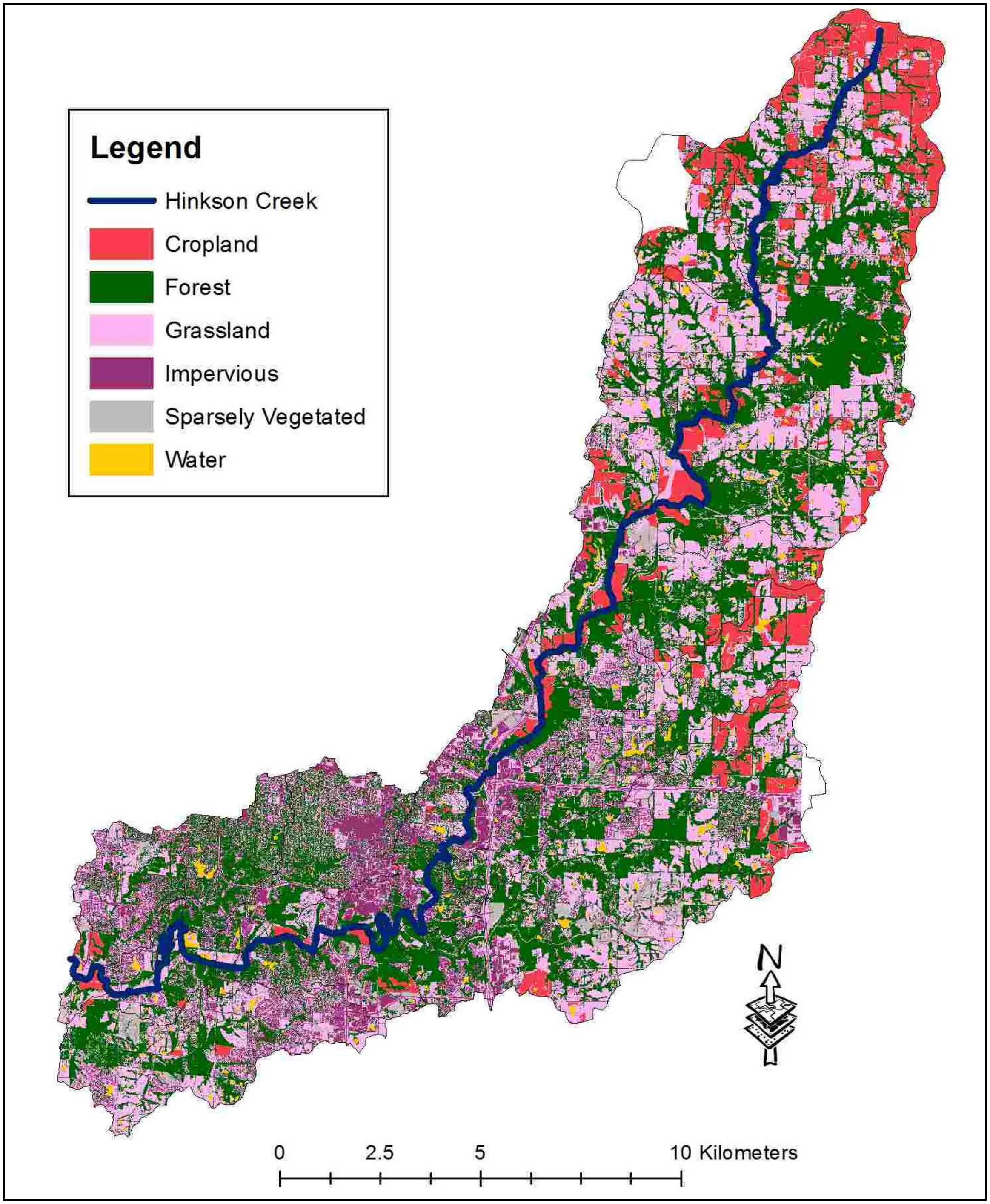

Figure 45. Land-use and land cover map of Hinkson Creek Watershed, using data provided by MoRAP during Phase I of the PHA. White spaces indicate absence of available LULC data for presentation.

The photographic database developed during Phase II of the PHA provided an opportunity to present a more qualitative perspective of the effects of land-use change on physical habitat in Hinkson Creek. The photographs that follow were selected to illustrate certain aspects of stream physical habitat that were repeatedly observed by the field team during the PHA of Hinkson Creek.

It is worth noting that some of the features observed in Hinkson Creek, for example dead trees that had fallen into the stream, occur naturally in streams that are not affected by human land-use changes (Cordova et al. 2007). Although streambank erosion and other hydraulic effects from large woody debris may appear to be undesirable for the benefit of aquatic biota, large woody debris in the stream channel has been observed (and was observed in Hinkson Creek) to create habitat for aquatic turtles, fish, and other species (Figure 46) (Cordova et al. 2007, Johnson et al. 2003).

Figure 46. Large woody debris in stream has created deep pools and habitat for aquatic turtles just downstream of Forum Nature Area in Columbia (coordinates not available).

Similarly, moving from the headwaters to the mouth of a natural stream unaffected by human land-use changes some degree of channel incision and streambank erosion would be expected based upon flow concentration and stream adjustment during natural hydrogeomorphological processes (for example the collapse of a sand stream bank during a natural flood event) (Piégay and Schumm 2003, Vannote et al. 1980). As there are no pre-human settlement (or previous data at all) PHA data available, it is not possible to quantify what portion of alterations to stream physical habitat in Hinkson Creek may be attributable to these and other natural processes in this complex system.

Effects of human land-use changes on stream physical habitat are generally observable beginning within 200 to 500 m downstream of terrestrial processes, as well as at the reach, catchment, and sometimes at river basin scales (Sponseller et al. 2001, Larsen et al. 2009). At times, in-stream physical habitat impacts are visible immediately adjacent (lateral) to land-use processes (Allan et al. 1997) which may be apparent in a few of the photographs presented below. Unless otherwise noted, all photographs are from the perspective of the photographer looking upstream, so that the left descending bank appears on the right side of the photograph. The discussion that follows is framed by tributary catchment basin, moving from the headwaters to the mouth of Hinkson Creek.

Varnon Branch (headwaters to 12.1 km downstream of headwaters)

Varnon Branch tributary catchment is at the uppermost reaches of Hinkson Creek. The catchment is 26.78 km^2, and percent land-use in Varnon Branch tributary catchment is as follows: forest 33.65%; crop (agricultural) 30.14%; impervious surface 1.79%; water 1.13%; sparse 0.15%; grass 33.14%. In addition to agricultural uses in Varnon Branch tributary catchment, there is also pastureland and grazing by local landowners. The pasture land-use was not separately designated by MoRAP as it would be difficult to ascertain using aerial images, but it is likely that some portion of the sparse vegetation and/or grass areas are used for pasture.

Hinkson Creek begins near a cornfield representative of the land-use in Varnon Branch tributary catchment (Figures 47A and 47B), and is barely more than a drainage ditch for the first few hundred meters. Channel incision and streambank erosion is observed 300 m downstream of the headwaters (Figure 48B) suggesting potential land-use effects on stream physical habitat from deforestation and agricultural land-uses in the uppermost reaches of HCW.

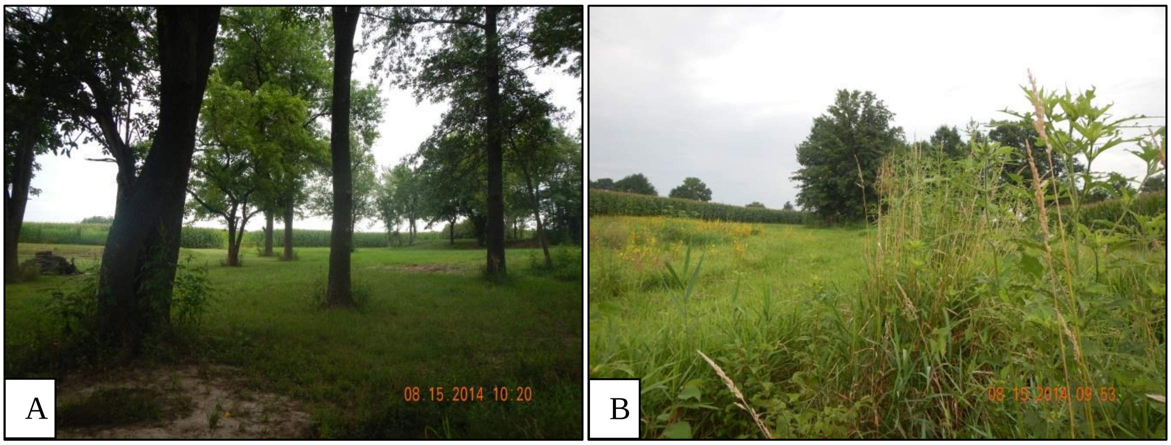

Figure 47. A. The headwaters of Hinkson Creek, as determined by GIS analysis performed by MoRAP during Phase I of the PHA (lat. 39.13039, long. -92.18058). B. 100 m downstream of the headwaters (lat. 39.129498, long. -92.180592).

Figure 48. A. The view 200 m downstream of the headwaters, during the "drainage ditch" portion of the stream's beginnings, 08-15-2014, 09:21 (lat. 39.128743, long. -92.180752). B. Channel incision is evident 300 m downstream of the headwaters on the left descending bank where tree roots are visible, 08-15-2014, 08:52 (lat. 39.127875, long. -92.180977).

Moving downstream from the headwaters, drainage area from the rural/agricultural land-uses upstream increases, and in-stream habitat effects of streambank erosion and channel incision become more apparent. Even in the upper reaches of the watershed at approximately 4.5 km downstream from the headwaters (drainage area roughly 13 km^2), increased streambank erosion may be the result of increased runoff, although definitive data are lacking (Figure 49A). Streambank erosion can lead to loss of trees from the riparian area as banks fail, and then the fallen trees themselves can further alter local hydrology (Figure 49B) (Nakamura and Swanson 1993).

Figure 49. A and B. View of the right descending bank approximately 4.5 km downstream of the headwaters, where streambank erosion has caused riparian trees to fall in to the stream, 08-06-2014, 11:21 (lat. 39.106112, long. -92.19592).

Nelson Creek (stream distance from headwaters 12.1 km to 26.1 km)

Nelson Creek tributary catchment is still in the primarily rural (agricultural – note the percentage of land-use designated as grass) reaches of Hinkson Creek. The catchment is 66.4 km^2, and cumulative percent land-use (including upstream land-use in Varnon Branch) in Nelson Creek tributary catchment is as follows: forest 42.05% (a 19.98% increase from Varnon Branch tributary catchment); crop (agricultural) 16.66% (a 44.72% decrease from Varnon Branch tributary catchment); impervious surface 2.86%; water 1.86%; sparse 0.95%; grass 36.38%. At the point furthest downstream in Nelson Creek tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 93.18 km^2, more than tripling the drainage area at the point furthest downstream in Varnon Branch tributary catchment. The volume of water draining into Hinkson Creek after a precipitation event would increase dramatically with the increased drainage area, resulting in increased flow volume and flow velocity.

At meanders in the stream, streamflow exerts more stress on streambanks (Azzola et al. 1986), and it is at the bends of Hinkson Creek that some of the most extensive and rapid change seems to be occurring. The next set of photographs was taken approximately 15 km downstream from the headwaters (drainage area between 43 and 44 km^2), near the central point in an "S" meander in Hinkson Creek (Figure 50). The section of streambank pictured is immediately adjacent to an extensive agricultural field, so the streambank erosion shown here is potentially due to a combination of upstream and lateral effects of land-use changes. The composition of the streambank in this location is largely sand which would not offer much resistance (lack of cohesiveness) to the effects of altered hydrology from upstream deforestation and agricultural land-uses (Geyer et al. 2001).

Figure 50. A view of the right descending bank adjacent to an agricultural field approximately 15 km downstream of the headwaters shows an incised streambank with ongoing mass wasting, 06-16-2014, 09:12 (lat. 39.055623, long. -92.218477).

Hominy Branch (stream distance from headwaters 26.1 km to 36.1 km)

Hominy Branch tributary catchment covers the area that transitions from the primarily rural reaches of Hinkson Creek into the length of the stream that passes through the City of Columbia. The catchment is 36.29 km^2, and cumulative percent land-use in Hominy Branch tributary catchment is as follows: forest 41.39%; crop (agricultural) 14.19%; impervious surface 5.71% (approximately a 50% increase from cumulative impervious surface area in Varnon Branch and Nelson Creek tributary catchments; the percent of impervious surface area in Hominy Branch alone is 14.98%); water 1.87%; sparse 1.50%; grass 35.34%. At the point furthest downstream in Hominy Branch tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 129.47 km^2 (an increase of approximately 39% from the furthest downstream point in Nelson Creek tributary catchment).

Near the rural / urban interface at the northern edge of the city limits of the city of Columbia (drainage area between 102 and 103 km^2), streamflow volume and velocity exerts sufficient shear stress to incise banks not made of sand, but composed of clay, gravel, and roots from riparian vegetation (Figure 51). Moving downstream into the city of Columbia, the additional cumulative effects from land-use will include less crop (agricultural) influence, and an increasing percentage of impervious surface area drainage concurrent with urbanization in the watershed.

Figure 51. View of the left descending bank of Hinkson Creek 1 km upstream from the bridge over Hinkson Creek at Mexico Gravel Road in northern Columbia, 05-16-2014, 12:39 (lat. 38.969027, long. -92.278697).

The interchange of Interstate 70 and Highway 63 was constructed with large quantities of impervious materials including concrete and asphalt, contributing to stormwater runoff directly into Hinkson Creek during precipitation events as the stream flows directly beneath both highways. Just downstream of the highway interchange, the stream is constrained by solid bedrock walls on the bends of an “S” curve in the stream channel (Figure 52). The bedrock constraints protect the streambanks from the erosional effects of the increased streamflow until approximately 2 km downstream of the highway interchange. At the location 2 km downstream of the interchange, upstream rural and urban land-uses from approximately 114.5 km^2 drainage area converge. For many years, adjacent runoff from a large parking lot and commercial complex (approximately 0.14 km^2) uphill from this area (detention ponds have been installed uphill of Hinkson Creek to capture overland flow from the impervious surface area) added to stormwater effects during periods of high flow. There is very little riparian vegetation in this area as observed on the left descending bank in Figure 53A, and the left descending streambank is very low (0.98 m). Although not pictured, riparian vegetation is also absent from the right descending bank as it was removed by the golf course landowner. Riparian vegetation is beginning to grow in the gravel bar in the center of the stream as shown in Figure 53B, suggesting that a new floodplain may be forming.

Figure 52. Just downstream of the I-70 and Hwy 63 interchange in Columbia, Missouri. These two photographs were taken approximately 300 m apart, and show the bedrock constraints on the left descending bank (12-03-2013, 13:04; lat. 38.960268, long. - 92.298872), and right descending bank (12-04-2013, 14:57; lat. 38.959427, long. - 92.300617), respectively.

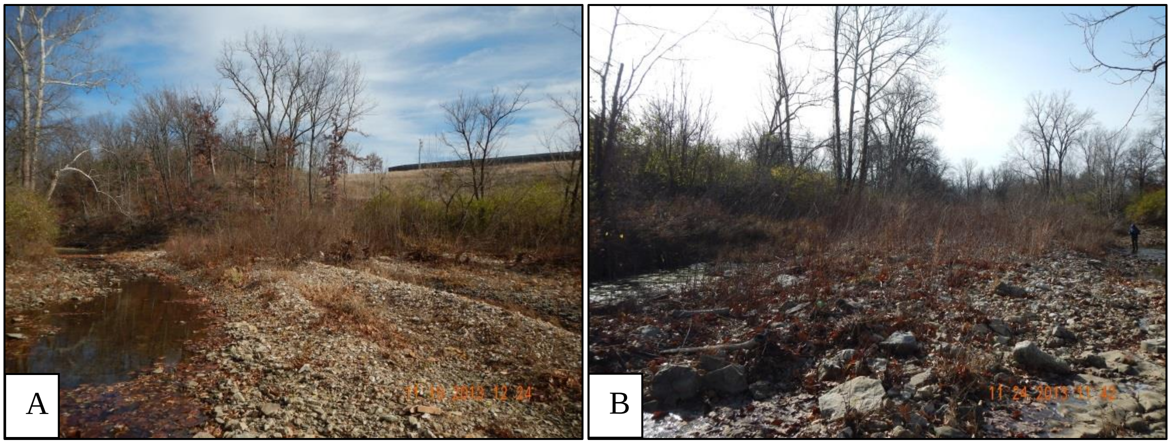

Figure 53. A. Looking upstream at the possible beginnings of a new floodplain in the center of the stream channel approximately 2 km downstream of the I-70 and Highway 63 interchange, 11-19-2013, 12:24 (lat. 38.955503, long. -92.299478). B. The view downstream from approximately the same position, 11-24-2013, 11:42 (lat. 38.955803, long. -92.296231).

In addition to terrestrial land-use practices in HCW having effects on stream physical habitat, there are a number of manmade structures in/across the stream which have likely contributed to alteration of stream hydrologic processes and in-stream physical habitat (for a discussion of the effect of bridges, see Paul and Meyer 2001). Three examples are presented here as Figures 54, 55 and 56. The first example is a bridge constructed to provide access from one side of a private golf course to the other less than 500 m upstream of the area shown in Figure 53. The bridge has in effect created a low-water dam with a pool on the upstream side, and may impede flow of the stream during periods of low or baseflow conditions (Figure 54). A second example is a rock wall constructed by a landowner on the left descending bank just a few hundred meters upstream of the bridge over Hinkson Creek at E. Walnut St. The intention of the rock wall was presumably to reduce streambank erosion and prevent loss of the landowner's property. However, the photographs indicate the observed effect of streambank erosion just downstream of the rock wall (Figure 55). The final example shows the replacement of riparian vegetation with riprap near a footbridge on the Hinkson Creek Trail constructed by the City of

Columbia, located between Broadway Street and Old Highway 63 (Figure 56). Riprap is frequently used near bridges in Hinkson Creek presumably to prevent streambank erosion at the hillslopes enhanced during bridge construction.

Figure 54. A bridge constructed by Columbia Country Club which owns the land on either side of Hinkson Creek approximately 300 m upstream of East Walnut Street in Columbia, Missouri, 11-24-2013, 14:06 (lat. 38.958472, long. -92.29949).

Figure 55. A manmade erosion control structure consisting of a rock wall on the left descending bank of Hinkson Creek, just upstream of East Walnut Street in Columbia, Missouri, and the streambank erosion and incision just downstream of the structure, 11-19-2013, 10:50 (lat. 38.953833, long. -92.300263).

Figure 56. A footbridge across Hinkson Creek between E. Broadway Street and Old Highway 63 on the Hinkson Creek Trail, 11-10-2013, 13:41 (lat. 38.946007, long. -92.306657).

Between E. Walnut Street (Hominy Branch tributary catchment) and the area just below the confluence with Grindstone Creek (Grindstone Creek tributary catchment), there are a number of bedrock constraints along Hinkson Creek which seem to mitigate the effects of land-use on some characteristics of in-stream physical habitat (Figures 57 and 58). The relative stability of some stream metrics in this section of Hinkson Creek may be attributable to the stabilizing effects of bedrock on the stream channel.

Figure 57. A. Looking upstream approximately 2 km downstream of E. Broadway St. in Columbia, with bedrock on the right descending bank, 11-07-2013, 12:01 (lat. 38.944068, long. -92.309618). B. Approximately 0.8 km upstream of Stadium Blvd. in Columbia, with bedrock on the left descending bank, 09-26-2013, 08:54 (lat. 38.935558, long. -92.308967).

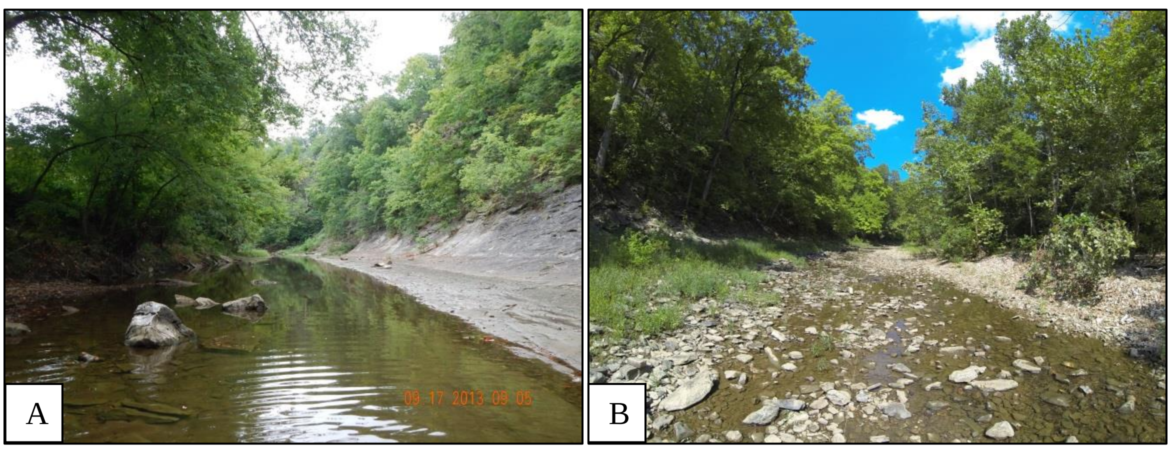

Figure 58. A. The view 2.4 km upstream of the Hinkson Creek and Grindstone Creek confluence, with bedrock constraints on the left descending bank, 09-17-2013, 09:05 (lat. 38.928952, long. -92.315007). B. The view just 0.8 km upstream of the Grindstone confluence, 09-10-2013, 13:49 (no coordinates available) – the forested bluff on the right descending bank is rooted in thin soil over bedrock.

Grindstone Creek (stream distance from headwaters 36.1 km to 40.2 km)

Grindstone Creek tributary catchment (Figure 1) lies in a primarily urban area of HCW, but Grindstone Creek tributary catchment contains approximately 51% less impervious surface area and 4.6% more forested area than Hominy Branch tributary catchment. Grindstone Creek tributary catchment is 41.23 km^2, and cumulative percent land-use in Grindstone Creek tributary catchment is as follows: forest 41.42%; crop (agricultural) 12.41%; impervious surface 6.72%; water 1.78%; sparse 2.27%; grass 35.41%. At the point furthest downstream in Grindstone Creek tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 170.7 km^2 (an increase of approximately 32% from the furthest downstream point in Hominy Branch tributary catchment).

The confluence of Grindstone Creek and Hinkson Creek is an impressive expanse measuring almost 50 m across at the widest point on Hinkson Creek upstream of the confluence. A bedrock cliff forms the left descending streambank downstream of the confluence, and the bedrock continues across the stream as the substrate in some areas near the confluence (Figure 59). The biodiversity observed at this confluence placed it among one of the “hotspots of biodiversity” along Hinkson Creek. During the initial survey of this area in September of 2013, the field team observed signs of deer and raccoon, hundreds of tadpoles and minnows, as well as bullfrogs, American toads, and numerous plant species in bloom.

Figure 59. A panorama of the confluence of Grindstone Creek and Hinkson Creek beginning at left descending bank of Grindstone Creek and ending with the view upstream in Grindstone Creek, 09-05-2013, 10:43 and 09-10-13, 08:28 (lat. 38.927533, long. - 92.321808).

Flat Branch (stream distance from headwaters 40.2 km to 45.7 km)

Flat Branch tributary catchment is the most urban area of HCW, and Flat Branch Creek starts underground beneath downtown Columbia. Flat Branch tributary catchment is 17.8 km^2, and cumulative percent land-use in Flat Branch tributary catchment is as follows: forest 41.29% (40.04% in Flat Branch tributary catchment itself); crop (agricultural) 11.47%; impervious surface 8.77% (Flat Branch tributary catchment standing alone has the highest percentage of urban surface area of any of the tributary catchments at 28.47%); water 1.65%; sparse 2.31%; grass 34.51% (the percentage of grass in Flat Branch tributary catchment is one of the two lowest in HCW at 25.86%). At the point furthest downstream in Flat Branch tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 188.5 km^2 (an increase of approximately 10.4% from the furthest downstream point in Grindstone Creek tributary catchment).

Although the photographic database contains many examples streambank erosion in Hinkson Creek, the photographs in Figure 60 are distinct in several ways. The bankfull width at the bend in these photographs is among the widest along the entire length of Hinkson Creek (maximum 74 m). At this point in the stream, the cumulative land-use effects include upstream rural land-use, some urban land-use runoff from urban development in the city of Columbia, some drainage from the University of Missouri – Columbia campus, and influx from the confluence of Hinkson Creek with Grindstone Creek approximately 3.4 km upstream. The bankfull width at this point in the stream is 64 m, and the cumulative drainage area is approximately 177.5 km^2. An aerial view of this bend (Google Earth) is shown in Figure 61.

Figure 60. Photographs showing the extent of bank erosion of left descending bank around bend in Hinkson Creek approximately 3.4 km downstream of the Grindstone confluence, 08-08-2013, 13:51 (lat. 38.923943, long. -92.3269).

Figure 61. A wide bend in Hinkson Creek located 3 km upstream of Providence Road and 3.4 km downstream of the confluence with Grindstone Creek in Columbia, Missouri.

This bend of Hinkson Creek is not bedrock constrained, and there are no natural or manmade barriers to prevent the stream from continuing to widen at the bend as high flow velocities (shear stress) carve out the left descending stream bank and deposition on the point bar on the right bank continues.

Flat Branch Creek carries much of the stormwater runoff from the impervious urban center to Hinkson Creek after precipitation events. The confluence of Flat Branch and Hinkson Creek is approximately 4.4 km downstream from Providence Road. As was discussed earlier in text, the physical habitat in Hinkson Creek downstream is greatly influenced by the Flat Branch confluence, which represents an inflection point in graphs in Chapter IV depicting changes in bank height, relative thalweg depth, and thalweg depth with stream distance from headwaters and increase in drainage area. Bank height, relative thalweg depth and thalweg depth all increase moving downstream from Flat Branch Creek. A few illustrations of the general shift in stream physical habitat downstream of the Flat Branch confluence follow.

County House Branch (stream distance from headwaters 45.7 km to 49.4 km)

County House Branch tributary catchment lies below the urban center of the City of Columbia, but drains residential areas that still have a large percentage of impervious surface area (17.55% in County House Branch tributary catchment standing alone). County House Branch tributary catchment is 10.29 km^2, and cumulative percent land-use in County House Branch tributary catchment is as follows: forest 41.92% (53.58% in County House Branch tributary catchment standing alone which is the highest percentage of forest in any of the tributary catchments in HCW); crop (agricultural) 10.88%; impervious surface 9.23%; water 1.75%; sparse 2.22%; grass

34.0% (the percentage of grass in County House Branch tributary catchment is the lowest in HCW at 24.72%). At the point furthest downstream in County House Branch tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 198.79 km^2.

Streambank erosion in the lower reaches of Hinkson Creek has led to clusters of riparian trees sliding into the stream as mass wasting and bank slumping occur. The loss of trees from the streambanks has several consequences for stream physical habitat. When the banks fail and the trees fall into the stream, they either remain in place where they may alter local hydrology (Figure 62A), or they may catch in the streambed and form snags which can become the beginnings of large debris dams as other fallen trees are transported downstream (Figure 62B). The altered hydraulics due to the fallen tree is the immediate cause of the mass wasting in Figure 62A.

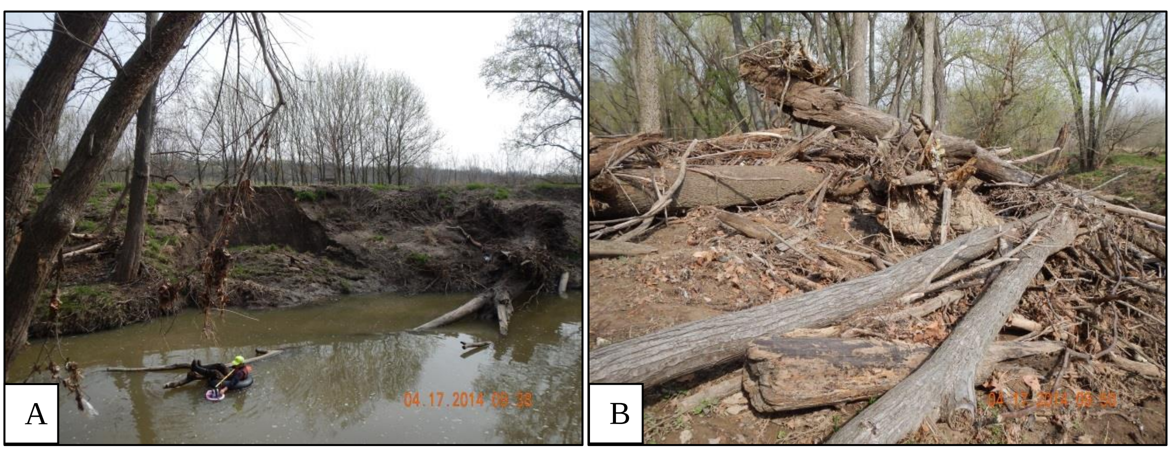

Figure 62. A. A view of the mass wasting on the right descending bank just downstream of Forum Nature Area in Columbia, 04-17-2014, 09:38 (lat. 38.922188,long. - 92.377815). B. A large woody debris pile on the left descending bank 20 m upstream from the bank failure in photograph A, 04-17-2014, 09:50 (lat. 38.921907, long. - 92.377642).

Mill Creek (stream distance from headwaters 49.4 km to 53.8 km)

Mill Creek tributary catchment drains large residential areas south and southwest of the City of Columbia, and has the highest percentage of grass of any of the tributary catchments (41.56% in Mill Creek tributary catchment standing alone). Mill Creek tributary catchment is 19.49 km^2, and cumulative percent land-use in Mill Creek tributary catchment is as follows: forest 41.41% (36.14% in Mill Creek tributary catchment standing alone, which is approximately a 48% reduction from County House Branch tributary catchment immediately upstream); crop (agricultural) 9.99%; impervious surface 9.75%; water 1.74%; sparse 2.42%; grass 34.68%. At the point furthest downstream in Mill Creek tributary catchment, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 218.28 km^2.

A wide bend in Hinkson Creek at approximately 51.8 km downstream of the headwaters (drainage area approximate 205 km^2) is an example of the cumulative land-use effects observed in the Mill Creek catchment. In the downstream view (Figure 63C), a bedrock wall has mitigated bank erosion at the outside of the bend, but erosion is visible in the remaining photographs (Figures 63A, 63B, and 63D). Large downed trees are observed, and the substrate is a thick silt and clay formed due to the loss of stream competence at this bend, causing suspended fine particles to deposit from suspension.

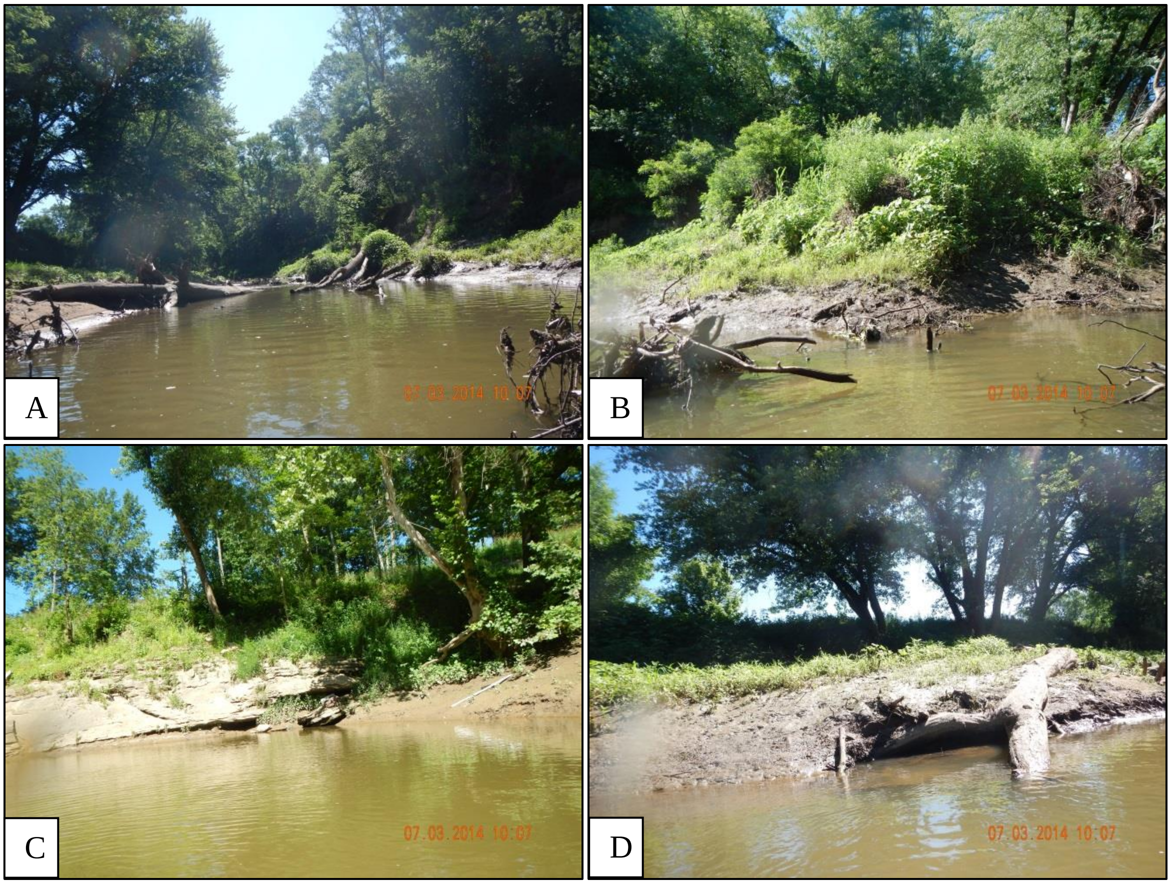

Figure 63. A selection of standard photographs taken at RP 84 during the PHA of Hinkson Creek, 07-03-14, 10:07 (lat. 38.92105, long. -92.389038): A) looking upstream; B) a view of the left bank; C) looking downstream; D) a view of the right bank.

Merideth Branch (stream distance from headwaters 53.8 km to 56 km)

Merideth Branch tributary catchment drains large residential areas southwest of the City of Columbia, but also has agricultural areas near the mouth of Hinkson Creek at Perche Creek (4.26% in Merideth Branch tributary catchment standing alone, a 426% increase from Mill Creek tributary catchment). Merideth Branch tributary catchment is 8.77 km^2, and cumulative percent land-use in Merideth Branch tributary catchment is as follows: forest 41.17% (35.33% in Merideth Branch tributary catchment standing alone, which is the lowest in HCW except for

Varnon Branch at the headwaters that contains 33.65% forest); crop (agricultural) 9.77%; impervious surface 10.14%; water 1.70%; sparse 2.40%; grass 34.81%. At the point furthest downstream in Merideth Branch tributary catchment at the mouth at Perche Creek, drainage area into Hinkson Creek as calculated in ArcGIS has increased to approximately 227 km^2, but the actual total drainage area of HCW is 4 to 6 km^2 higher (see blank spaces in Figure 45).

Physical habitat is very homogeneous in the lowest 2 or 3 km of Hinkson Creek before the mouth of the stream at Perche Creek. At this point along the stream distance, the substrate consists almost entirely of clay and silt, and observations in this area did not support habitat essential to support biodiversity of aquatic biota. Bank failure is common, and mass wasting and slumping have led to large sections of riparian corridor falling into the stream (Figure 64A). The process of mass wasting and slumping begins with a portion of the bank breaking away, as illustrated in Figure 64B.

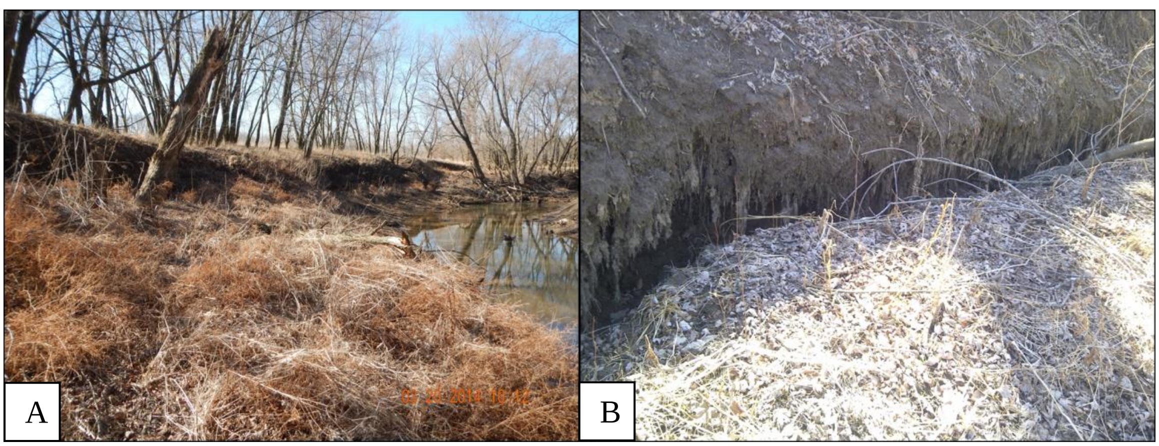

Figure 64. A. Looking downstream approximately 1 km upstream of the mouth of Hinkson Creek, 03-20-2014, 10:12 (lat. 38.9181, long. -92.408655). B. A crack at the top of the slumping bank shown in photograph A.

Qualitative analysis of the photographic database generated during the PHA suggests potential effects of deforestation and agriculture land-uses beginning in the upper reaches of the watershed, beginning at approximately 300 m downstream of the headwaters. The upper reaches of HCW were deforested and then used as cropland or pasture beginning approximately 200 years ago (Hubbart et al. 2010). As PHA data are not available as a baseline prior to the deforestation in the watershed, or at any point in time since the initial deforestation and conversion of crop and pasture lands, it is not possible to separate legacy effects of these initial land-use changes from in-stream physical habitat effects which are current and ongoing.

Although precise quantitative comparisons between LULC and stream physical habitat were not feasible based upon the results of this project, the physical habitat data and photographs indicate a general pattern of cumulative land-use effects moving downstream from the headwaters to the mouth of Hinkson Creek, particularly downstream of the city of Columbia. The observed channel characteristics in the upper reaches of the watershed are consistent with those documented in the literature as being attributable to land-use change: reduction of riparian corridor (Reid et al. (a) 2010); increased sediment loading (Stone et al. 2005); increased runoff (Hogg and Norris 1991) leading to increased streambank and channel erosion (Reid et al. (a) 2010). The observed land-use effects in the lower reaches of the watershed are similar to the effects of urban stream syndrome, discussed in the work of Walsh et al. (2005) among others.

4.12 Statistical Analysis of Resurveys and Recommendations for Future Surveys

Statistical accuracy of PHA measurements was examined by conducting resurveys on the 10th field day of every other site surveyed on the 1st field day (see *3.12 Statistical Analysis of Cross-Section Accuracy*). The results of the surveys (A values) compared to the resurveys (B values) are presented in box and whisker plots in Figure 65. The median value of each measurement is shown by the horizontal line through the box, and the mean value of each measurement is shown by the small box near the horizontal line. Outliers are denoted by asterisks. If the two sets of measurements were statistically different, there would be greater vertical distance between the larger boxes and the horizontal lines and small boxes. Based upon the analysis performed here (Student's T-test using Origin© software, OriginLab© Corporation, 2015), there were not statistically significant differences (p-value 0.05) in the measurements between the initial surveys and the resurveys of the same sites.

It was noted in the results section (see *3.12 Statistical Analysis of Cross-Section Accuracy*) that the initial survey points were not marked by flags or other means. In future PHA work in Hinkson Creek, it would be useful to mark survey points with stakes or other semi-permanent features so that recurrent surveys would occur at exactly the same points along the length of the stream.

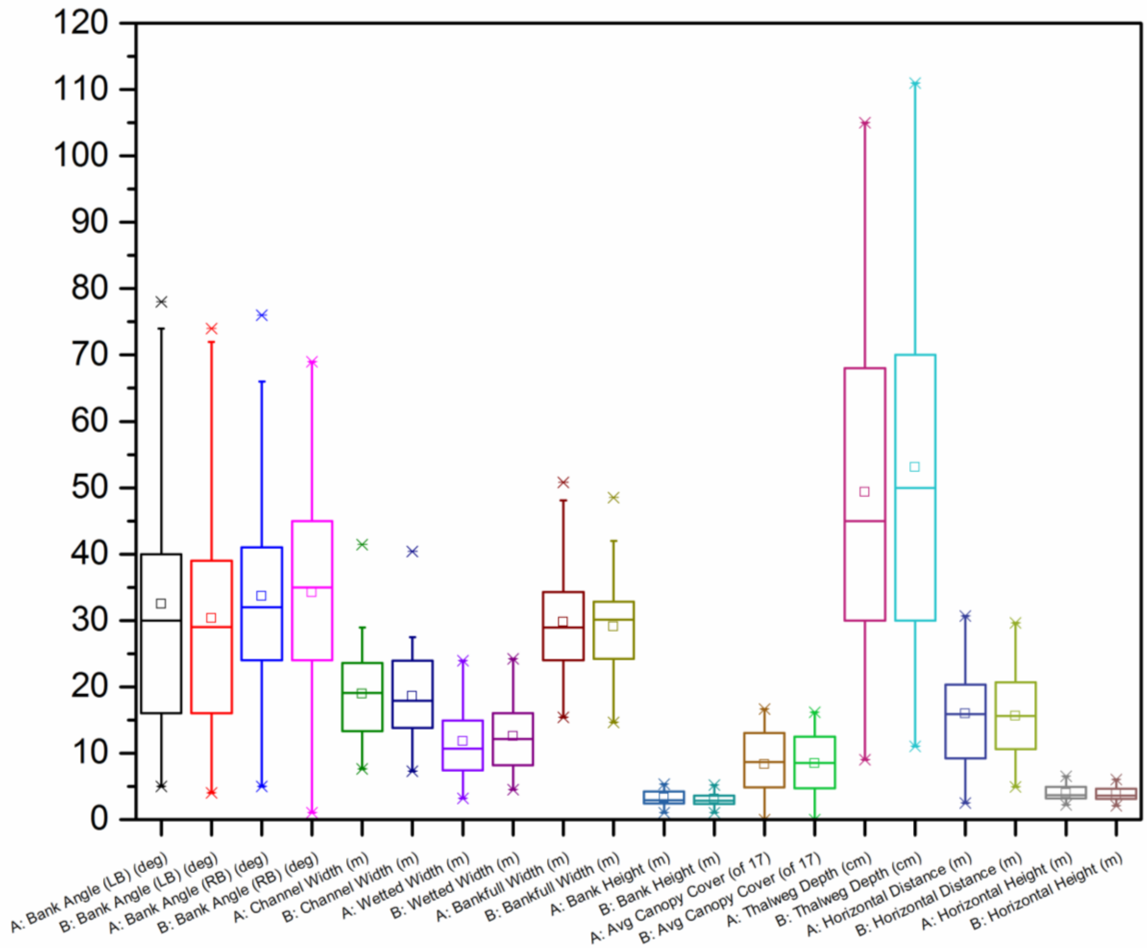

Figure 65. Box and whisker plot of comparison of initial survey metric (A) and resurveyed metric (B) at resurvey points of various measurements taken during PHA of Hinkson Creek.

4.13 Comparison of Observed Data to GIS Data

Due to the separately designed phases of this study, Phase I (GIS modeling) and Phase II (field observations in the current work), there were only two metrics that were directly comparable: center of the stream point location, and bankfull width at survey points. There were a number of calculations in Phase I that were not measured at all in Phase II, for example the width of the valley, the location of sand and gravel bars, and the location of the continuous centerline of

Hinkson Creek. Additionally, calculations were made in Phase I that were measured differently in the field during Phase II. One example of this is the location of the streambanks, determined in Phase I by the geographic location of the top of the streambanks, and during Phase II by coordinates taken at the bottom of the streambanks.

The purpose of comparing observed to GIS data was to validate some of the data generated by the Phase I MoRAP compiled data for HCW. The accuracy of the handheld GPS unit used by the field team was ±3 m. This range of accuracy explains the majority of the difference in the average distance between modelled and observed data. Other factors that may have affected the accuracy of the modelled and observed measurements include: human error (in both the modelling and observed scenarios), bank channel movement (the images and DEM files used by MoRAP predate at least one significant flooding event on Hinkson Creek in May of 2013), and interference with GPS satellite signal by land forms, weather, or the fact that the field team was down in the stream channel (for the point comparison).

CHAPTER V

CONCLUSIONS

The data collected during the field component of the PHA highlight irregular longitudinal variations in stream physical habitat in Hinkson Creek that are numerous and complex. Geologic processes have been at work in the HCW since glacial retreat, and include lateral cutting of the stream through the surrounding landscape, and channel incision in the lower reaches of the watershed, both as an adjustment to the dropping elevation of the bed of the Missouri River (Tarr 1924). These geologic processes may have set the stage for more recent effects from land-use changes or physiographic changes due to backwater from the Missouri River (see Knox, 2006). Legacy effects in the watershed from human land-use alterations 200 years ago may or may not also still be causing changes in stream hydrogeomorphology (see Allan, 2004). Additionally, this study and others in the HCW suggest that multiple land-uses in the watershed continue to alter stream hydrology, particularly the potential effects of urban stream syndrome downstream of Columbia (see Walsh et al. 2005), including the timing and velocity of stream flows, and the sediment regime. The PHA conducted for this study is only one data set during one window of time.

The increase in bank height and thalweg depth with stream distance below the confluence with Flat Branch Creek (below the City of Columbia) stand out as possible examples of land-use effects on stream physical habitat (e.g. urban stream syndrome). However, this analysis is complicated by complex processes in Hinkson Creek, including floodplain sedimentation from Missouri River backwater. However, increased bank height, deeper stream depth, and clay substrate are likely indications of some of the effects of urban stream syndrome (Walsh et al. 2005) in Hinkson Creek, in addition to the disconnected floodplain (channel incision), and reduced habitat heterogeneity observed below the City of Columbia. Other examples of stream habitat features in Hinkson creek that may be the result of human land-use changes discussed in the text include long trench pools with fine substrate, and a higher percentage of fines and sand as sampled substrate particles rather than loose gravel beds preferred as habitat by many macroinvertebrate and fish species.

Although heterogeneity of habitat for small aquatic organisms has potentially been reduced, Hinkson Creek and the adjacent riparian corridor are still being used by numerous terrestrial and aquatic species. Hinkson Creek is on the 303(d) list of impaired waters for failure to fully support aquatic life, namely certain taxa of macroinvertebrates that are expected to be found in a biologically stable stream. A review of the data from this PHA might suggest that hydrogeomorphological changes have altered ecological function in Hinkson Creek, specifically the physical habitat available for aquatic biota, but additional studies are needed to inform a more complete understanding of complex interacting water quality issues. The data from this study also shows that there are many species of wildlife that still make use of Hinkson Creek and the adjacent riparian corridor, in spite of macroinvertebrate impairment.

The data collected in this research are the first of such information generated in Hinkson Creek. Methods are scalable, and transferrable to other watersheds, and results have applicability for land-use managers and agency planners in the Hinkson Creek Watershed, and elsewhere. Notably, while highly informative, these results will be greatly enriched by ongoing future Physical Habitat Assessments (i.e. repeated surveys) recommended at 3 to 5 year intervals to enable identification of key impacts (e.g. climate, development, engineered structures, etc.). The photographic and numeric databases can be used to identify potential locations of previous, current or future hydrologic disturbance, and may indicate sites that would benefit from conservation or restoration efforts. The large dataset generated by the PHA is an invaluable resource for current, ongoing and future management activities and policy initiatives in the Hinkson Creek Watershed and provides a rich baseline that will be valuable for future assessments.

Stream restoration in Hinkson Creek is problematic. The first question that arises is if Hinkson Creek is restored, then to what set of conditions? Restoration to natural conditions pre-human settlement is impossible, and because there are not data to use as a baseline of the pre-human settlement condition, we don't even know what that means. To further complicate matters, as legacy effects cannot be separated from ongoing degradation, it is not known whether the stream has finished adjusting from the initial deforestation in the watershed 200 years ago, or from the lateral cutting and incision which began after glacial retreat.

The problems associated with stream restoration in a multi-use watershed are not unique to Hinkson Creek. Hinkson Creek is typical in a number of ways to similar multi-use watersheds worldwide. At this point in time, there are not sufficient data to inform a sufficient understanding of all of the hydrogeomorphological (and hence ecological) functions of Hinkson Creek. For example, future research could connect geologic formations and structure with the data from this (and future) PHA work in Hinkson Creek to formalize the theory presented as to bedrock constraints limiting movement of the channel in HCW. If it is known that bedrock acts as a physical constraint in Hinkson Creek, limiting the land-use effects in certain reaches of the stream, then land-use managers and agencies could focus efforts on restoration of areas that are not constrained by bedrock. Future work in the HCW should include modeling and data from future physical habitat assessments used in combination with GIS or other methodology to advance understanding of the progress of changes in the watershed and how land-use changes impact physical and biological processes in mixed-land-use watersheds.

CHAPTER VI

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CHAPTER VII

APPENDICES

Appendix A: PHA Phase I Report to CAM Stakeholder Committee (MoRAP)

Hinkson Creek Watershed Restoration Project

Collaborative Adaptive Management (CAM)

Physical Habitat GIS Data Development Technical Report

July 31st, 2013

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1 Executive Summary

As part of the Hinkson Creek Restoration project we used GIS and Remote Sensing techniques to create basic information on the geomorphology of Hinkson Creek and the distribution of land cover within the valley and watershed. Basic input data including air photos, LiDAR, a stream center line, and fine spatial resolution land cover for about 75% of the watershed were provided by partners (Boone County and City of Columbia). Staff from our partners also viewed progress and provided input on interim products so that modifications could be made at regular intervals. The Hinkson Creek Restoration team partners (Boone County, City of Columbia, and University of Missouri) will use this information for a variety of initiatives, including selection of field data sampling sites and stand-alone analyses such as the influence of land cover on the geomorphology and biology of the stream. The information is fine-resolution, and will serve as input for analyses at multiple scales of resolution.

Data sets developed include: (1) stream centerline update, (2) spatially explicit points at multiple intervals on centerline of stream, (3) bankfull boundaries on the stream, (4) valley boundaries along stream, (5) new fine spatial resolution land use/landcover for 25% of study area, (6) attribution of physical data to stream points at multiple scales (i.e., LULC composition, bankfull width, valley width, slope, sinuosity, and distance to valley wall), (7) sand/gravel bar delineation, and (8) Hinkson Creek road crossings.

2 Data Development

2.1 Introduction

Missouri Resource Assessment Partnership (MoRAP) was contracted to create a number of geospatial datasets, requested by the Hinkson Collaborative Adaptive Management (CAM) Science Team, that would aid in the analysis of the physical, ecological, and geomorphic conditions of the Hinkson Creek watershed and its eight main tributaries. The study area extends from the headwaters of Hinkson Creek to its confluence with Perche Creek and includes the following watersheds: County House Branch, Flat Branch, Grindstone Creek, Hinkson Creek, Hominy Branch, Merideth Branch, Mill Creek, Nelson Creek, and Varnon Branch (Figure 1).

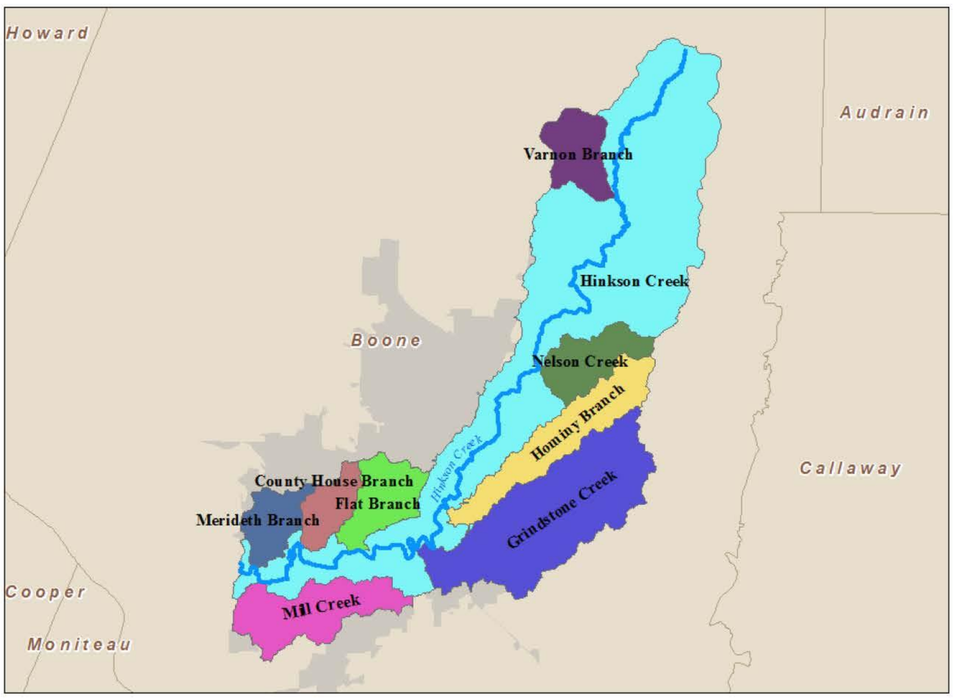

Figure 1. Watersheds that define the study area cover much of the Columbia metro area in central Boone County, Missouri.

2.2 Data collaboration

Boone County and the City of Columbia shared critical geospatial data with MoRAP (Table 1). The shared data was to be used only for this project and a GIS data agreement was signed prior to receiving data from the City of Columbia and Boone County.

2.2.1 Data Used

Table 1. List of GIS data provided by partners to develop physical habitat products.

Data Name	Source	Description	Use
2009 1' DEM	Boone County	Digital elevation raster model derived from 2009 LiDAR data	stream centerline update, bankfull, valley delineation, sand and gravel bar delineation, and % slope
2009 1' Hill Shade	Boone County	Hill Shade raster derived from 2009 1' DEM	stream centerline update, bankfull, valley delineation, sand and gravel bar delineation, and % slope
Hydro_lines	Boone County	Hydrography lines based on 2007 Ortho-imagery	Source for Hinkson Creek centerline, though centerline was updated by MoRAP.
2011 6 inch Leaf-off Aerial Photography	Boone County	6 inch leaf-off true color aerial photography	Stream Centerline update, Sand and Gravel Bar Delineation, MoRAP LULC, Hinkson Road Crossings
2007 Natural Resources Inventory (NRI)	City of Columbia	6 class vector Land Use/Land Cover data set for City of Columbia	Used to determine LULC and impervious surface composition throughout study area. Used as training data source for MoRAP LULC of study area not covered by NRI.
Watersheds	City of Columbia	Watershed vector layer used to define study area	Study area delineation and LULC statistics
2010 1 Meter Leaf-on 4 band CIR NAIP	MSDIS	2010 1 Meter Leaf-on 4 band CIR NAIP. Used original, non-compressed, quads.	MoRAP LULC

2.3 Subject Matter Expert/Science Team Collaboration

Multiple meetings with subject matter experts Dr. Robb Jacobsen - United States Geological Survey, Dr. Paul Blanchard – Missouri Department of Conservation, and Dr. Jason Hubbard – University of Missouri, were conducted to identify GIS data products that would be useful to the overall Hinkson Creek restoration effort. Additionally, meetings with a wider audience were held to review GIS data during the data development process to ensure that the data was on track with what was requested and that everyone had similar expectations. By working in a collaborative manner and conducting meetings throughout the data development process, expert information helped to improve the final products.

2.4 Data Development Methodologies

2.4.1 Study Area Extent

The study area consists of 57,338 acres in central Boone County, Missouri and is centered on Hinkson Creek. The following watersheds are included: County House Branch, Flat Branch, Grindstone Creek, Hinkson Creek, Hominy Branch, Merideth Branch, Mill Creek, Nelson Creek, and Varnon Branch (see Figure 1).

2.4.2 Projection

The standard projection used for all datasets was Missouri State Plane Central, NAD 83, FIPS 2402, US Survey feet. Distances in tables should be assumed to be feet unless otherwise noted.

2.4.3 Stream Centerline Update

The Hinkson Creek stream centerline (Hydro_Lines) provided by Boone County was based on 2007 ortho-imagery and upon visual inspection, discrepancies between the centerline and stream channel in the 2009 LiDAR hillshade (provided by Boone County) and the 2011 6 inch Leaf-off aerial photography (provided by Boone County) were noticed. As a result, MoRAP manually edited the Hinkson Creek stream centerline at a 1:1000 scale to reflect its location based on 2009 LiDAR hillshade and the 2011 imagery (Figure 2). Upon editing, it was discovered that there were locations where the LiDAR and imagery did not match due to bank and stream channel changes between 2009 and 2011. In these situations the stream centerline was modified to more closely reflect its location in the LiDAR, which was used to develop several other datasets.

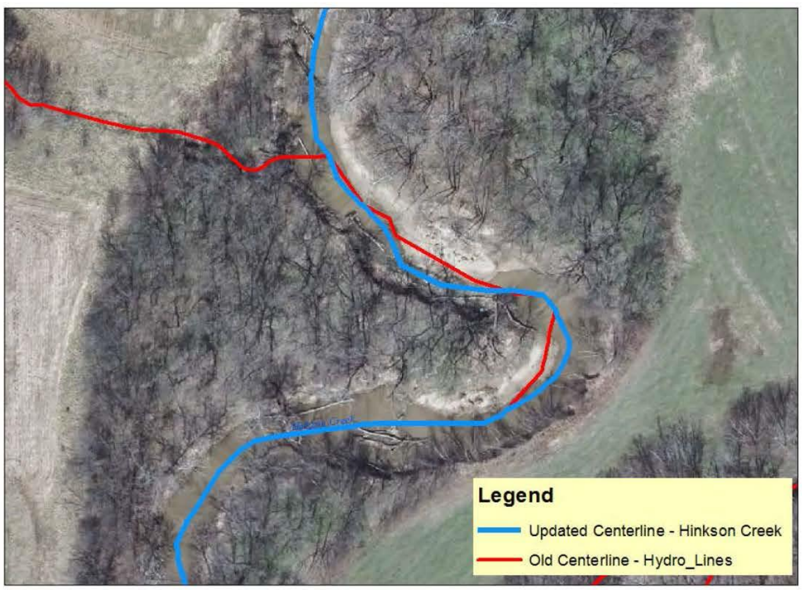

Figure 2. The centerline for Hinkson Creek was updated (blue) in places where old line work (red) did not reflect stream conditions in 2011.

2.4.4 Top of Bank/Bankfull

A bankfull or top of bank dataset was created to identify where the slope break between the stream channel and floodplain exists. It should be understood that 'top of bank' as determined via GIS data may not represent bankfull, due to possible down cutting of the channel and limitations of the spatial resolution of the imagery.

Several methods of delineating bankfull were explored, including the automated River Bathymetry Toolkit (RBT). The data for our study area proved to be too cumbersome for the RBT and the results on sample areas were not satisfactory. We were able to develop a straightforward and effective method of delineating bankfull. Image objects/polygons were created for a buffered extent of the Hinkson Creek centerline on the 2009 1 foot LiDAR DEM and slope derived from the DEM, using Ecognition software. Polygons were generated to encompass textural, tonal, and/or statistical homogeneity, thus delineating features with similar elevation and slope values to circumscribe bankfull based on these criteria. Due to file size restrictions, the study area was divided into 22 tiles and image objects were created for each tile. The image object tiles were merged together to create one file encompassing the total study area.

Polygons that delineated top of bank/bankfull were manually selected, at a scale of 1:1000, where steep slope breaks between the floodplain and stream channel occurred (Figure3). There was an effort to select the polygon line that was on the floodplain or top side of the slope break, as the slope break is actually part of the bank and not the top of the bank. Two foot elevation contours were also used to aid in top of bank/bankfull delineation where one bank was higher than the other, especially in cases where one of the banks was a bluff or high valley wall. In these instances the elevation on the lower bank was used to determine where the bankfull line should be placed on the higher bank.

Image objects were based on raster data, resulting in squared and pixelated looking polygons, so a smoothing technique was applied to the polygons after bankfull delineation was complete (Figure 3 A and B). The polygon shapefile was smoothed in ArcMap using the PAEK smoothing algorithm with a 25' tolerance and all other defaults were retained. This smoothing technique was also applied to valley boundaries and sand/gravel bar boundaries, which were similarly developed using image objects based on raster data.

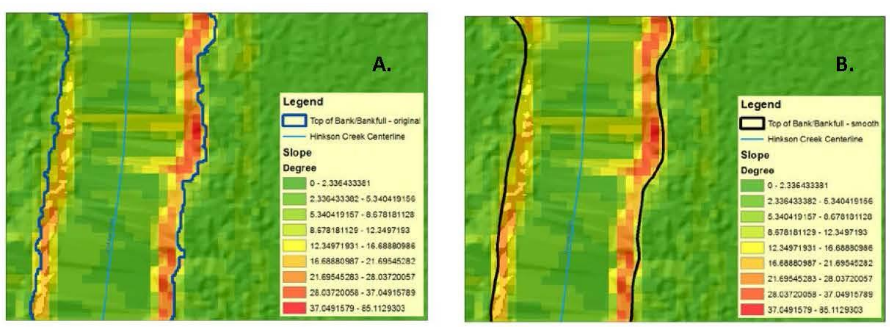

Figure 3. A) The original, pixel based polygon delineation of bankfull where the surrounding valley begins to slope down into stream channel. B) Smoothed bankfull polygon.

2.4.5 Valley Delineation

The initial Hinkson Creek valley delineation concept aimed at defining the stream valley from "bluff to bluff", including the entire bottomland area and all recent as well as ancient terraces. After initial review with subject matter experts it was determined that this was a broad definition of the valley, which should be retained, but a more constricted "modern floodplain" version of valley should also be delineated (Figure 4). The constricted modern floodplain concept attempts to limit the delineation to more recent terraces subject to flooding during high flow events in the modern landscape. Delineation of the modern floodplain is based on more subtle elevation changes as well as accounting for man-made features such as roads, bridge abutments and levees. Thus, the delineation of the modern floodplain was quite subjective, however one person did all of the delineation to ensure consistency, and results were viewed and vetted via our expert panel.

FEMA floodplain data was not used to delineate the valley for Hinkson Creek. The FEMA dataset was developed to identify flood hazards and will be a useful tool in further analysis. The valley bottom datasets created were intended for assessment of distance to non-erodible boundaries, width of alluvial materials, as well as backwater effects of bridges and constrictions; and should not be used for flood hazard assessment.

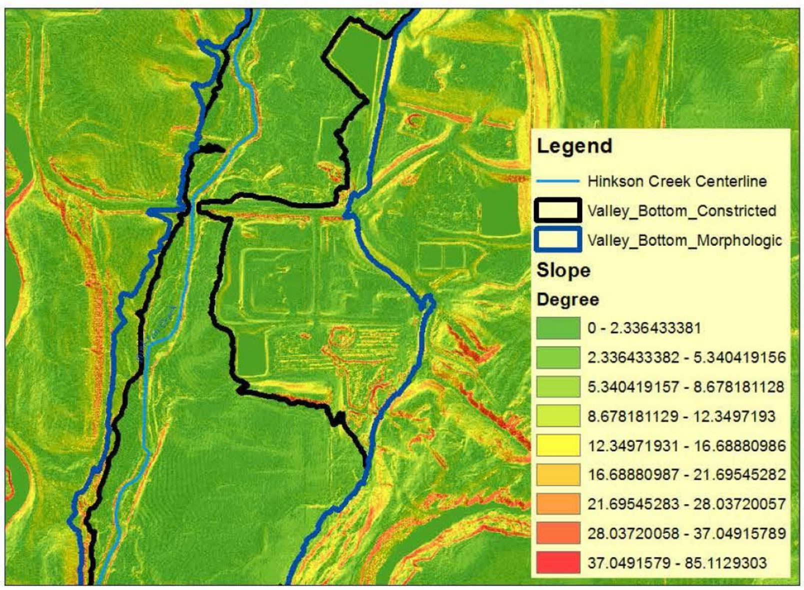

Figure 4. Location within the valley where constricted (black) valley is narrowed due to levee and road build. Morphological valley (blue) is considerably wider in some areas.

2.4.5.1 Morphological Valley Delineation

The morphological boundary broadly defines the bottomland between bluffs (Figure 5). The same image objects created for top of bank/bankfull were used to delineate the morphological boundary. Image objects that intersected with alluvial bottomland/valley soils were selected and attributed as an initial selection of valley polygons. The valley was further refined using a subjective manual process, generally at a scale of 1:1000. The image objects were compared against the 2009 1 foot LiDAR hillshade and slope to identify the boundary of the valley. Ideally the valley boundary was at the bottom of a slope or valley wall with a distinct slope break to an area with a much higher elevation than that of the surrounding valley. However, the majority of the time a subjective call had to be made on a more subtle slope break where no distinct valley wall or bluff existed. In areas with more subtle valley breaks the valley boundary line was drawn at the bottom of ditches formed due to erosion, which is a sign of sloping terrain.

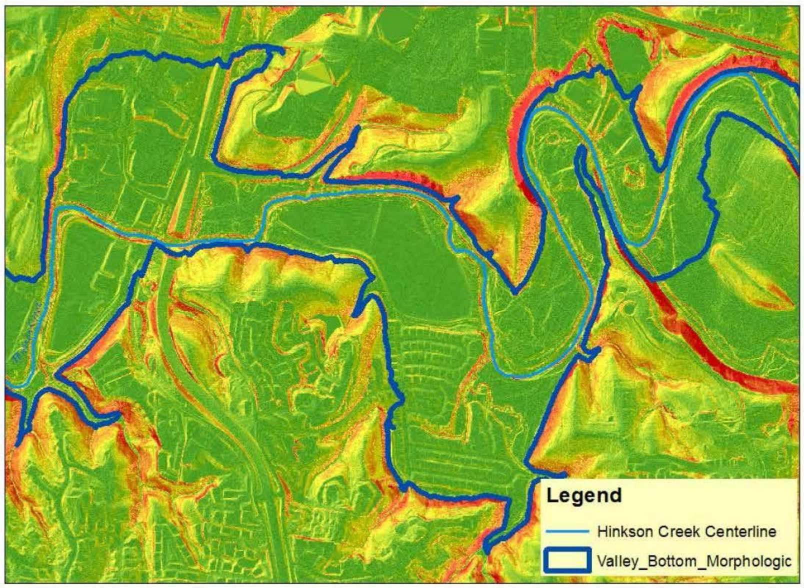

Figure 5. Morphological valley delineating bluff to bluff boundary.

2.4.5.2 Constricted Valley Delineation

The constricted valley is often defined by anthropomorphic impedances, such as roads, bridges, trails, levees, neighborhoods, etc. The same image objects generated for top of bank/bankfull and morphological valley boundary were used to delineate the constricted valley (Figure 6). The morphological boundary was modified to create the constricted valley boundary by constraining the boundary to bridge abutments, built up road and trail corridors, levees, built up residential and commercial developments, and more gentle inflections within the landscape. This process was also a manual and subjective process at an average scale of 1:1000.

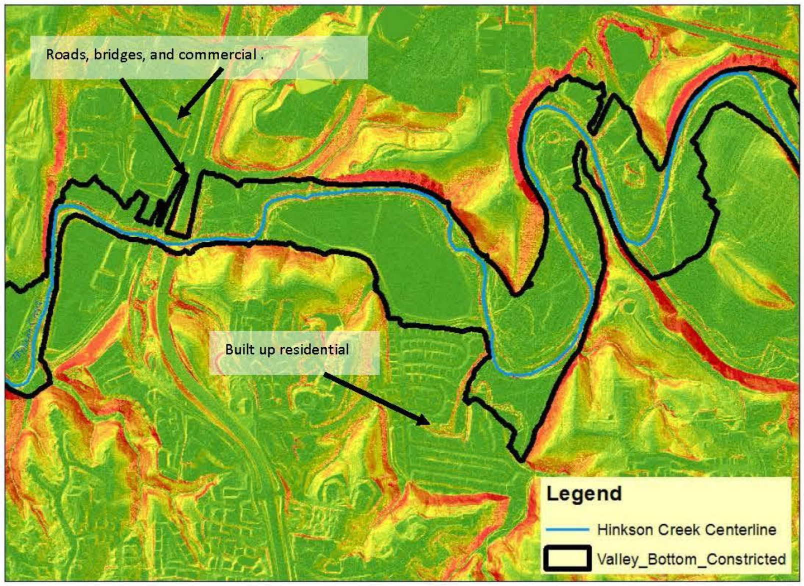

Figure 6. Valley is constricted due to roads, bridges, and built up residential and commercial properties.

2.4.6 Sand and Gravel Bar Delineation

Sand and gravel bars within Hinkson Creek channel were delineated based on 2011 6 inch 3-band true color leaf off aerial photography, provided by Boone County (Figure 7). Image objects were generated based on the 2011 photography using Ecognition software. Due to file size restrictions, the imagery was divided into seven tiles and image objects/polygons were generated based on the textural and tonal homogeneity of the imagery. The image object tiles were merged into a single file for sand and gravel bar delineation. Polygons that circumscribed sand or gravel bars were manually selected and modified, at a scale of 1:1000, as needed by scanning the entire length of Hinkson Creek from the confluence to the headwaters. No distinction between sand versus gravel bars was possible due to limitations of the imagery. Accordingly, the resultant dataset is a record of sand or gravel bars that existed in the spring of 2011.

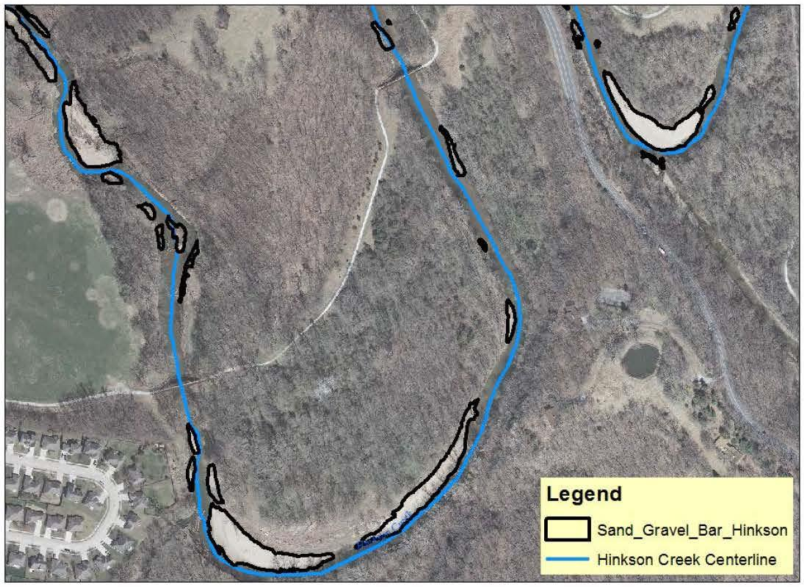

Figure 7. Sand and gravel bars were identified based on 2011 6" true color leaf-off imagery.

2.4.7 LULC

Land Use/Landcover (LULC) was used to determine the composition of vegetation and impervious surface within the study area. LULC from the City of Columbia's 2007 Natural Resources Inventory (NRI), a 6 class vector LULC based on 2007 6 inch 4-band leaf on aerial photography, covered approximately 75% of the study area within the metro area. The remaining 25% of the study area, mainly north of the city of Columbia, was not covered by high spatial resolution LULC. MoRAP developed a NRI-like LULC to fill in the gap (Figure 8).

The MoRAP NRI-like LULC is based on 2011 3-band leaf off imagery (provided by Boone County), 2010 4-band leaf on imagery, 2009 LiDAR DEM derivatives: slope and aspect, and a LiDAR digital surface model (DSM). All datasets used in classification were resampled to 1 meter spatial resolution. A supervised classification approach was employed to match the 6 NRI LULC classes (forest, grass, impervious, sparsely vegetated, crop, and water). A total of 3,000 training samples from the NRI dataset, 500 per class, were used to map LULC in raster format. Image objects were generated, using Ecognition software, based on the 2011 and 2010 imagery, to approximate the shapes and sizes of the NRI polygons. Each polygon was attributed with the majority LULC value based on the raster LULC dataset. The NRI and MoRAP NRI-like LULC datasets were merged together to create a seamless high spatial resolution vector LULC dataset that covers over 99% of the study area (Figure 9). There was approximately 100 acres not covered by LULC due to lack of data at the time of classification.

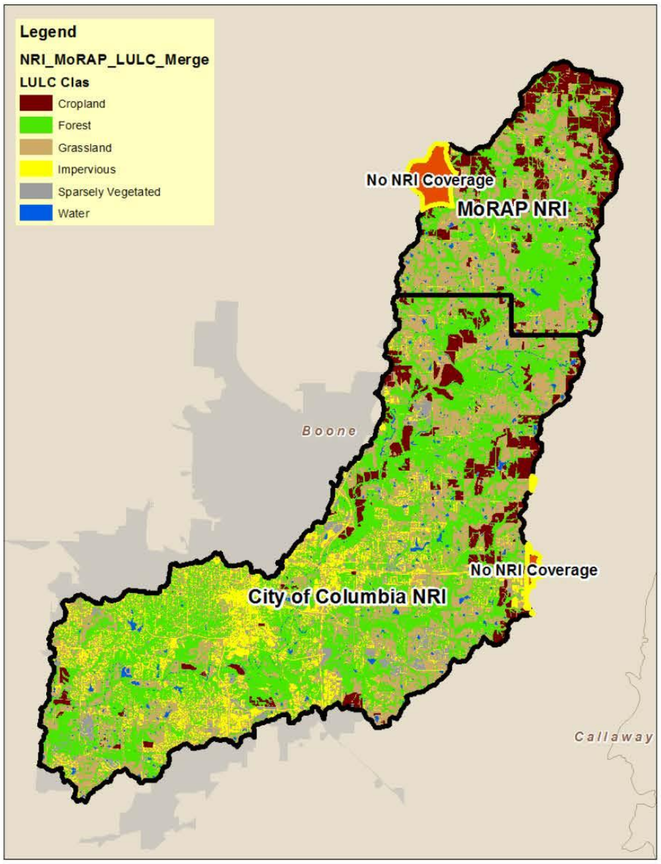

Figure 8. MoRAP created NRI-like LULC for the northern portion of the study area. The areas in red indicate where no LULC exists.

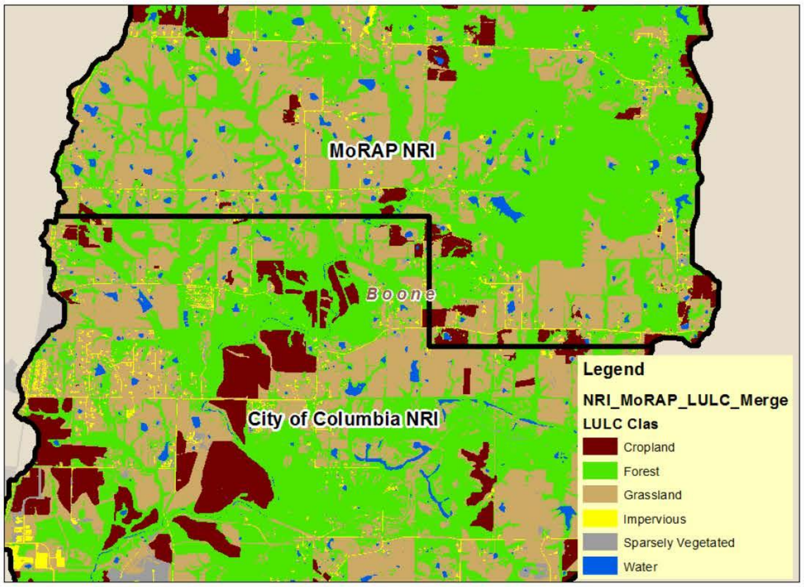

Figure 9. The addition of the MoRAP created LULC provided a virtually seamless LULC for the study area.

2.4.7.1 Thiessen Polygon LULC Summary

Thiessen polygons represent areas or zones around a set of points where any location associated with a given point is closer to that point than any other point. A set of thiessen polygons was generated for each set of stream points in order to associate the surrounding LULC with a spatially specific location within the stream based on the point's unique identifier. The polygons were clipped to both the morphological and constricted valley boundaries and LULC composition was summarized (total area and % area of each class) for every polygon within each dataset, resulting in 2 sets of polygons for each stream interval. A caveat to comparing LULC values for a given point is that the size of the area within polygons associated with any given point can vary greatly. The shorter the stream centerline interval between points, the more varied in size the area within polygons. Variation leveled off at 500 meters of stream centerline distance between points. Polygons based on 50 meter interval stream points have a coefficient of variance (CV) of roughly 0.91 (Figure 10) and become less variable at 500 meters, where CV was 0.49 (Figure 11), with the lowest CV of 0.41 occurring at 2000 meters. LULC composition was also summarized for each of the major watersheds.

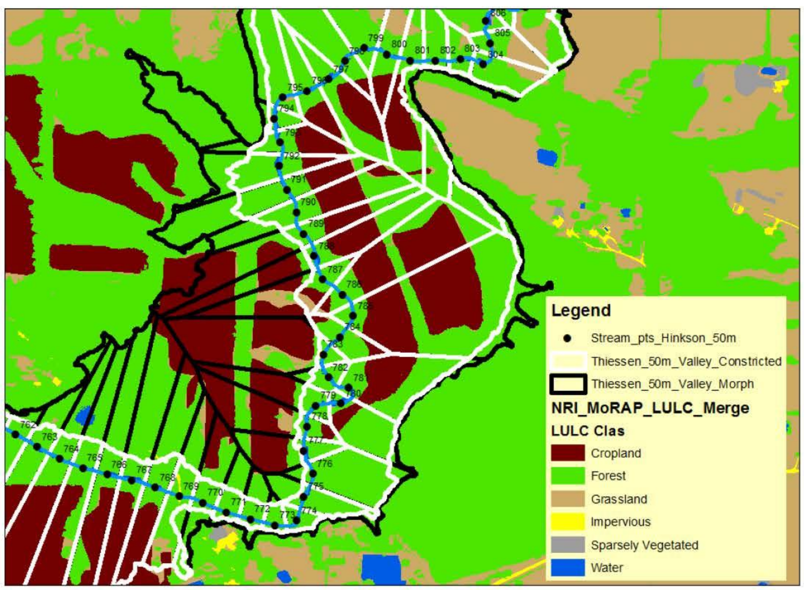

Figure 10. Theissen polygons based on stream points at 50 meter intervals vary greatly in size. Thiessen polygons were clipped to morphological (black) and constricted (white) valley boundaries.

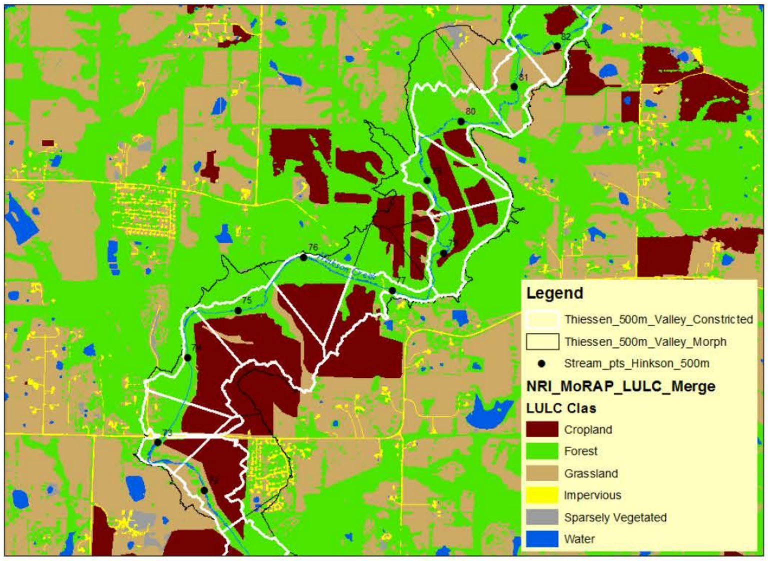

Figure 11. Theissen polygons based on stream points at 500 meter intervals were much more uniform in size compared to 50meter intervals (Figure 10). Thiessen polygons were clipped to morphological (black) and constricted (white) valley boundaries.

2.4.8 Stream Points

Points were generated along the Hinkson Creek centerline at various intervals to assist in selection of stream sampling locations and to apply physical attributes of the stream at given centerline intervals, so that field data could be compared to GIS data (Figure 12). Attributes applied to the points were % slope, sinuosity, bankfull width, morphological and constricted valley width, and distance to valley wall. Points were created at intervals of 50, 100, 250, 500, 1000, 2000, and 4000 meters. All points at an interval greater than 50 meters were based on the 50 meter points. Physical stream attributes at multiple scales allow fine and broad scale views of the stream. The unique identification number for each set of points begins at 0 at the confluence of Perche and Hinkson Creeks and increases chronological upstream to the headwaters.

Figure 12. Shown are points at 50 meter intervals along the Hinkson Creek centerline, beginning at the confluence with Perched Creek, used to apply attributes of physical information (i.e. slope, sinuosity, bankfull width, valley width, etc.) to a specific point within the stream.

2.4.8.1 % Slope

Slope is a measure of stream gradient or steepness and was based on the surface water elevation of the stream at the time of LiDAR DEM (provided by Boone County) data acquisition, March 18 and 19, 2009. Average stream discharge during the period of data acquisition was 19 cubic feet per second (waterdata.usgs.gov). Percent slope between stream points along the centerline was calculated at all point intervals. Slope was calculated beginning at the confluence of Hinkson and Perche Creeks and ending at the headwaters. Slope was calculated by first extracting the elevation for each point from the LiDAR DEM, then calculating the elevation difference between the adjacent points to determine the rise value. The elevation difference was divided by the stream distance to produce a percent slope value.

% slope = (elevation difference/stream line distance) x 100

2.4.8.2 Sinuosity

Sinuosity is a measure that indicates the degree at which a stream meanders. It is the ratio between the stream distance and Euclidean or straight-line distance between two points. A value of 1 indicates a straight stream and the higher the value the more sinuous or meandering the stream is (Figure 13). Sinuosity was calculated between points at all stream point intervals and began at the confluence of Hinkson and Perche Creeks and ended at the headwaters (Figure 14).

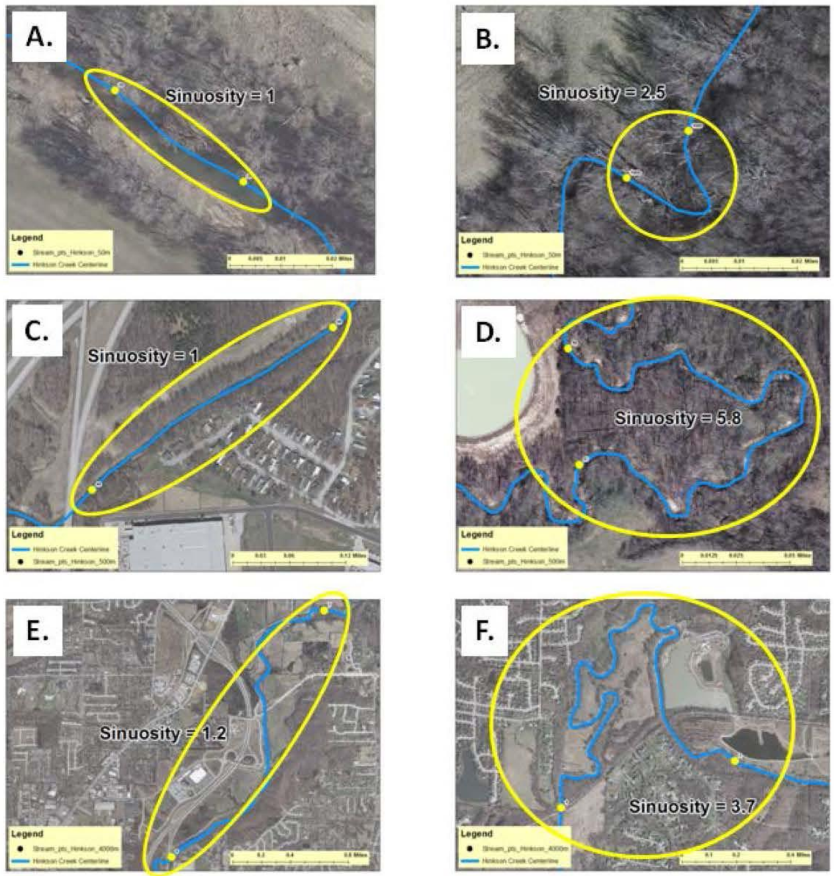

Figure 13. Shown is sinuosity at various scales. A) Sinuosity value of 1 between 50 meter points, indicating a straight section of the creek. B) Maximum sinuosity value of 2.5 within the 50 meter point dataset. C) Sinuosity value of 1 between 500 meter points. D) Maximum sinuosity value of 5.8 within the 500 meter point dataset. E) Sinuosity value of 1.2 between 4000 meter points. F) Maximum sinuosity value of 3.7 within the 4000 meter point dataset.

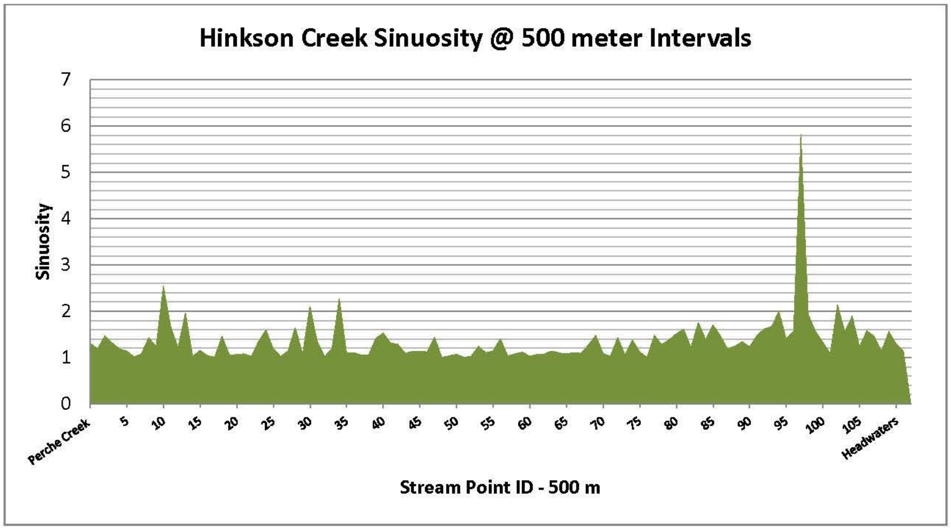

Figure 14. Longitudinal plot of sinuosity measures of Hinkson Creek at 500 meter point intervals. See Figure 23 for locator map of points at 500 meter intervals.

2.4.8.3 Bankfull and Valley Width

Top-of-bank/bankfull and valley widths were measured at each point for all point intervals. A transect perpendicular to the stream centerline was generated for each point and clipped to bankfull, morphological and constricted valley boundaries (Figures 15, 16, 17, and 18). The Geospatial Modeling Environment (GME) "sampleperpointsalonglines" function was used to generate points perpendicular to the stream centerline at 50 meter intervals and a distance of 300 feet on each side for bankfull width and 10,000 feet for valley widths. A python script was written to convert the endpoints for transects into polylines. The polylines were clipped to bankfull, morphological and constricted valley boundaries. Extraneous lines remaining as a result of clipping the polylines to boundaries were removed. Line distance, in feet, was calculated for the remaining polylines. A spatial join was performed to apply transect lengths for bankfull and valley widths to each set of stream points.

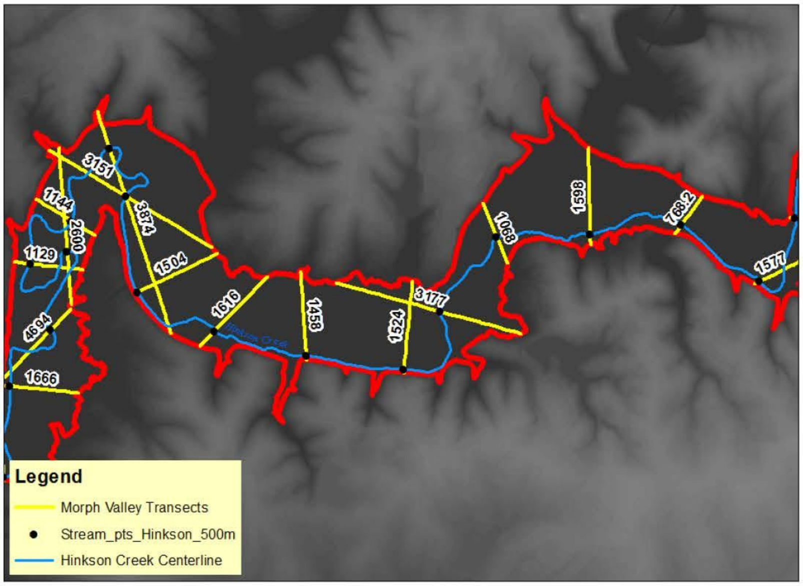

Figure 15. Transects perpendicular to the stream centerline were calculated for each point and clipped to both valley boundaries and the bankfull boundary to calculate width and applied to each point. Shown are transects clipped to the morphological valley boundary with width distances in feet on the transect lines. Due to stream sinuosity within the valley, these values may be more or less meaningful.

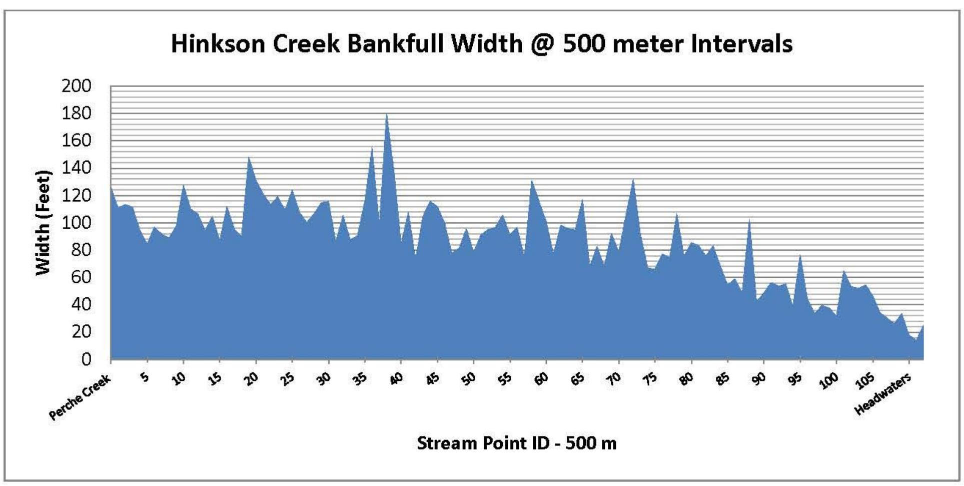

Figure 16. Longitudinal profile of Hinkson Creek bankfull width at 500 meter intervals shows decreasing width from the confluence with Perche Creek upstream to the headwaters. See Figure 23 for locator map of points at 500 meter intervals.

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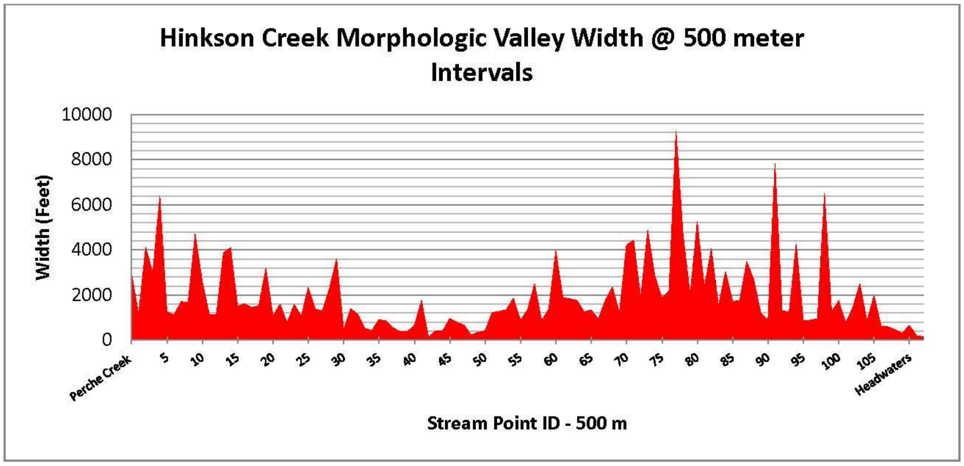

Figure 17. Width of Hinkson Creek morphologic valley at 500 meter intervals. See Figure 23 for locator map of points at 500 meter intervals.

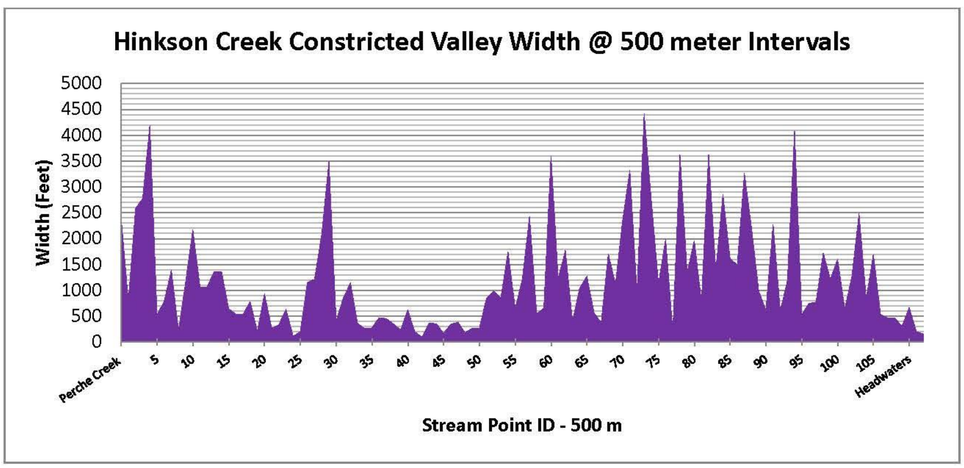

Figure 18. Width of Hinkson Creek constricted valley at 500 meter intervals. See Figure 23 for locator map of points at 500 meter intervals.

2.4.8.4 Distance to Valley Wall

Distance to morphological and constricted valley walls were calculated and applied to points for all point intervals. Transects used to measure valley width were split at the stream centerline and the length of the remaining transects for each side of the stream was calculated (Figures 19, 20, and 21). Two distance values were assigned for each point, one for distance valley wall/boundary edge on one side of stream and one for distance on the opposite side. Right and left sides of the stream were assigned based on navigating upstream from the confluence of Hinkson and Perche Creeks.

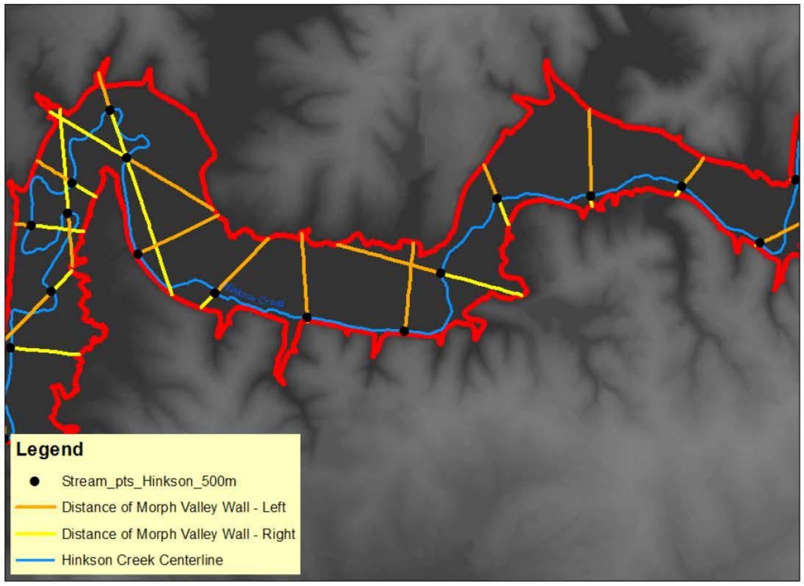

Figure 19. Perpendicular transects used to calculate valley widths were cut in half using the stream centerline and distance from centerline to right and left side valley boundaries were calculated and applied to each point. Due to sinuosity within the valley, these values may be more or less meaningful.

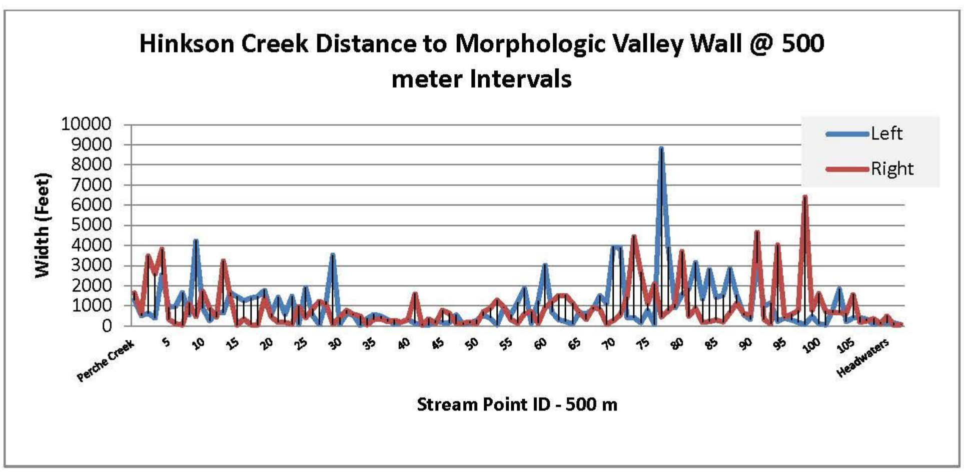

Figure 20. Distance to morphologic valley wall from Hinkson Creek centerline at 500 meter intervals. Red line line represents distance from right side of stream to valley boundary and blue line represents distance from left side of stream to valley boundary based on navigation upstream from confluence of Hinkson and Perche Creeks. See Figure 23 for locator map of points at 500 meter intervals.

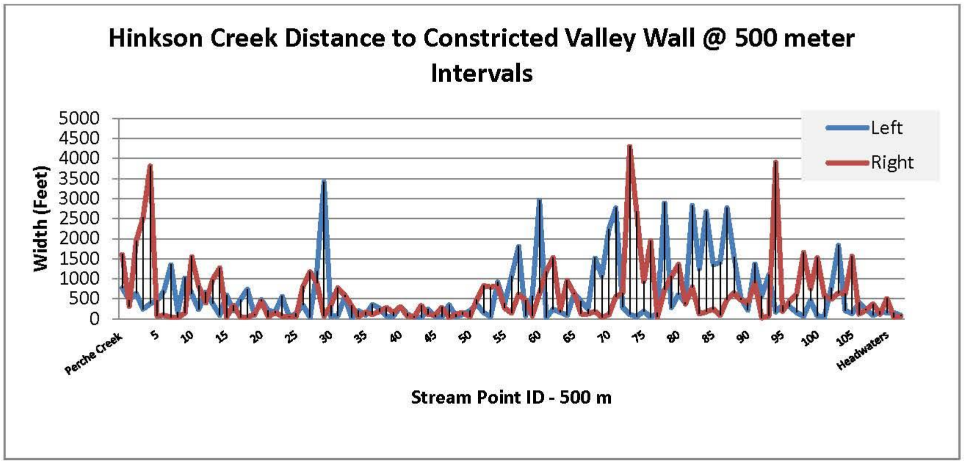

Figure 21. Distance to constricted valley wall from Hinkson Creek centerline at 500 meter intervals. Red line line represents distance from right side of stream to valley boundary and blue line represents distance from left side of stream to valley boundary based on navigation upstream from confluence of Hinkson and Perche Creeks. See Figure 23 for locator map of points at 500 meter intervals.

2.4.9 Hinkson Road Crossings

A point file was created indicating where roads, bridges, trails, cart paths, etc. cross Hinkson Creek (Figure 16). A point was manually placed on the stream centerline at the location of a stream crossing based on visual inspection of the 2011 6" leaf off imagery provided by Boone County at a scale of 1:1000.

Figure 22. A point file of road crossings was manually created by marking any road, bridge, trail, or low water crossing along the stream centerline visible in Spring 2011.

3 Results

3.1 LULC Analysis

3.1.1 LULC – Morphologic Valley

Land Use/Landcover figures can be analyzed in a number of ways to help evaluate contribution to stream conditions at multiple scales. Figures 23 and 24 indicate that spikes in impervious cover within the morphologic valley occur at the lower reaches of Hinkson Creek. Forest and grass comprise the majority of LULC throughout much of the valley, except at the lower reach where impervious cover increases and in the upper middle portion of the reach , between points 61 and 72, where crop increases.

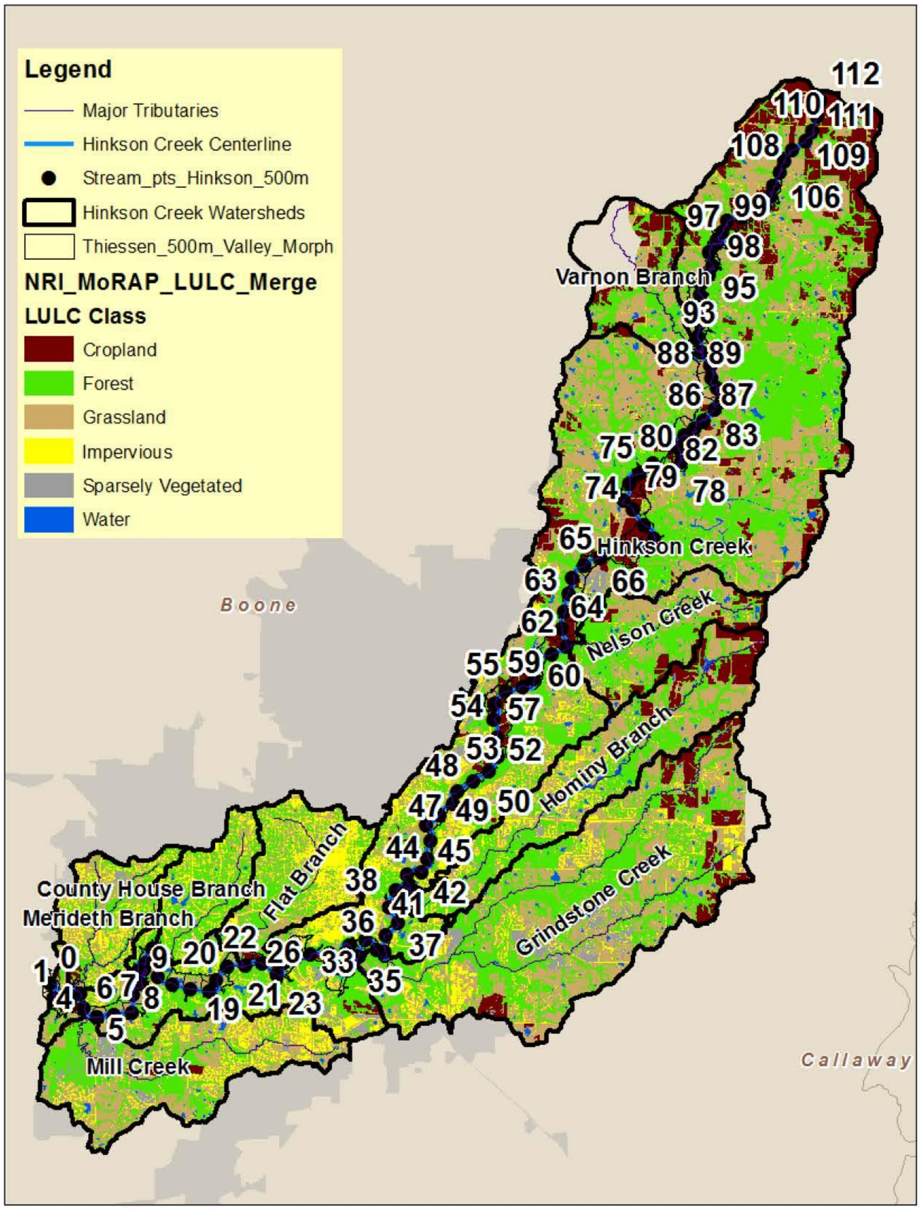

Figure 23. LULC summarized at 500 meter intervals at morphologic valley extent. Numbers represent ID of stream points and thiessen polygons at 500 meter intervals along stream centerline.

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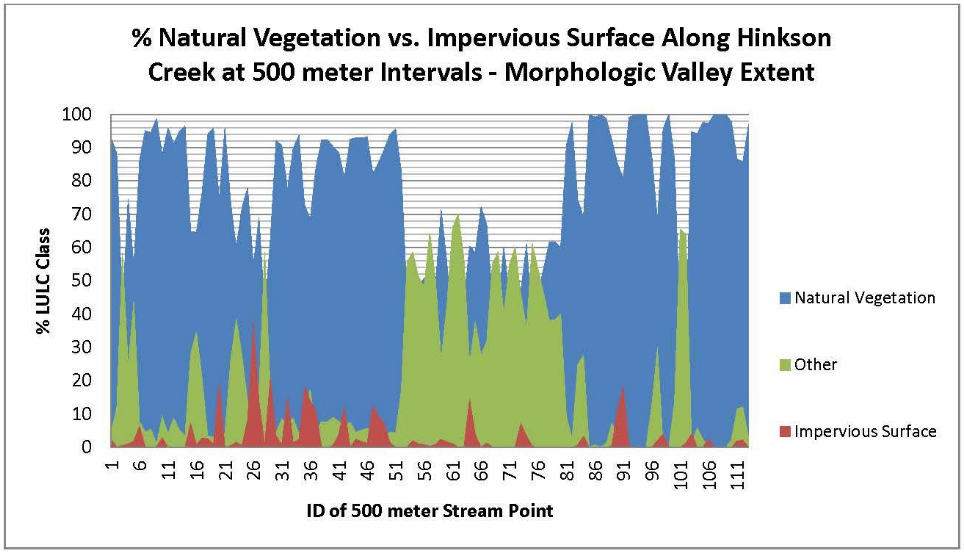

Figure 24. Chart illustrating LULC composition within thiessen polygons at 500 meter intervals within the morphologic valley. Spikes in impervious surface mostly occur along lower portions of stream. While natural vegetation (grass and forest) drops just below mid-point of the stream, but typically comprises the majority of LULC within the morphologic valley. Points along the x-axis correspond to spatially explicit points along Hinkson Creek (Figure 17) beginning at the confluence and ending at the headwaters.

3.1.2 LULC – Watershed

At a broader scale, LULC composition within each watershed is illustrated in Figures 25, 26, and 27. Hinkson Creek watershed has the most total area in all cover classes (Figure 26) based on its overall larger size. Forest and grass are the predominant cover types in all watersheds. Flat Branch watershed has the highest percentage of impervious of all watersheds at 31% followed by Meredith Branch at 23%.

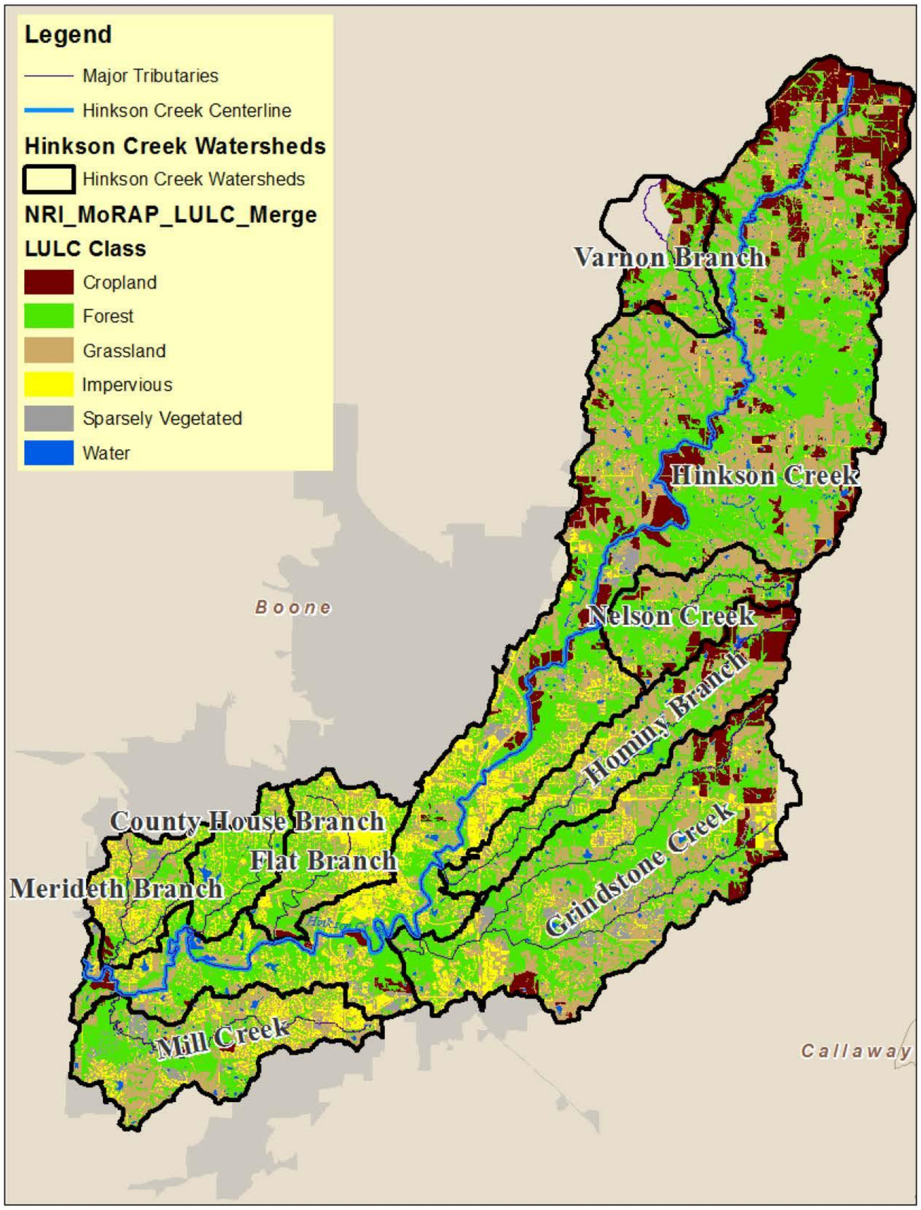

Figure 25. Watersheds and LULC within Hinkson Creek study area.

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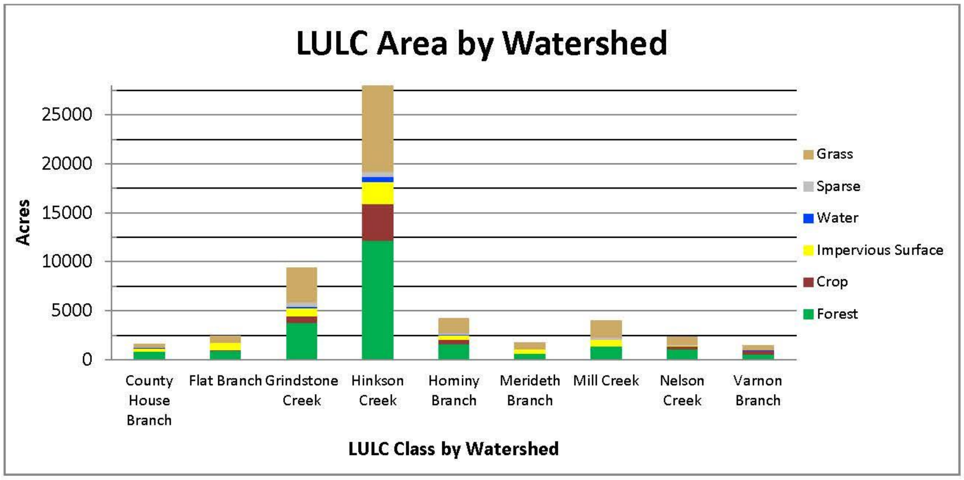

Figure 26. Area of LULC within each watershed in acres.

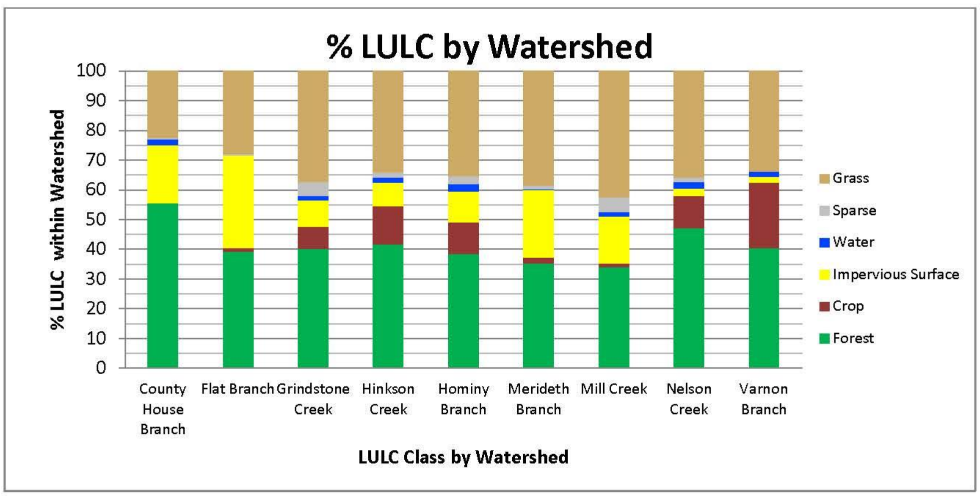

Figure 27. Percent LULC class within each watershed.

3.1.3 LULC – Cumulative Upstream Catchments

To quantify the cumulative upstream values of LULC at each major tributary the watershed was divided into hydrologic drainage catchments that roughly correspond with the watershed layer. The Hinkson Creek watershed was subdivided at the confluence of major tributaries. Breaklines lines were drawn based on Hinkson Creek basin hydrologic catchments generated from 30 m DEMs (Figure 28). Catchments were numbered from 1 to 8, starting at the headwaters, with each major tributary resulting in a break point.

Figure 29 shows the percent LULC within each catchment. Forest and grass comprise the majority cover in all catchments, while percent crop decreases downstream and impervious increases. Catchment 5 (Flat Branch) is 28% impervious, which is the highest percentage of all the catchments. The percent cover by catchment portrays a more accurate longitudinal LULC trend following the course of Hinkson Creek than the watersheds due to the subdivision of the Hinkson Creek watershed at major tributaries.

Cumulative upstream LULC depicts the composition of LULC above each major tributary. Forest, grass and impervious steadily increase downstream, while the addition of crop levels off at catchment 4, the Grindstone Creek confluence (Figure 30). A significant spike in impervious occurs between catchments 2 (Nelson Creek) and 3 (Hominy Branch) and continues to increase up to the confluence with Perche Creek.

Percent LULC cover type relative to total area of a given cover type helps to identify which catchment contains the majority of a specific cover class. Figure 31 shows that roughly 32% of all forest is within catchment 2 (Nelson Creek), 36% of all crop is in catchment 1 (Varnon Branch), 60% of impervious surface exists in catchments 3 through 5; with catchment 3 (Hominy Branch) having the highest value at 23%. More than 31% of grass exists in catchment 2 (Nelson Creek). Despite the fact that the values are heavily influenced by the size of the catchments, the values are a good indicator of where the cover types are located within the study area.

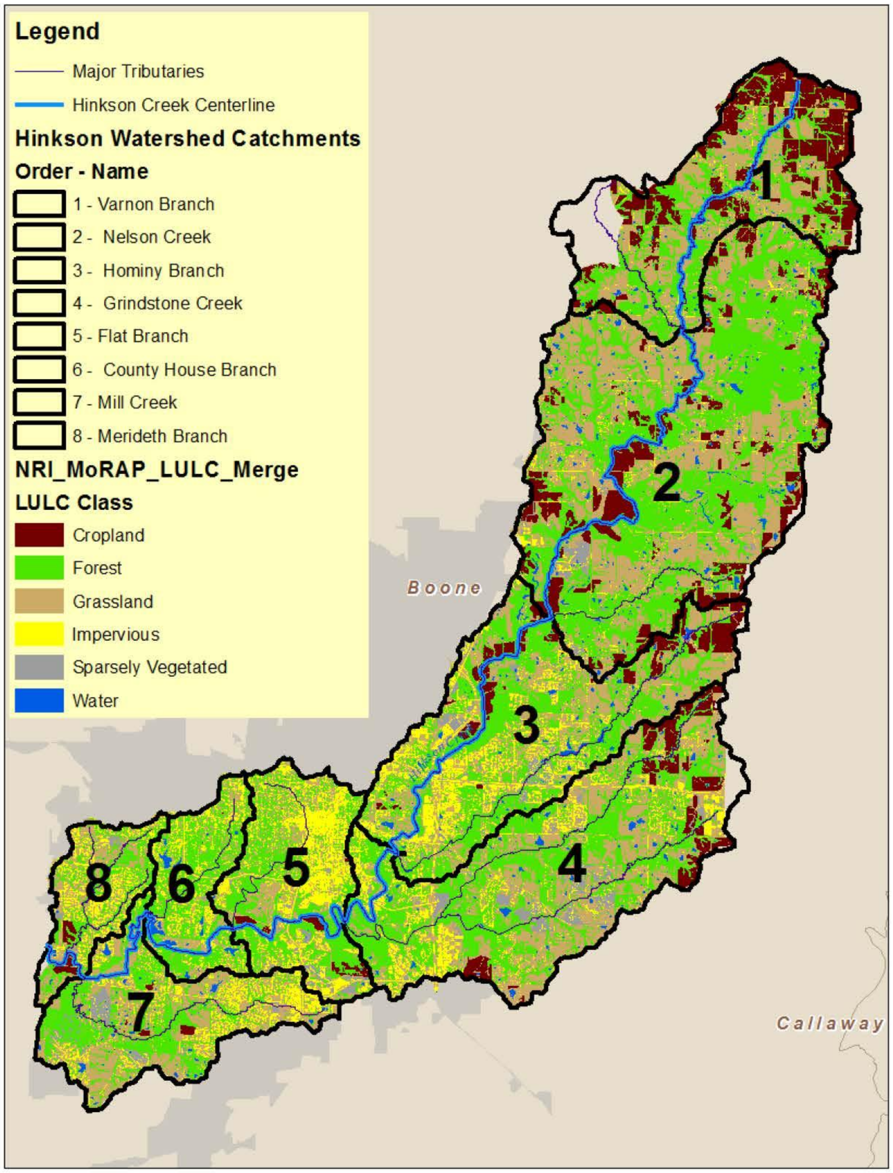

Figure 28. "Catchments" developed to calculate cumulative upstream LULC composition statistics at major tributaries of Hinkson Creek. Watersheds were divided at major tributaries based on fine scale catchments and lumped into broader watershed catchments. Catchments were numbered arbitrarily starting at #1 for the headwaters and increasing downstream.

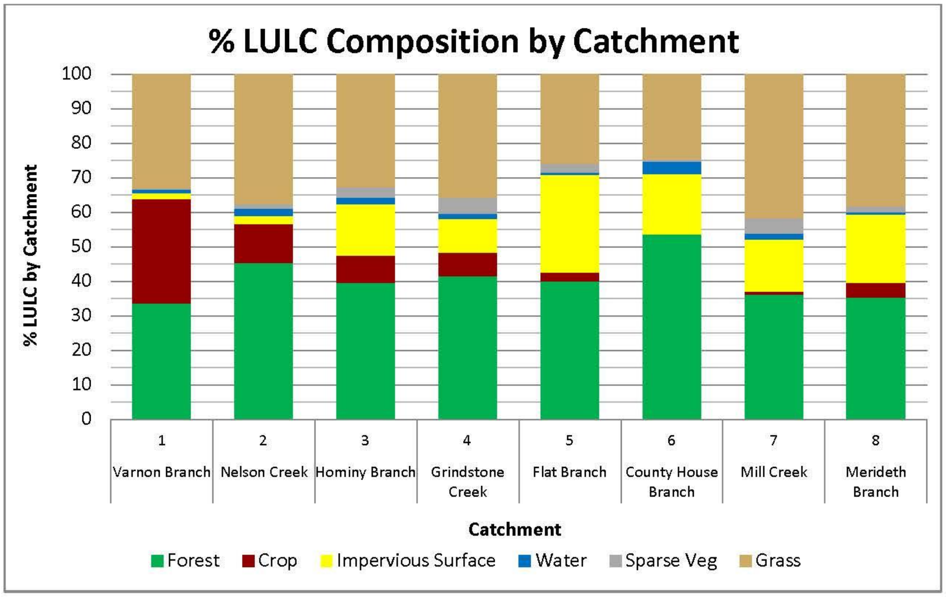

Figure 29. Percent LULC composition within each catchment. Note the dominance of the forest and grass cover types in all catchments, the increase in impervious cover from catchmentsa 3 to 8, and decrease in crop cover type from catchments 1 through 8.

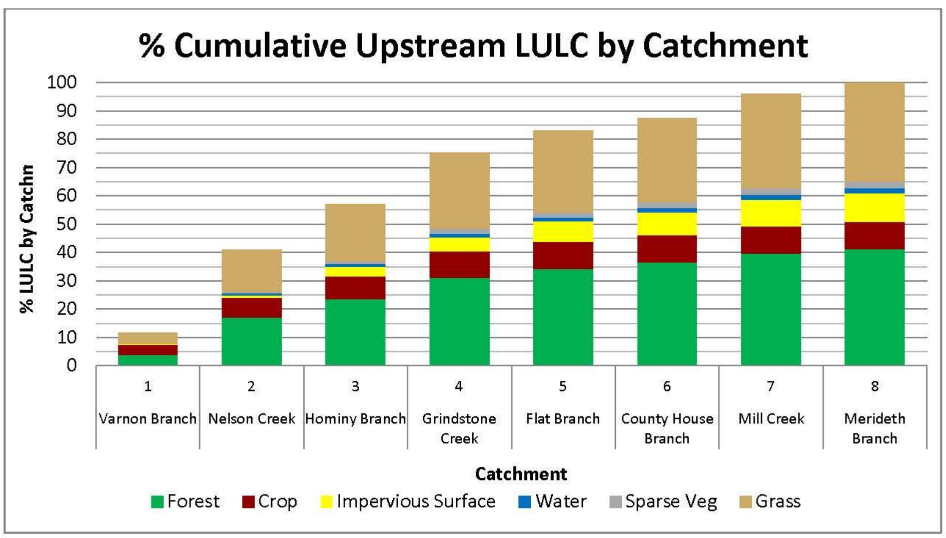

Figure 30. Percent cumulative upstream LULC by catchment shows the contribution of each catchment toward total land cover values for the entire watershed, progressively moving downstream. Note the gradual addition of all forest, grass, and imperverios in a downstream direction. Crop, water, and sparse vegetation cover level off before catchment 8.

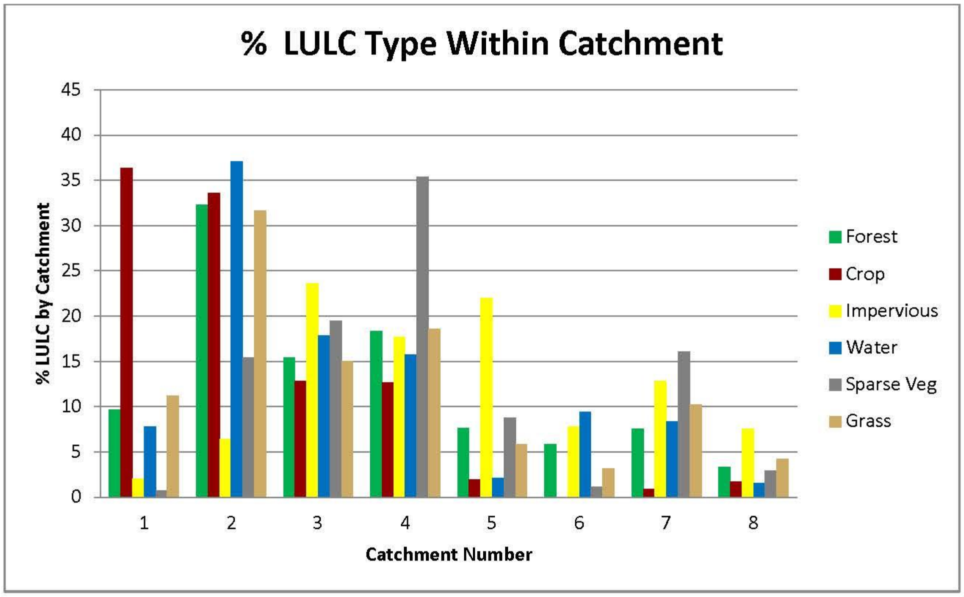

Figure 31. Percent of each LULC type by catchment relative to total area for each LULC type. This chart illustrates the percentage of the total area of a single cover type that exists within each catchment. Note that over 35% of all crop exists in catchment one and over 60% of all impervious surface can be found in catchments 3 thru 5.

Appendix B: PHA Phase II Report to CAM Stakeholders (IHL)

Hinkson Creek
Collaborative Adaptive Management

Physical Habitat Assessment
Phase II: Field Component

Final Report

March 1, 2015

University of Missouri Research Team

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1.0 Project Summary

To quantify current physical habitat in Hinkson Creek the Hinkson Creek Collaborative Adaptive Management (CAM) team partners (Boone County, City of Columbia, and University of Missouri-Columbia) funded a two-tiered study called the Physical Habitat Assessment (PHA) in 2013. Phase I of the study was conducted by Missouri Resource Assessment Partnership (MoRAP). Results from Phase I are provided in a final report from MoRAP dated July 31, 2013. The MoRAP study used GIS models to delineate various features of the Hinkson Creek Watershed. The end product of Phase I is a fine-resolution dataset that describes specific geomorphological features of the creek, adjacent floodplains and riparian areas, and can be accessed by land managers and agencies for making more informed land use and/or conservation or restoration decisions. Phase II of the PHA included a field component, the results of which are described in this report. One of the goals of Phase II was to generate some observed data that are comparable to features described in Phase I. The results of this comparison are presented in section 7.2 of this report. An additional goal of Phase II was to provide measurements of physical habitat at consistent spatial intervals along the entire length (56 km) of Hinkson Creek that can be analyzed using current land use and land cover data in the watershed (see MoRAP report dated July 31, 2013). The results of analyses of the PHA Phase II data are presented in section 7.0 of this report.

Data sets developed during Phase II of the PHA included the following: descriptive statistics for all bank and channel measurements, channel width with stream distance, bankfull width with stream distance, bank height with stream distance, percent canopy cover with stream distance, substrate particle size class distribution, percent substrate embeddedness with stream distance, percent channel unit type for Hinkson Creek, and major tributary confluence bank and channel measurement comparison.

2.0 Introduction

As a member-partner of the Hinkson Collaborative Adaptive Management (CAM) Science Team, the University of Missouri-Columbia was charged to conduct Phase II of the PHA. At the request of the Collaborative Adaptive Management (CAM) team partners (Boone County, City of Columbia, and University of Missouri-Columbia), Dr. Jason Hubbart agreed to lead the effort and assembled a field crew consisting of three graduate research assistants who collected physical and photographic data in Hinkson Creek. A Field Protocol was prepared, and data were collected over the entire length of Hinkson Creek from headwaters to mouth, including additional detailed data at each of the eight major confluences of Hinkson Creek (Figure 1).

3.0 Data Collection

During Phase I of the PHA, Missouri Resource Assessment Partnership (MoRAP) used GIS and remote sensing tools to generate a fine resolution data set delineating various geomorphological features of the Hinkson Creek Watershed. Data sets developed by MoRAP included: (1) stream centerline update, (2) spatially explicit sample points at 50 m intervals on the centerline of the stream, (3) bankfull boundaries on the stream, (4) valley boundaries along the stream, (5) new fine spatial resolution land use/landcover (LULC) for 25% of the study area, (6) attribution of physical data to spatially specific points within the stream at multiple scales (i.e., LULC composition, bankfull width, valley width, slope, sinuosity, and distance to valley wall), (7) sand/gravel bar delineation, and (8) Hinkson Creek road crossings. Some of the data generated by MoRAP (PHA Phase I) were used as a basis of comparison with observed data from PHA Phase II presented in this report (see section 7.2). MoRAP also provided the PHA field team with coordinates for the set of 100 m survey points along the length of Hinkson Creek. The data provided by MoRAP are publicly available and can be used in conjunction with a map viewer. For more information, please visit: http://maps.showmeboone.com/viewers/RM_Hinkson_GIS_Technical_Report_Final_2013/.

Data for Phase II of the PHA were collected as delineated in the Physical Habitat Assessment Field Protocol, dated January 25, 2014. The PHA Phase II protocol was developed by Dr. Jason Hubbart, with assistance from his students and consultation and feedback from members of the CAM Science Team. The majority of the Phase II protocol used in the field is included in the following text. A complete copy of the original field protocol will be forwarded to the web administrator of http://helpthehinkson.org/ upon request, and posted therein.

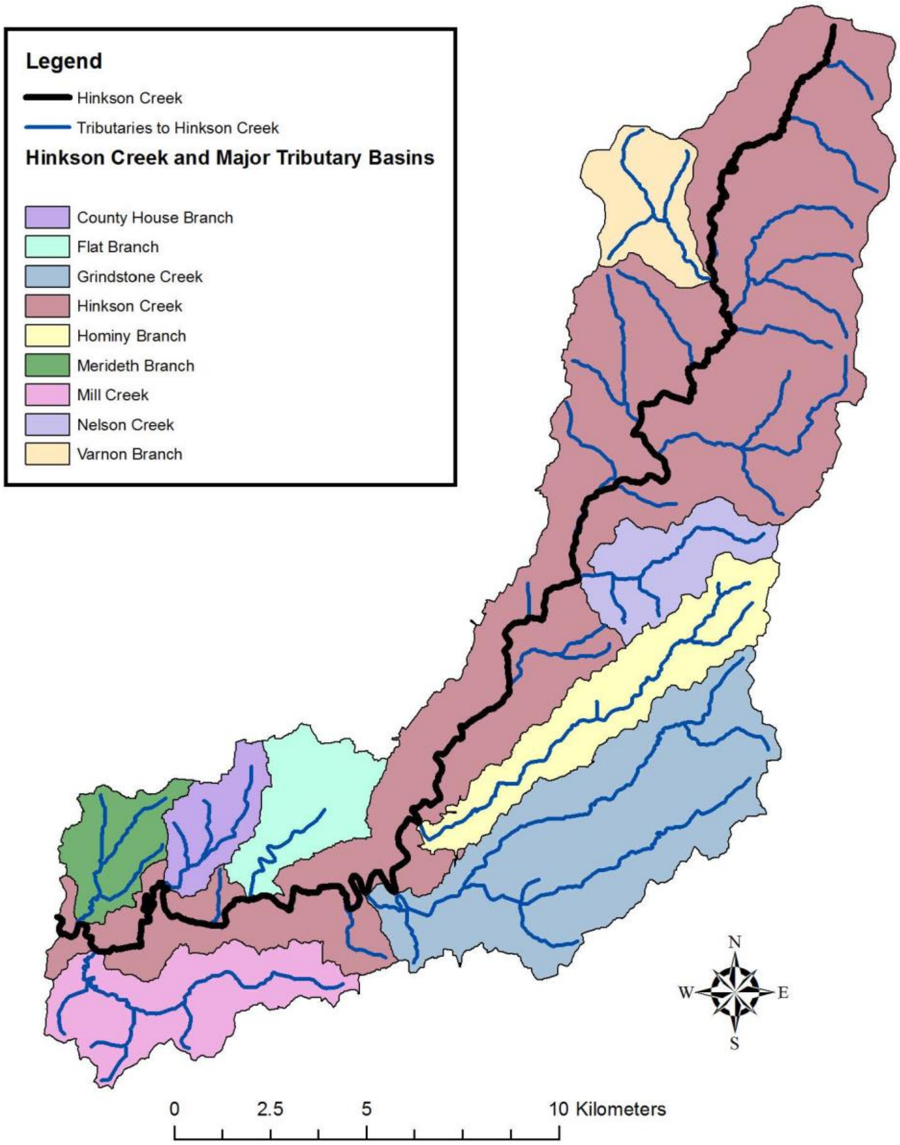

Figure 1. Hinkson Creek Watershed in Boone County, Missouri, including Hinkson Creek and major tributary basins including (see color legend): Varnon Branch, Hinkson Creek, Nelson Creek, Hominy Branch, Grindstone Creek, Mill Creek, Merideth Branch, County House Branch, and Flat Branch Creek.

4.0 Physical Habitat Assessment (Phase II) Field Protocol

4.1 Global Positioning System Data

The PHA Phase II survey was conducted at pre-determined survey points at 100 m intervals, starting at the mouth of Hinkson Creek at its confluence with Perche Creek and continuing upstream to the first second-order confluence at the headwaters of Hinkson Creek. Coordinates for the 100 m survey points were provided by MoRAP PHA Phase I, and were pre-loaded into a global positioning system (GPS) unit used by the field team. The field team travelled to the coordinates of each survey point, and recorded the coordinates provided by MoRAP and the coordinates of the center of the stream channel for each point on the data sheet(s) (see example at end of field protocol). In addition, coordinates were collected at each survey point to mark the position of the stream banks and streambeds. Major objects including woody debris piles, public utilities, engineered structures, eroded gullies, bank failures, debris piles, and any other obvious habitat altering features were photographed with a camera that recorded GPS coordinates in the properties of the photograph. Additional survey points were established at the confluence of each of the following tributaries as they were encountered on the survey path from the mouth to the first second order confluence at the headwaters of Hinkson Creek: Meredith Branch (MB), County House Branch (CH), Mill Creek (MC), Flat Branch Creek (FB), Grindstone Creek (GC), Hominy Branch (HB), Nelson Creek (NC), and Varnon Branch (VB). Coordinates were collected at confluence survey points as described in Section 4.3 and recorded in the same manner as the 100 m survey points.

4.2 Survey Point Naming Convention

GPS waypoints were named using a two letter code for the feature and the nearest survey point number. For example, the waypoint for survey point one was be named SP1 (i.e. Survey Point 1). Each survey point was sequentially numbered from the first point at the mouth of Hinkson Creek through the final point near the first second order confluence at the headwaters. The survey point number was recorded on the data sheets with the corresponding MoRAP and field team GPS coordinates. For those survey points that were at the confluence with tributaries, data were collected and stored separately to avoid confusion with the 100 m survey points.

4.3 Description of Survey Points

Each survey point was located in the center of the stream channel and served as the center point of a study plot. The study plot consisted of a principal transect running from bank to bank through the survey point perpendicular to the direction of stream flow. Upstream and downstream transects delineated the beginning and end of the plot and were located 5 meters upstream and downstream of the principal transect. Upstream and downstream transects were parallel to the principal transect and extended from bank to bank (Figure 2a).

For purposes of the survey, the field protocol called for the survey cross section of the study plot at any confluence to be set in Hinkson Creek 5 m downstream of the downstream bank of the confluence with the tributary so that the study plot was as close to the confluence as possible. This placement of the survey transect proved to be impractical in the field, as the width of the channel tended to be greater at the confluences, and the effects on physical habitat from the tributary flow were not evident at the 5 m distance. After consultation with Dr. Hubbart, the field team set three transects for each confluence: one upstream of the confluence in Hinkson Creek, one downstream of the confluence in Hinkson Creek, and a third upstream in the tributary. Transects were located 20 m to 50 m from the center point of the confluence, with all three distances being measured and recorded (Figure 2b). All bank and channel measurements described in this field protocol were collected at each of the three transects.

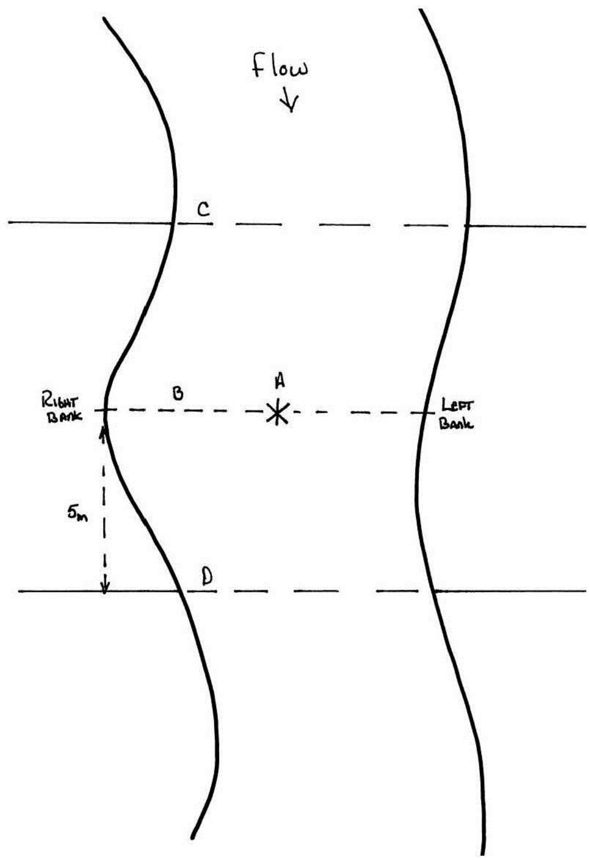

Figure 2a. Layout of study plots used for habitat measurements. A: survey point. B: principal transect. C: upstream transect D: downstream transect.

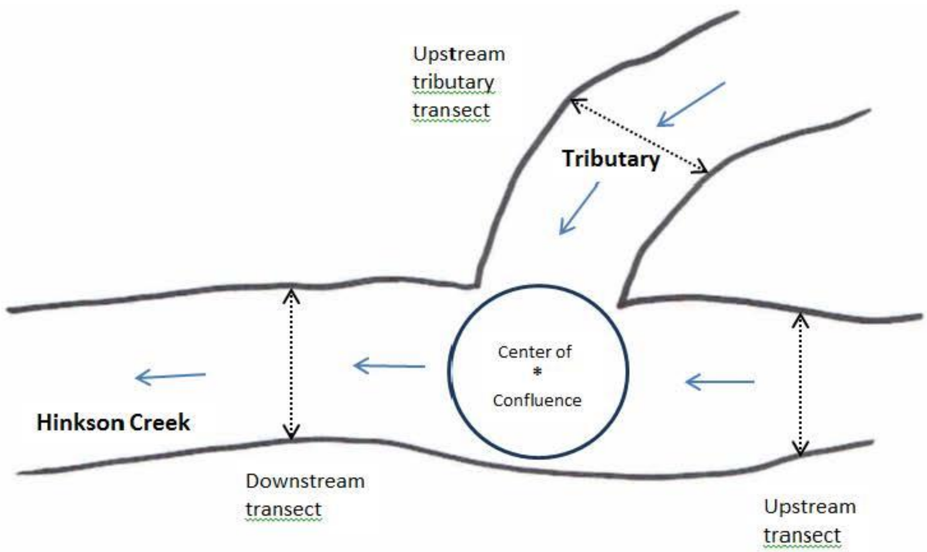

Figure 2b. Layout of three measured transects at confluence sites.

4.4 Photographic Journal

A digital camera was used to create a photographic journal of each study plot. A mandatory set of photos were collected from the survey point as follows: directly down at a distance of 1 m from the streambed (streambed composition), directly upstream (normal with the channel), then turning clockwise a perpendicular (90 degree angle) photograph of the left bank, downstream (parallel with the channel), a perpendicular photograph of the right bank, and a final photo directly upwards to capture canopy cover. Photographs of the stream banks captured the extent of vegetative cover present. A photograph of the survey point number (either written on a dry erase board or from the face of the GPS unit) was taken immediately before the first (streambed) photo in the series and again before photos taken at any transect between survey points (survey point – transect number, e.g. SP1-3) so that the photographs could be catalogued later.

At confluence survey points, additional photographs were taken to document physical characteristics at the confluence, including the standard channel photographs described above, and a 360 degree panorama from the center of the confluence and at each of the three transects surveyed.

4.5 Special Features

GPS coordinates are embedded in the properties of photographs to document the presence of any of the following special features: bank stabilization structures, including rip-rap, gabion baskets, and other engineered structures; infrastructure not adequately mapped in GIS resources, including pipes, outfalls, discharge control structures, and utilities with any related infrastructure; disturbance features including erosion gullies, debris fans, slumps, bank failures, and woody debris piles; cattle tracks found on either bank or in the substrate; large trash dumps in or near the stream. Special features photographs are named using the survey point number, followed by a hyphen and the distance downstream from the survey point (where applicable), the date, the type of feature, and the streambank. A sample file name is SP40-8_2014-07-16_erosion_and_woody_debris_rb.

4.6 Canopy Measurements

Canopy cover was estimated following the method described by Peck et al. (2006). A convex densiometer (Lemmon 1957) was used after modification to prevent overlap from measurements taken close together. The modification consisted of creating a "V" comprised of tape on the face of the densiometer with the vertex pointing towards the viewer such that 17 line intersections exist within the V (Mulvey et al. 1992) (Figure 3). The number of line intersections covered by canopy was recorded on the data sheet. During the winter months, the number of line intersections covered by branches was recorded on the data sheet, and a notation was made as to the presence or absence of leaves. Canopy cover was determined by quantifying the percentage of points covered by canopy (Peck et al. 2006).

4.6.1 Procedure for Canopy Cover Measurements

1. A field team member stood on the principal transect at mid channel facing upstream.
2. The densiometer was positioned 1 m above the streambed, and levelled using the bubble level. The densiometer was then positioned so that the face of the field team member was reflected just below the apex of the taped "V" (Figure 3).
3. The number of grid intersection points within the "V" that were covered by a tree, a leaf, or a high branch were counted (0 to 17) and recorded in the appropriate place on the datasheet.
4. The field team member then faced the left descending bank (left, facing downstream). Steps 2 and 3 were repeated, and the value was recorded in the appropriate place.
5. Steps 2 and 3 were repeated again facing downstream and again facing the right bank, and the values were recorded in the appropriate places.
6. Steps 2 and 3 were repeated at the channel's edge on the left bank at the end of the principal transect, and again on the right bank, and the values were recorded in the appropriate places.

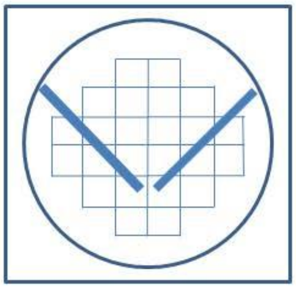

Figure 3. Diagram of taping of "V" on face of convex densiometer.

4.7 Bank Angle, Stream Width and Channel Depth

At the principal transect running through each survey point, measurements of channel width, wetted width of the stream, bank angle, bankfull width, and bank height were recorded (Figure 4). Bank angle was measured on both banks and calculated as the average slope of the bank extending 2 m from the bottom (top of gravel) to the top of the bank. Normally, slope was between 0° and 90°; however, by definition undercut banks had an angle greater than 90° because the edge of the water was underneath the overhanging bank.

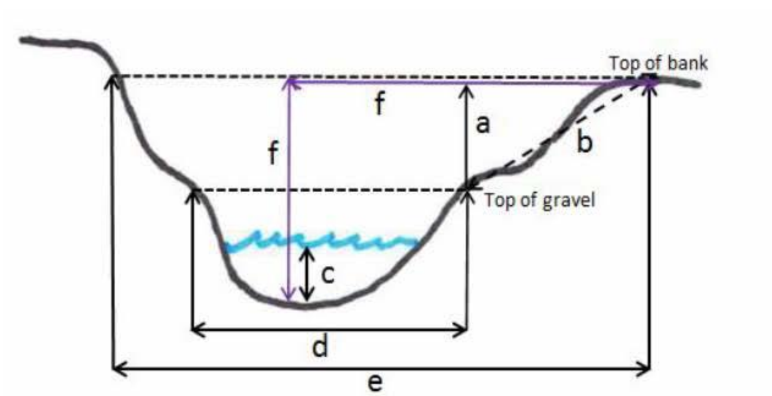

Figure 4. Cross-section view of measured channel dimensions: a) bank height, b) bank slope, c) thalweg depth, d) channel width, e) bankfull width, and f) relative thalweg depth (vertical) and thalweg position (horizontal).

Bankfull flows are events large enough to erode the streambed and banks, and frequent enough to prevent substantial growth of terrestrial vegetation (Peck et al. 2006). Annual peak flows are used to compare channel morphology measurements on a consistent basis, relative to flows thought to have a consistent 1.5-2.0 year return interval (Leopold et al. 1964). Common indicators of bankfull level included the top of pointbars, changes in vegetation from aquatic to terrestrial, changes in slope, changes in bank material (e.g. from coarse gravel to sand), bank undercuts, or stain lines on bedrock or boulders (Harrelson et al. 1994). More detailed descriptions of these indicators can be found in Harrelson et al. (1994). Determination of bankfull levels at times required some discussion among crew members and if possible, multiple indicators that "agreed" with each other were used. Bankfull width was measured as the distance between banks at the bankfull level perpendicular to stream flow. All measurements in this section were collected using a laser level and/or laser range finder, except if wetted width was less than the minimum threshold of the laser range finder (5 m) in which case a 1 m measuring stick was used.

4.7.1 Procedure for measuring bank angle:

1. An extension pole was laid on the bankfull bank at the end of the principal transect so that the base of the pole was at the bottom of the bank (top of the line of gravel from the streambed). The extension pole was extended 2 m up toward the top of the bank. A clinometer was placed on the extension pole and the bank angle was read and recorded in degrees (0-90°). If the bank was undercut (>90°), the measurement was made from the water's edge along the underside of the undercut, and the clinometer reading was subtracted from 180° and recorded.
2. If the bank was undercut, the undercut depth was recorded by placing a meter stick horizontally parallel to the stream, and the distance from the back of undercut to the edge of the bank was measured.
3. If there was a large boulder or a log at the transect point, the measurement point was moved ($\leq$ 5 m) to a nearby point which was more representative.
4. Step 1 (and Step 2 if necessary) was repeated on the opposite bank.

4.7.2 Procedure for measuring Channel Width, Wetted Width, Bankfull Width, Bank Height, Channel Depth, and Relative Thalweg Depth and Thalweg Position (Figure 4):

1. Using a laser range finder, the distance from the bottom of the bank (the top of the gravel from the streambed) was measured across the stream channel from one bank to the other (channel width). Also using a laser range finder, the distance from one side of the stream to the other (wetted width) was measured. If there was a split in the channel due to a bar or island, the following wetted width values were recorded where possible and applicable: entire width of wetted portion of stream, wetted width nearest to left bank, wetted width of center stream channel, wetted width nearest to right bank. Values for channel width and wetted width(s) were recorded on the data sheet.
2. To measure bankfull width, the bankfull level on the streambank with the highest terrace was located. For a description of bankfull indicators see Harrelson et al. (1994). While squatting at the top of the streambank with the lowest terrace (presumed bankfull), the

laser range finder was used to measure the width to the bankfull level on the opposite streambank.

3. Whether the right bank or left bank (descending) was used for bank measurements was determined at each survey point by which bank had the lower elevation (bankfull bank), and was indicated on the data sheet. Bank height was measured as the distance from the bottom of the bankfull bank (frequently determined by the top of the line of gravel from the streambed) to the top of the stream bank, using a laser level and an extension pole with a receiver.
4. Thalweg depth was measured by positioning the meter stick or extension pole on the stream bed at the deepest part of the channel and reading the depth of the water. In the event that the water was more than chest deep, a depth finder and battery with float were deployed for measuring thalweg depth.
5. Relative thalweg depth and thalweg position were measured relative to the bankfull bank. Relative thalweg depth was measured using a laser level and an extension pole with a receiver. The extension pole was set at the bottom of the stream in the thalweg, and raised or lowered until the receiver was on a horizontal plane with the laser level stationed at the top of the bank. Thalweg position was measured using a laser rangefinder to measure the distance between the top of the bankfull bank and the laser receiver on the extension pole.

4.8 Longitudinal Thalweg Depth Profile

The thalweg is the path of the stream that follows the deepest point of the channel (Armantrout 1998). This is also the last part of the channel to become dry during a drought. Although this series of measurements is not a topographic profile, a longitudinal profile of thalweg depth yields information about habitat complexity and channel form variability. The thalweg was measured at each survey point and every 10 m in between survey points. At the location of each thalweg measurement a field crew member recorded the thalweg depth, the channel unit according (Table 1), the substrate size classification (Table 2), and the presence or absence of periphyton on the substrate. More detailed descriptions of the channel form can be found in Table 7.3 in Peck et al. (2006).

Table 1. Channel unit types and codes used in data recording in Hinkson Creek. Adapted from Peck et al. (2006).

Channel Unit	*Code*	*Description*
Plunge Pool	PP	Pool at base of plunging cascade or falls.
Trench Pool	PT	Pool-like trench in the center of the stream.
Lateral Scour Pool	PL	Pool scoured along a bank.
Impoundment Pool	PD	Pool formed by impoundment above dam or constriction.
Pool	P	Pool (unspecified type).
Glide	GL	Water moving slowly, with smooth unbroken surface. Low turbulence.
Riffle	RI	Water moving with small ripples, waves and eddies – waves not breaking, surface tension not broken. Sound: babbling, gurgling.
Dry Channel	DR	No water in the channel or flow is under the substrate (hyporheic).

* Due to the local topography of Hinkson Creek, cascades are unlikely to occur, and thus this category was omitted from the Channel Unit Code on the data sheet in order to conserve space.

4.8.1 Procedure for Measuring Thalweg Profile

1. The depth of the water was measured at the deepest part of the channel along the principal transect. This depth (cm) was recorded under station "1" on the data sheet.
2. The channel unit was identified and the channel unit code was recorded on the data sheet.
3. The size classification of a random substrate particle was determined at the thalweg and the appropriate code from Table 2 was recorded.
4. Where possible, the presence or absence of periphyton on the substrate at the thalweg was determined and noted on the data sheet. This determination was not attempted in deep pools.
5. Using the string line marked at 10 m intervals, the field team continued downstream following the thalweg, and Steps 1 and 2 were repeated every 10 m between survey points. The data from steps 1 through 4 were recorded on the data sheet under stations 2-10, respectively.
6. After the depth at the 90 m mark was recorded, the field team moved to the next coordinate provided by MoRAP and started a new data sheet.

4.9 Substrate Characterization (Pebble Count)

The method for substrate particle size characterization described here was adapted from Peck et al. (2006) and Wolman (1954). The procedure required estimation of the diameter size class of 15 substrate particles at each study plot. Five particles were sampled from each of the principal transect, the upstream transect, and the downstream transect (Figure 2a). On each transect, particles were sampled from the left and right banks, and from 25, 50, and 75% of the distance across the width of the channel. Particle size was estimated according to the size classes listed in Table 2.

Table 2. Particle size classes and codes used on data sheets.

Diameter (mm)	*Size Equivalent*	*Code*	*Substrate Type*
>4000	Larger than a car	RS	Bedrock (Smooth)
>4000	Larger than a car	RR	Bedrock (Rough)
>4000	Larger than a car	RC	Concrete/Asphalt
1000 to 4000	Meterstick to Car	XB	Large Boulder
256 to 1000	Basketball to Meterstick	SB	Small Boulder
64 to 256	Tennis ball to Basketball	CB	Cobble
16 to 64	Marble to Tennis ball	GC	Coarse Gravel
2 to 16	Ladybug to Marble	GF	Fine Gravel
0.06 to 2	Gritty - up to Ladybug	SA	Sand
<0.06	Smooth, Not gritty	FN	Silt/Clay/Muck
Any size	NA	HP	Hardpan (Firm, Consolidated Fine Substrate)
Any size	NA	WD	Wood
Any size	NA	OT	Other - (Write comment)

4.9.1 Procedure for measuring substrate:

1. The procedure started on a bank of the principal transect. Using a meter stick, the first particle that the meter stick came into contact with was selected. If the substrate was sand or finer material, multiple particles were picked up and size class was determined by texture.
2. The size of the selected particle was estimated (or particles for finer material) according to Table 2, and the size class was recorded on the data sheet.
3. The percent vertical embeddedness of the particle in the substrate (what percentage of the particle is not visible) was estimated to the nearest 5%. Note that sand and silt are by definition 100% embedded, and bedrock or claypan are 0% embedded. The percent vertical embeddedness was recorded on the data sheet.
4. The field team member moved to the next station along the principal transect and repeated Steps 1 to 3, recording the data in the appropriate locations on the data sheet. Five particles were sampled on the principal transect.
5. Steps 1 to 4 were repeated along the upstream transect and the downstream transect (see Figure 1).

5.0 Subject Matter Expertise/Science Team Collaboration

The field protocol for Phase II of the PHA was accepted and approved by the CAM Science Team in July of 2013. In the fall of 2013, CAM Science Team members Dr. Paul Blanchard (Missouri Department of Conservation), Dr. Robert Jacobson (United States Geological Survey), and Dr. Joe Engeln and Dave Michaelson (both from Missouri Department of Natural Resources) met in the field with Dr. Jason Hubbart and Lynne Hooper for a demonstration and discussion of methods for PHA Phase II data collection following which, the PHA Phase II field protocol were finalized and approved by the CAM Science Team during this meeting.

6.0 Data Development Methodologies

6.1 Projection

MoRAP used a standard projection (see Phase I report) in their Phase I analyses of Hinkson Creek Watershed, including the determination of survey points for the study area, which consisted of the entire length of Hinkson Creek (56 km). The survey points provided by MoRAP were loaded into the GPS units used by the PHA field team in Phase II. The same standard projection was used in any comparison analyses performed in ArcGIS.

6.2 Phase I Analyses Comparable to Phase II Observed Data

Comparable data from MoRAP PHA Phase I to PHA Phase II include bankfull width measurements and stream center point coordinates. The remaining analyses provided by MoRAP in Phase I are not directly comparable to the Phase II data. For example, MoRAP provided a stream centerline update in their Phase I report dated July 31, 2013. The centerline was manually edited using LiDAR hillshade and 2011 aerial photographs. The data collected during the PHA Phase II cannot be compared to the MoRAP centerline because point coordinates in Phase II were only collected at 100 m intervals, and any attempt made at interpolation at this spatial resolution would be incorrect. Some data analyzed during Phase I were not collected during Phase II (land use / landcover, valley delineation and sinuosity, among others), or were measured from a different position than a measurement during Phase II. An example of the latter includes the geographic coordinates for the presumed bankfull bank in Phase I which were located at the top of the bank, but were recorded at the bottom of the bank in Phase II as per the field protocol.

7.0 Results and Discussion

7.1 Data Analyses

A summary of the types of data collected during the PHA Phase II is provided in Table 3. These data will be provided upon request in spreadsheet format (i.e. .xlsx). Data will then presumably be available to land managers and managing agencies as requested or needed to help guide watershed management and restoration decisions.

Table 3. Measurements collected for Physical Habitat Assessment database.

Coordinates	**Bank Measurements**	**Channel Measurements**	**Substrate Qualification**	**Thalweg Profile**
Survey point	Bank slope (both)	Wetted width	Pebble count	Thalweg depth
Right bank	Undercut	Channel width		Substrate particle size
Left bank	Bankfull width	Canopy cover		Periphyton p/a
Streambed*	Bank height**	Thalweg depth		Channel unit
		Relative thalweg depth		
		Thalweg position		

* If different from survey point. Also if site included a split channel, coordinates of sub-channels may be provided.
** Bank height was measured on the presumed bankfull bank.

The following sections provide a summary of the data collected during Phase II of the PHA. In the interest of consistency an attempt was made to generate data analyses that are reasonably comparable to the data presented in the Phase I PHA and summarized in the MoRAP report dated July 31, 2013. Comparisons are largely based on descriptive statistics or measurements at survey points as a function of stream distance.

7.2 Comparison of Observed Data to GIS Data

A point file of observed stream center point coordinates was opened in ArcMap and compared to a point file of stream center points (the survey points) generated by MoRAP. Using ArcGIS tools, the distance between the modelled and observed points was calculated at each survey point. The maximum distance between stream points was 93.44 m. This maximum was a very extreme outlier, and was presumably influenced by the presence of two bridges side by side immediately upstream of the survey point that may have blocked satellite signals to the handheld GPS unit. On this basis, this outlier was removed from the data comparison pool. The new maximum distance between MoRAP and observed points was 39.93 m, minimum distance 0.00 m, mean distance 4.18 m, median of data set 2.99 m (data are right-skewed), and standard deviation 4.25 m (Table 4).

Bankfull width data generated by MoRAP were copied as a column from the attribute table of the Hinkson Creek 50 m survey points file, and pasted into an Excel spreadsheet side by side with a column of the observed bankfull width measurements. The MoRAP data corresponding to every 100 m were converted to meters (data were in feet) for an exact comparison with the survey points. Comparison of the data yielded a maximum distance between points of 55.22 m, a minimum of 0.01 m, and an average of 4.72 m, median of and a standard deviation of 6.15 m (Table 4).

The purpose of this comparison was for validation of the data generated by the MoRAP GIS modelled data for the HCW relative to observed data. The accuracy of the handheld GPS unit used by the field team was ±3 m. This range of accuracy explains the majority of the difference in the average distance between modelled and observed data. Other factors that may have affected the accuracy of the modelled and observed measurements include: human error (in both the modelling and observed scenarios), bank channel movement (the images and DEM files used by MoRAP predate at least one significant flooding event on Hinkson Creek in May of 2013), and interference with GPS satellite signal by land forms, weather, or the fact that the field team was down in the stream channel (for the point comparison).

Table 4. Descriptive statistics of the differences between GIS modelled (Phase I) and observed (Phase II) center of stream points and bankfull width at survey points.

Statistic	**Center of stream points**	**Bankfull width measurements**
Maximum	39.93 m	55.22 m
Minimum	0.00 m	0.01 m
Mean	4.18 m	4.72 m
Median	2.99 m	2.76 m

7.3 Bank and Channel Measurements

At every 100 m survey point, measurements were collected of bank and channel variables including bank angle (left and right), channel width, wetted width, bankfull width, and bank height. Bank angle exhibited the greatest variability, with a maximum of 100°, minimum of 0°, mean of 35.0°, and standard deviation of 16.1°. Channel width and bankfull width varied from a maximum of 70.0 m and 74.0 m respectively, to a minimum of 0.8 m and 1.8 m, respectively, near Hinkson Creek headwaters. Bank height reached a maximum of 5.8m near the mouth of Hinkson Creek at Perche Creek, with a minimum of 0.3 m, mean of 2.8 m, and standard deviation of 1.0 m. Please see Table 4 for a complete listing of descriptive statistics of bank and channel measurements.

Table 4. Descriptive statistics of bank and channel measurements for entire length of Hinkson Creek

Statistic	Bank angle Left	Right	Channel width	Wetted width	Bankfull width	Bank height
Maximum	100°	96°	70.0 m	24.9 m	74.0 m	5.8 m
Minimum	2°	0°	0.8 m	0 m	1.8 m	0.3 m
Mean	34.6°	35.5°	15.4 m	9.8 m	24.2 m	2.8 m
Standard Deviation	15.8°	16.4°	8.2 m	5.5 m	9.4 m	1.0 m

Hinkson Creek is a mixed-land use watershed, with various dominant land uses. Agriculture is the dominant land use type in the upper reaches, while the urban center of Columbia is close to the center of the watershed and continues toward the mouth of the stream (MoRAP report July 31, 2013). For the purposes of exploring differences in measured bank and channel parameters with stream distance (and hence land use), Figures 5 through 8 are presented below. A legend of reference sites for Figures 5 through 9 and Figure 11 is presented as Table 5.

Table 5. Legend of reference sites shown in Figures 5 through 8, listed from headwaters to mouth. Sites that do not have an asterisk (*) are macroinvertebrate and water quality monitoring sites used by the Missouri Department of Natural Resources.

MDNR SITE #	LOCATIONS REFERENCED ON STREAM DISTANCE GRAPHS
	* E. Old Highway 124
	* Mt. Zion Church Road
	* Highway HH
8	Downstream of Rogers Rd. bridge
7	Upstream of Hinkson Creek Rd. bridge
6.5	Upstream of Highway 63 connector
6	East Walnut Street bridge
5.5	Downstream of Broadway and upstream of Old Highway 63
5	Upstream of Capen Park footbridge (upstream Grindstone Confluence)
4	Downstream of Rock Quarry Rd. bridge
3.5	Upstream of Recreation Dr. (MU intramural fields)
3	Downstream of Forum Blvd.
2	Upstream of MKT bridge near Twin Lakes Recreation Area
1	Downstream of Scott Blvd.

In streams that are impacted by human land use practices, certain changes in physical parameters are observable (and expected) with stream distance. For example, while channel width is expected to increase with stream distance in natural stream systems, it also increases in impacted systems (e.g. urban stream syndrome, Walsh et al. 2005). Increased overland flow resulting from deforestation, agriculture, and increases of impervious surface with urbanization can lead to channel incision. After incision, stream banks often slump and collapse, and stream channels widen (Shepherd et al. 2011, Paul and Meyer 2001, Piégay and Schumm 2003). Figure 5 shows a slight trend of increasing channel width with stream distance. The absence of a strong positive trend could be interpreted at least a couple of ways (there may be other explanations): 1) there is not a strong positive relationship between stream distance and channel width in Hinkson Creek, or 2) the positive relationship between channel width and the effects of human land use change with stream distance are just beginning to be observed in Hinkson Creek (E.g. Hubbart and Zell 2013).

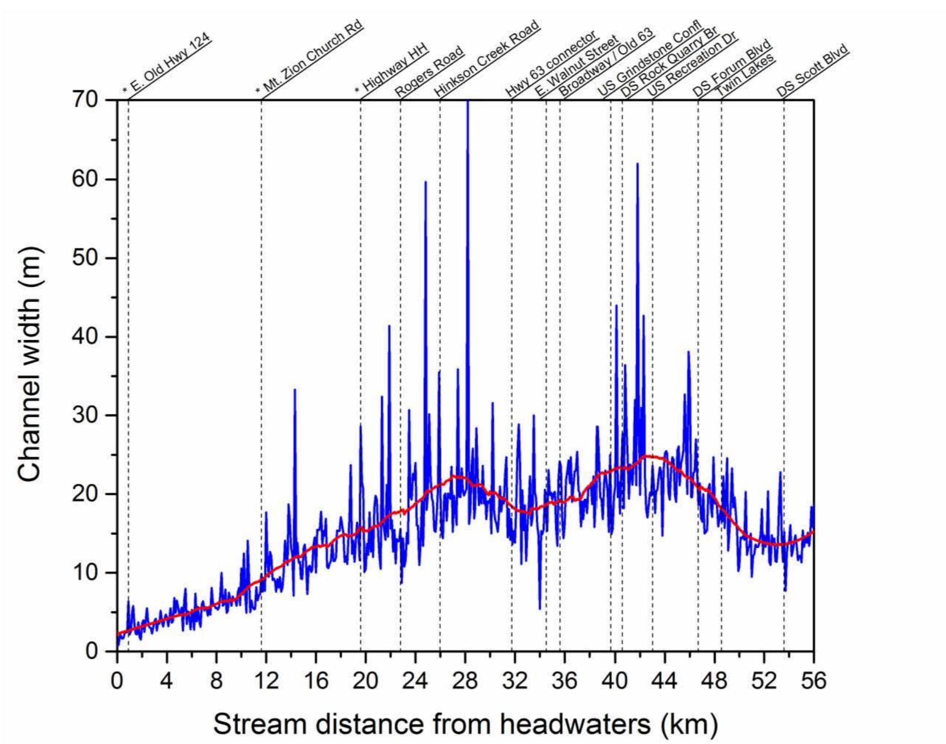

Figure 5. Channel width as a function of stream distance from the headwaters for the entire length of Hinkson Creek. 100pt moving average in red.

Wetted width in Hinkson Creek is highly variable. It would therefore not be expected that there would be a strong relationship between wetted width measured during the Phase II PHA and channel width because wetted width is highly dependent on discharge characteristics at the time of measurement whereas channel width and bankfull width are related to persistent hydrologic conditions. A comparison of channel width and wetted width with stream distance is shown below (Figure 6).

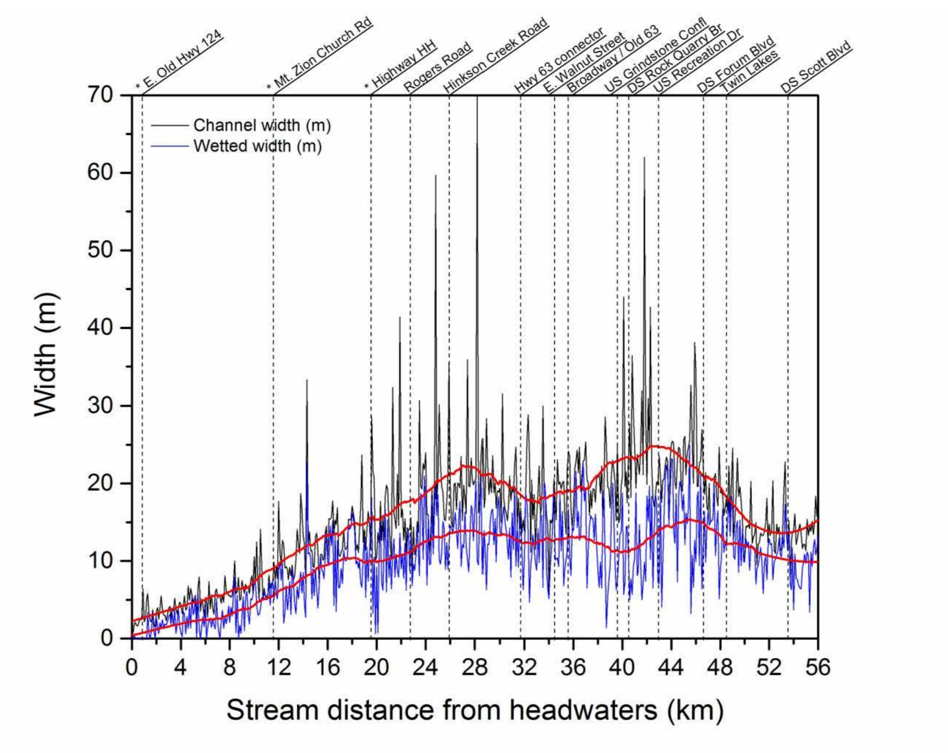

Figure 6. Channel width and wetted width as a function of stream distance for Hinkson Creek, with 100pt moving average shown in red.

Bankfull width measured from the top of the bankfull bank across the channel to the bankfull height on the opposite bank shows a slightly stronger positive relationship with stream distance than channel width (Figure 7). One possible explanation for this trend is that channel incision may be occurring in response to land use changes upstream (Booth and Jackson 1997).

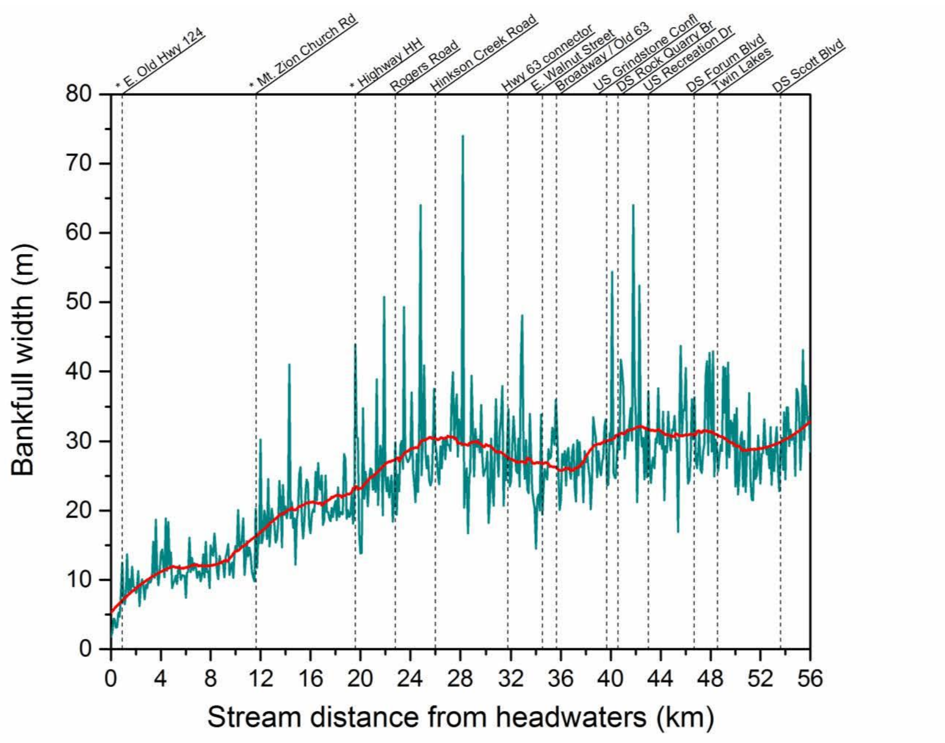

Figure 7. Bankfull width with stream distance in Hinkson Creek. The 100pt moving average is shown in red.

The graph in Figure 8 shows the strongest positive relationship (bank height increases as stream distance increases) of the bank and channel measurements illustrated between stream distances 42 km to 56 km. There is a rapid increase in bank height with stream distance in the lower reaches of the stream (from 3.44 m high at 42 km to 5.54 m high at 56 km), suggesting that channel incision may be ongoing and highly dynamic in the channel below the City of Columbia (Hubbart et al. 2011, Huang 2012). Channel incision and accompanying bank erosion may be indicative of cumulative effects, including (but not limited to) alteration of stream hydrologic processes, loss of bottomland hardwood forests, and increased impervious surfaces (Hubbart et al. 2011, Hubbart and Zell 2013).

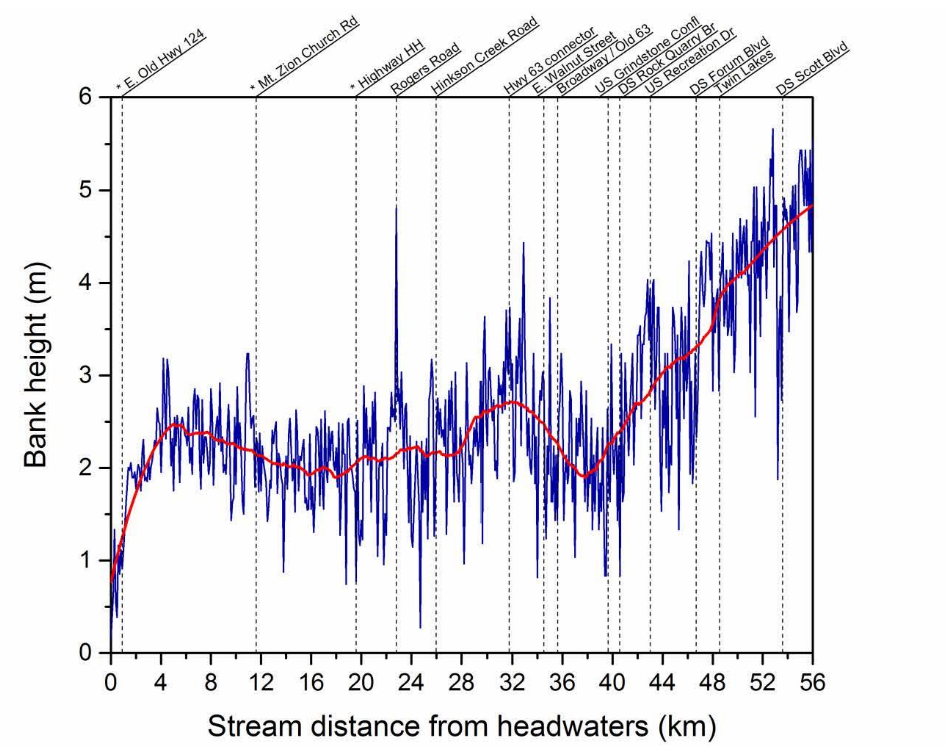

Figure 8. Bank height with distance downstream from headwaters, Hinkson Creek. The 100pt moving average is shown in red.

7.4 Relative thalweg depth and thalweg position measurements

The thalweg is the deepest point in the stream channel. The thalweg does not maintain a consistent position laterally across the stream, but varies due to stream geomorphology and shifting substrate moved by stream flows. Thalweg depth is simply a point measurement of the deepest point in the stream channel at a given moment in time. Thalweg depth was measured in Hinkson Creek at the 100 m survey points, and then approximately every 10 m between survey points. Thalweg depth varied from a maximum of 330 cm (10.83 feet) to a minimum of 0 cm near the headwaters when the channel was dry (Table 5).

Measurements during Phase II of the PHA included relative thalweg depth and thalweg position. Relative thalweg depth measures the height from the thalweg to the top of the bankfull bank. Thalweg position is the distance from the thalweg to the top of the bankfull bank to the thalweg on a horizontal plane (Figure 4). Descriptive statistics for relative thalweg depth and thalweg position are listed in Table 5, along with the percentage of measurements where the presumed bankfull bank was the right or left bank. The general trend was an increase in relative thalweg depth with stream distance, such that the minimum of 0.2 m was found near the headwaters, and the maximum of 8.6 m was at a survey point near the mouth of Hinkson Creek.

Table 5. Descriptive statistics of thalweg measurements taken at each principal transect.

Statistic	Thalweg depth*	Relative thalweg depth	Thalweg position	Bankfull bank	Percentage of sites
Maximum	330 cm	8.6 m	68.3 m	Right bank	52.9%
Minimum	0.0 cm	0.2 m	0.2 m	Left bank	46.2%
Mean	50.3 cm	3.4 m	13.7 m	Unrecorded sites (4)	0.9%
Standard deviation	38.7 cm	1.2 m	7.8 m		

*Descriptive statistics are for all thalweg depths measured during thalweg profile.

7.5 Canopy cover

Average canopy cover was calculated for each 100 m survey point by averaging the six canopy cover measurements (at left bank; at center of stream: facing upstream, facing left bank, facing downstream, facing right bank; at right bank) and dividing that average number by 17 (the maximum number of points that could be covered on the modified convex densiometer) to calculate average percent canopy cover per site. The percent canopy cover at the 100 m survey points ranged from a maximum of 100%, to a minimum of 0%, with a mean of 59.5% and standard deviation of 27.4%. A graph of the average percent canopy cover with stream distance illustrates the variability from site to site from headwaters to mouth in Hinkson Creek (Figure 9).

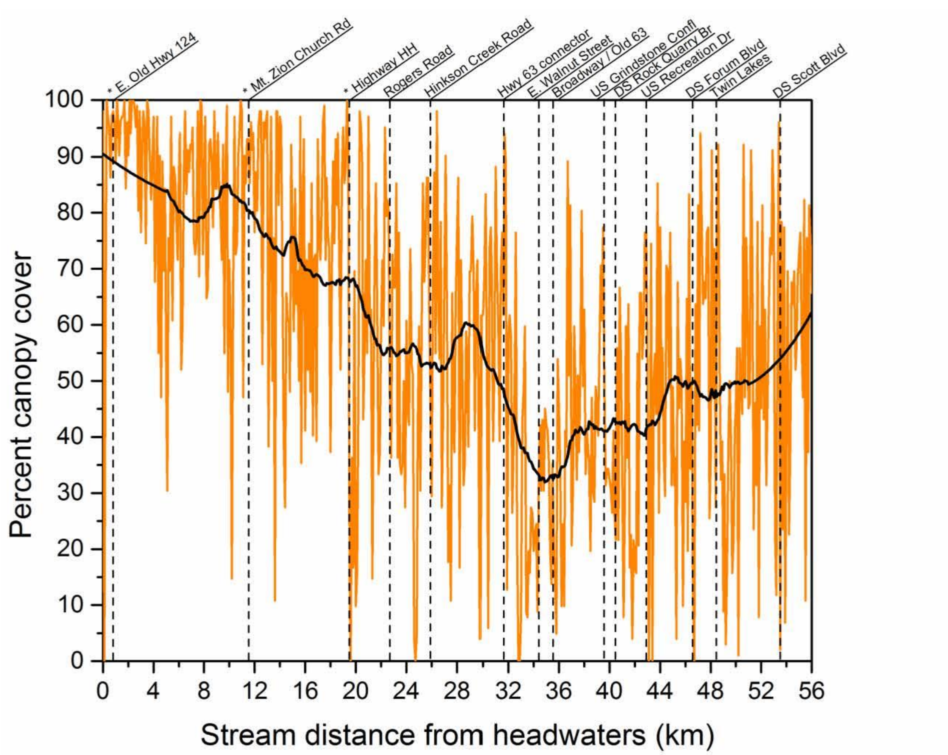

Figure 9. Percent canopy cover on each 100 m transect (average) with stream distance from headwaters, Hinkson Creek. The 100pt moving average is shown in black.

7.6 Substrate particle size and percent embeddedness

Substrate particles were collected during pebble count procedures (15 particles per 100 m survey plot), and then one additional particle was collected at the thalweg every 10 m between survey points. For ease of analysis, the particles were grouped into size classes. Small particles consist of fines (silt, clay), sand, and fine gravel (2 to 16 mm). Intermediate particles ranged from 16 to 1000 mm, and included vegetation (i.e. leaves, coarse particulate organic matter) and wood (i.e. logs, roots). The large size class included particles larger than 1000 mm, along with bedrock, both rough and smooth. The graph presented in Figure 10 below shows percentages of substrate particles broken down into individual particle size components. Substrate size is important for suitable microhabitat for aquatic organisms including macroinvertebrates such as clingers that require interstitial spaces between gravel particles in the substrate for habitat (Rabeni et al. 2005). Particle size composition was grouped into size classes in Table 6.

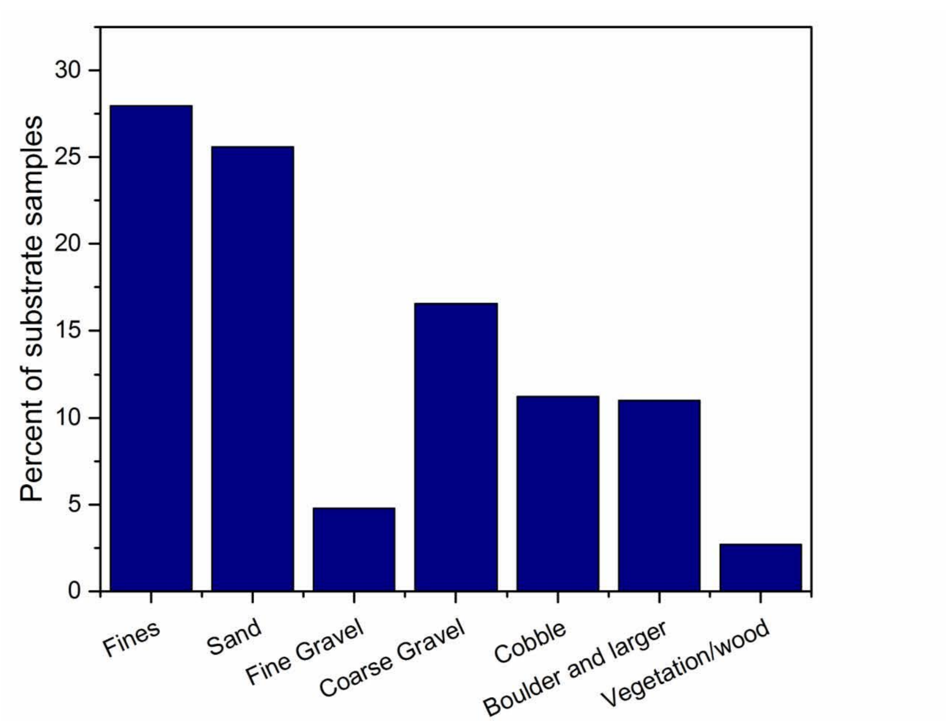

Figure 10. Substrate particles by size class (see Table 2) for all particles examined as a part of the Hinkson Creek physical habitat assessment, Phase II.

Table 6. Breakdown of size classes for sampled particles in pebble count and along thalweg profile.

Small		Intermediate		Large		Other
Sand	25.6%	Coarse gravel	16.5%	R bedrock	4.8%	0.24%
Fines*	28.0%	Cobble	11.2%	S bedrock	1.7%	
Sm gravel	4.8%	Sm boulder	3.3%	Xl boulder	0.8%	
		Vegetation	1.8%	Riprap	0.4%	
		Wood	0.8%	Lg concrete	0.06%	
Total:	58.4%		33.6%		7.76%	0.24%

*silt and clay

Substrate characteristics are the most significant habitat selection criteria for specific families of macroinvertebrates (Richards et al. 1993). However, substrate particle size is not the only characteristic of the streambed that is important for macroinvertebrate habitat. Embeddedness of the substrate due to deposition of fine sediment (i.e. sand, silt and clay) can fill interstitial spaces regardless of the particle size class composition (Rabeni et al. 2005).

Average percent vertical embeddednesss was calculated from percent vertical embeddedness of the 15 particles collected during the pebble count at each 100 m survey transect. Average percent vertical embeddedness is graphed as a function of stream distance in Figure 11 below. Average percent vertical embeddedness at survey transects ranged from a maximum of 100% to a minimum of 10%, with a mean of 72% and standard deviation of 21%. The average percent vertical embeddedness at a survey transect was calculated to be 100% fifty-one times along the length of Hinkson Creek, or approximately 9% of the survey transects. A highly embedded streambed significantly reduces habitat available for virtually all macroinvertebrates except those that are burrowers (Rabeni et al. 2005). Based on the results from the PHA Phase II, Hinkson Creek appears to have reduced habitat heterogeneity available for macroinvertebrate habitat.

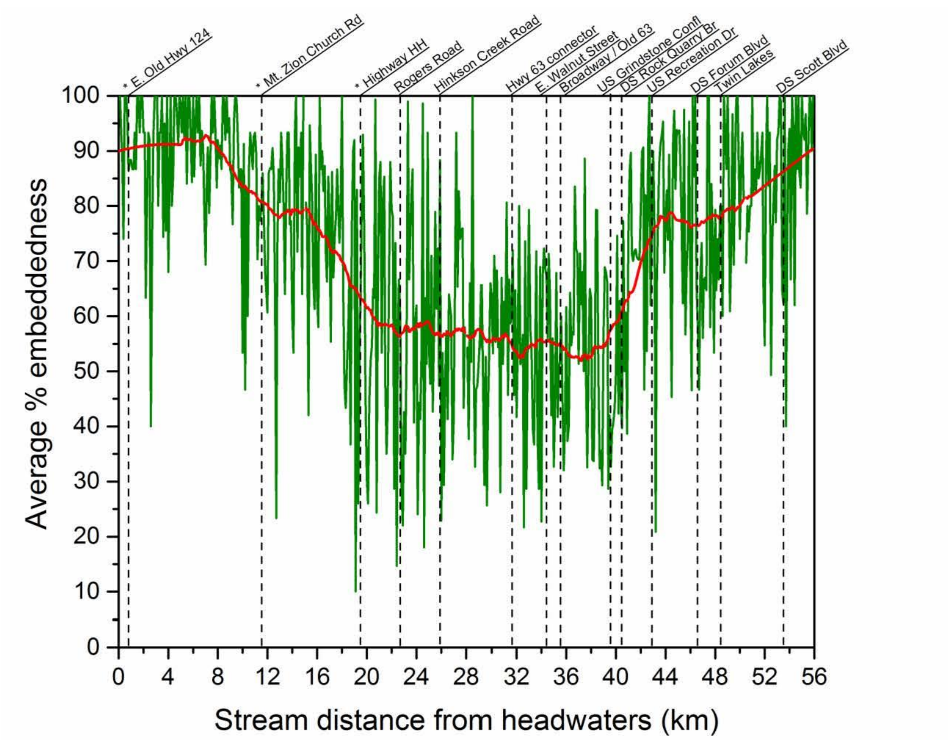

Figure 11. Average percent embeddedness for sampled particles (5) at each survey transect with stream distance from headwaters of Hinkson Creek. The 100pt moving average is shown in red.

7.7 Channel unit classification

Alluvial streams are expected to exhibit certain morphological characteristics, including a sequence of channel unit types, particularly riffles and pools. The riffle-pool sequence is expected at regular intervals along the stream continuum. The Missouri Department of Natural Resources (MDNR) procedure for Semi-Quantitative Macroinvertebrate Stream Bioassessment states that riffles are expected to occur at a distance of 7 to 10 stream widths (wetted width) due to the effects of sinuosity and the influence of point bars on streamflow velocity (MDNR 2003). The results of Phase II of the PHA showed that trench pools are the dominant form of channel unit at 70% of channel unit types recorded (survey point, and then every ten meters between survey points). Given the MDNR standard, and the average wetted width of 9.8 m in Hinkson Creek, a riffle would be expected approximately every 68.6 to 98 m. Using the more conservative estimate, 816 riffles would be expected along the length of Hinkson Creek (14.6% of channel unit classifications given total measurements of 5,583). Using this calculation, the results in Figure 12 are slightly above expected riffle-pool frequency in Hinkson Creek. The breakdown of channel unit types is listed in table form in Table 7.

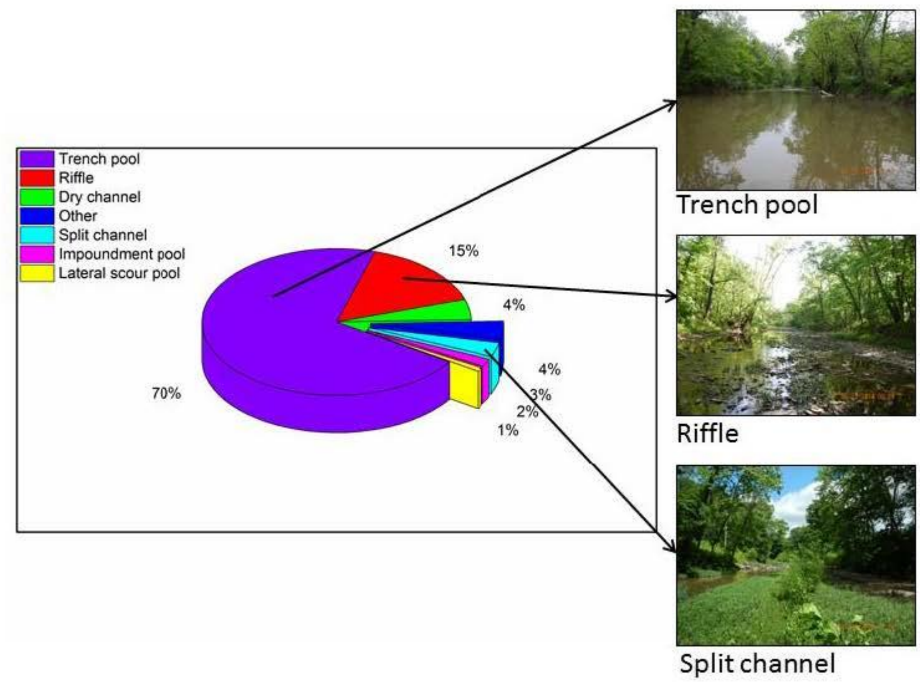

Figure 12. Breakdown of channel unit types in Hinkson Creek.

Table 7. Channel unit breakdown at principal transects and 10 m transects along thalweg profile.

Channel unit	Percent of total count
Trench pool	70%
Riffle	15%
Dry channel	4%
Split channel	3%
Impoundment pool	2%
Lateral scour pool	1%
Other	4%

7.8 Confluences

The point along the stream where a tributary enters the stream is called a confluence. Previous work showed that the effects of tributary convergence on stream morphology can be observed above and below a confluence (Benda et al. 2004). In Hinkson Creek, detailed bank and channel measurements were made at each of the eight major confluences. Three transects were used, one above and one below the confluence on Hinkson Creek, and then the last above the confluence on the tributary. The measurements from the three transects were averaged and confluence data are presented in Table 8. At the time of this work, bankfull width at the confluences was on average greater than average bankfull width along Hinkson Creek (average bankfull width 24.2 m).

Table 8. Summary of bank height and channel measurements for average of three transects at each major confluence of Hinkson Creek.

	Confluence*							
Measurement	**MB**	**MC**	**CH**	**FB**	**GC**	**HB**	**NC**	**VB**
Thalweg depth	**0.**43 m	0.49 m	1.34 m	0.41 m	0.44 m	0.60 m	0.35 m	0.35 m
Bank height	4.92 m	4.28 m	4.30 m	3.72 m	2.55 m	2.78 m	2.70 m	2.14 m
Wetted width	6.21 m	8.33 m	11.30 m	12.23 m	9.10 m	12.6 m	12.21 m	15.07 m
Bankfull width	23.67 m	24.80 m	27.90 m	37.97 m	35.83 m	26.6 m	23.87 m	22.8 m
Channel width	9.18 m	8.77 m	13.57 m	24.17 m	21.8 m	16.9 m	14.4 m	15.73 m

*MB = Meredith Branch, MC = Mill Creek, CH = County House Branch, FB = Flat Branch Creek, GC = Grindstone Creek, HB = Hominy Branch, NC = Nelson Creek, VB = Varnon Branch

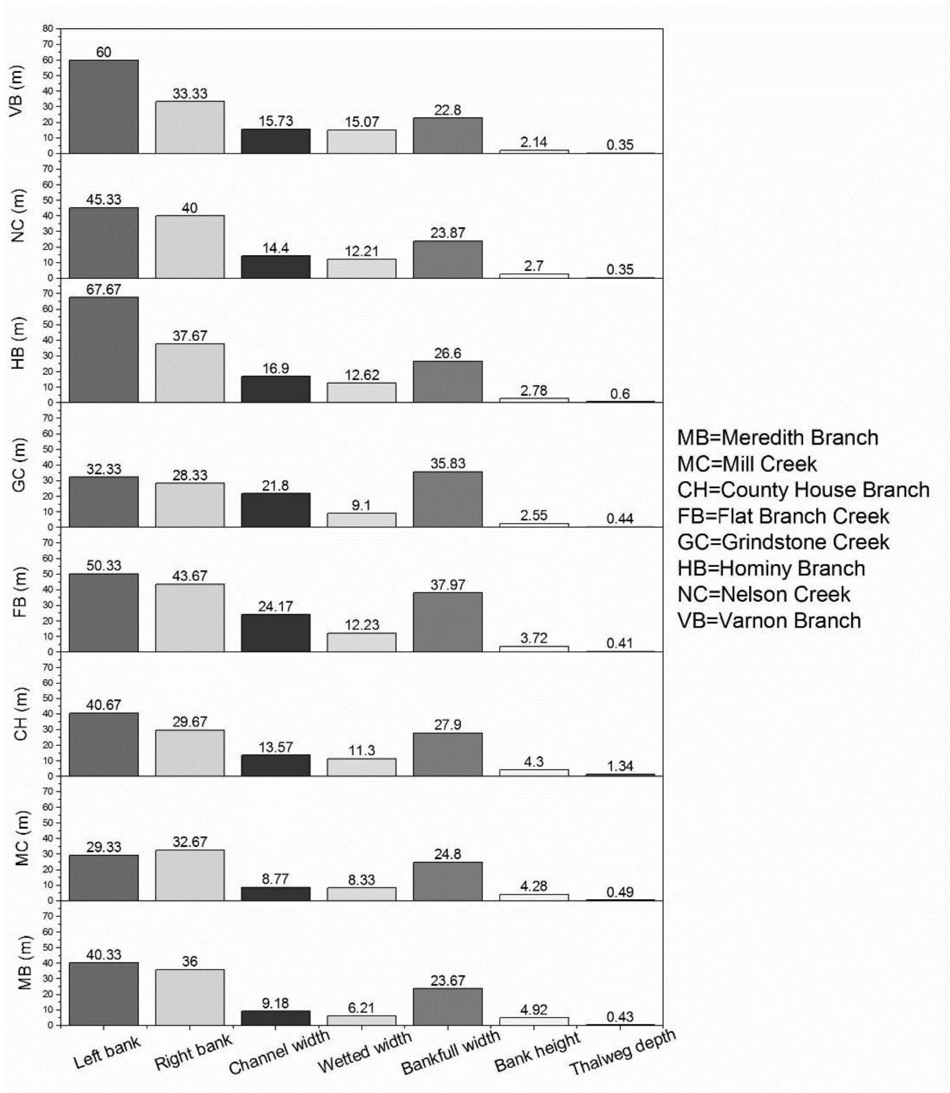

Figure 13. A comparison of averaged transect measurements (see Section 4.0 Field Protocol for how metrics are calculated) at the confluence of each of the eight major tributaries of Hinkson Creek. All measurements are in meters, with the exception of the left bank and right bank angles which are in degrees.

7.9 Photographic database

Standard channel photographs for each survey point will be presented to Boone County, Missouri at the time that this report is finalized and submitted, or as soon as a practicable mode of transferal is proposed. Presumably the photographic database will be uploaded to the project server and will be available to watershed stakeholders. The photographic database will also include photographs of special features (e.g. bank erosion, riprap, outlet pipes) for the survey point, and the 100 m section between survey points. For ease of cataloging, the photographs for the special features are named to include the survey point number, the date, the type of special feature, and whether the feature was noted on the right or left bank of the stream.

7.10 Statistical analysis of cross section accuracy

As per the field protocol, every tenth field day, one half day was spent resurveying every other survey point from the first field day in the sequence. If less than five sites were surveyed on the first field day, then all of the sites from the first field day in the sequence were resurveyed. The original bank and channel measurements were compared to the resurveyed measurements, and the differences were examined using descriptive statistics, including maximum, minimum, mean, median and standard deviation. Initial and return visit site data were arranged in columns and compared using the Student's T-Test to check for statistical relatedness (CI = 0.05) (Sokal and Rohlf 1981, Zar 1996). At the 0.05 level of significance, none of the metrics were statistically different between the two survey dates, and the lowest p-value of all of the metrics compared was 0.54 (Figure 14, Table 9) indicating very strong relationships between initial surveys and resurveys.

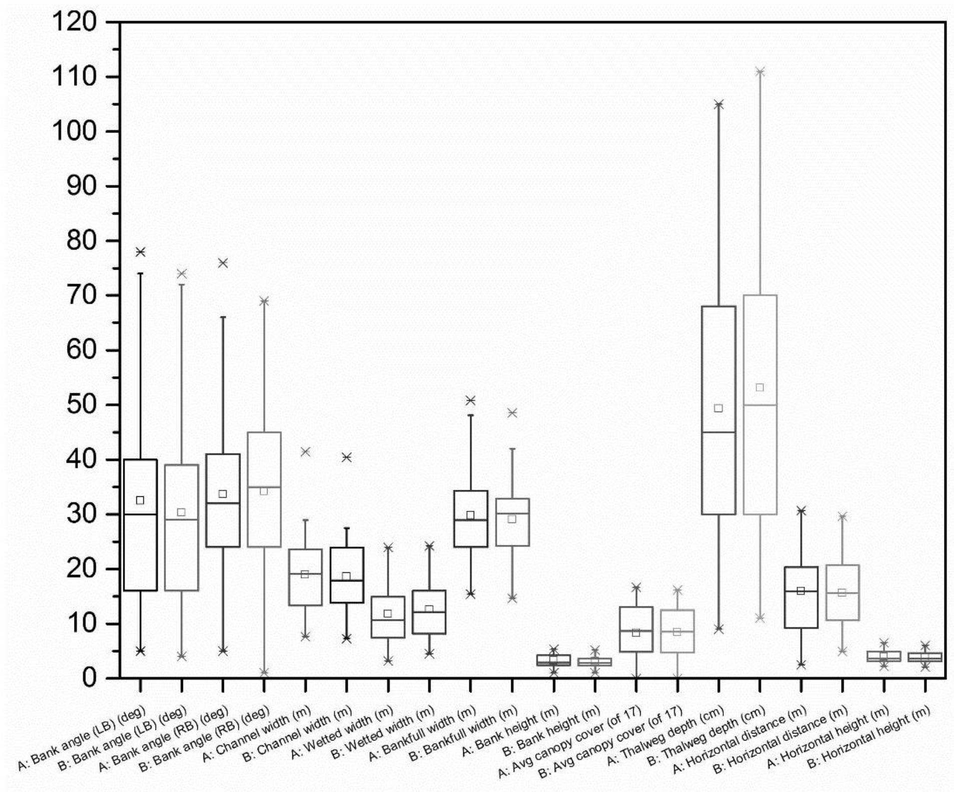

Figure 14. Box and whisker plot of comparison of initial survey metric (A) and resurveyed metric (B) at resurvey points. The median value of each measurement is shown by the horizontal line through the box, and the mean value of each measurement is shown by the small box near the horizontal line. Outliers are denoted by asterisks. If the two sets of measurements were statistically different, there would be greater vertical distance between the larger boxes and the horizontal lines and small boxes.

Table 9. Descriptive statistics of comparison of initial surveys to resurveys.

Metric	Mean	Standard Deviation	Minimum	Median	Maximum
A: Bank angle (LB) (deg)	32.46	18.60	5.00	30.00	78.00
B: Bank angle (LB) (deg)	30.34	18.28	4.00	29.00	74.00
A: Bank angle (RB) (deg)	33.66	15.30	5.00	32.00	76.00
B: Bank angle (RB) (deg)	34.20	16.29	1.00	35.00	69.00
A: Channel width (m)	18.96	6.91	7.60	19.10	41.40
B: Channel width (m)	18.57	6.63	7.30	17.90	40.40
A: Wetted width (m)	11.77	5.45	3.20	10.70	23.90
B: Wetted width (m)	12.56	5.30	4.50	12.10	24.20
A: Bankfull width (m)	29.75	7.85	15.40	28.90	50.80
B: Bankfull width (m)	29.07	7.12	14.60	30.10	48.50
A: Bank height (m)	3.22	1.17	1.04	2.90	5.30
B: Bank height (m)	3.07	1.07	1.01	2.85	5.19
A: Avg canopy cover (of 17)	8.31	4.46	0.00	8.67	16.67
B: Avg canopy cover (of 17)	8.44	4.96	0.00	8.50	16.17
A: Thalweg depth (cm)	49.36	27.81	9.00	45.00	105.00
B: Thalweg depth (cm)	53.11	27.75	11.00	50.00	111.00
A: Horizontal distance (m)	15.96	7.45	2.50	15.90	30.70
B: Horizontal distance (m)	15.61	6.24	4.90	15.60	29.60
A: Horizontal height (m)	3.94	1.11	2.17	3.64	6.50
B: Horizontal height (m)	3.81	1.11	2.09	3.60	6.00

8.0 Closing Statements

The products presented from this research are the first of such information generated in Hinkson Creek. Methods are scalable, and transferrable to other watersheds, and results have applicability for land use managers and agency planners in the Hinkson Creek Watershed, and elsewhere. Notably, while highly informative, these results will be greatly enriched by ongoing future Physical Habitat Assessments (i.e. repeated surveys) preferably conducted at 2 to 5 year intervals to enable identification of key impacts (i.e. climate, development, engineered structures, etc.). The photographic and numeric databases can be used to identify potential locations of previous, current or future hydrologic disturbance, and may indicate sites that would benefit from conservation or restoration efforts. Some of the data collected in the PHA Phase II will be further developed in the Master's thesis of Lynne Hooper that should be available via the University of Missouri's MoSpace website after June 1st, 2015. The large dataset generated by the PHA will be an invaluable resource for current, ongoing and future management activities and policy initiatives in the Hinkson Creek Watershed and provides a rich baseline data set that will be valuable for future assessments.

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Table 23. Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
0.00	5.25	1.02	0.00	28.10	9.48	1.00	1.00
0.10	3.09	1.04	0.00	28.20	29.60	1.26	1.00
0.20	3.08	1.06	0.00	28.30	5.96	1.06	1.00
0.30	2.64	1.00	0.00	28.40	7.50	1.01	1.00
0.40	3.86	0.99	0.00	28.50	7.91	1.02	1.00
0.50	5.16	1.03	0.00	28.60	5.22	1.02	1.00
0.60	3.38	1.06	0.00	28.70	7.75	1.01	0.00
0.70	3.56	1.02	0.00	28.80	8.57	0.98	0.00
0.80	5.59	1.06	0.00	28.90	14.33	1.04	1.00
0.90	10.87	1.05	0.00	29.00	8.03	1.19	1.00
1.00	4.93	0.99	0.00	29.10	6.92	1.04	0.00
1.10	3.69	1.02	0.00	29.20	9.09	1.00	0.00
1.20	4.45	1.10	0.00	29.30	8.46	1.02	1.00
1.30	5.78	1.03	0.00	29.40	9.47	1.05	1.00
1.40	3.28	1.00	0.00	29.50	7.28	0.99	0.00
1.50	4.26	1.07	0.00	29.60	10.70	1.02	1.00
1.60	3.28	1.03	0.00	29.70	5.68	1.01	1.00
1.70	4.72	1.07	0.00	29.80	6.94	1.04	1.00
1.80	3.84	1.07	0.00	29.90	7.14	1.19	1.00
1.90	3.97	1.03	0.00	30.00	9.36	1.03	1.00
2.00	3.38	1.06	0.00	30.10	7.92	0.99	0.00
2.10	3.93	1.01	0.00	30.20	4.42	1.00	0.00
2.20	4.83	1.03	0.00	30.30	6.68	1.03	0.00

Table 23 (**cont.**). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
2.30	2.46	1.03	0.00	30.40	10.00	0.99	0.00
2.40	3.84	0.99	0.00	30.50	6.53	1.00	0.00
2.50	3.53	0.99	0.00	30.60	4.93	1.02	1.00
2.60	3.36	1.25	1.00	30.70	9.59	1.02	1.00
2.70	2.79	1.08	0.00	30.80	13.67	1.05	1.00
2.80	4.08	1.03	0.00	30.90	7.30	1.04	1.00
2.90	3.52	0.99	0.00	31.00	7.11	1.09	0.00
3.00	3.83	1.01	1.00	31.10	8.14	0.99	0.00
3.10	4.10	1.00	0.00	31.20	8.23	1.12	0.00
3.20	3.53	1.00	0.00	31.30	10.61	1.02	0.00
3.30	4.13	1.02	0.00	31.40	6.20	1.01	1.00
3.40	5.76	0.99	0.00	31.50	6.48	0.99	1.00
3.50	3.60	1.22	1.00	31.60	6.63	1.01	1.00
3.60	6.58	1.00	0.00	31.70	7.98	1.03	1.00
3.70	3.38	1.06	0.00	31.80	8.90	1.06	1.00
3.80	3.16	1.01	0.00	31.90	6.93	1.08	0.00
3.90	3.57	0.99	0.00	32.00	7.18	1.02	0.00
4.00	5.07	0.99	0.00	32.10	10.85	1.01	0.00
4.10	4.34	1.08	1.00	32.20	9.39	1.07	0.00
4.20	3.37	1.01	1.00	32.30	8.81	1.00	0.00
4.30	2.89	1.04	0.00	32.40	8.16	1.05	0.00
4.40	5.82	1.13	0.00	32.50	6.12	1.08	0.00
4.50	3.21	1.16	0.00	32.60	6.80	1.02	0.00
4.60	5.23	1.03	0.00	32.70	6.56	0.99	0.00
4.70	3.44	0.99	0.00	32.80	10.42	1.02	0.00
4.80	4.73	1.01	0.00	32.90	8.86	1.00	1.00
4.90	2.39	1.33	1.00	33.00	7.46	1.02	1.00
5.00	4.44	1.18	0.00	33.10	7.94	1.05	1.00

Table 23 (**cont.**). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
5.10	3.25	1.06	0.00	33.20	9.44	1.00	1.00
5.20	3.58	1.06	0.00	33.30	6.05	1.00	1.00
5.30	3.37	1.44	0.00	33.40	6.25	1.06	1.00
5.40	3.84	1.02	0.00	33.50	13.60	1.01	0.00
5.50	4.23	0.99	0.00	33.60	9.97	1.02	2.00
5.60	3.48	1.02	0.00	33.70	5.63	0.98	1.00
5.70	3.20	1.46	0.00	33.80	8.27	1.02	1.00
5.80	3.62	1.08	0.00	33.90	7.52	1.06	0.00
5.90	3.88	1.07	0.00	34.00	8.06	1.05	0.00
6.00	2.40	1.02	0.00	34.10	6.58	1.08	0.00
6.10	4.06	1.00	0.00	34.20	6.37	1.02	0.00
6.20	3.68	1.14	0.00	34.30	5.56	1.00	0.00
6.30	5.35	1.03	0.00	34.40	8.92	1.02	0.00
6.40	4.11	1.09	0.00	34.50	4.97	1.13	1.00
6.50	4.71	1.45	0.00	34.60	9.16	1.04	1.00
6.60	3.63	1.19	0.00	34.70	10.40	1.05	1.00
6.70	3.72	1.13	0.00	34.80	7.61	1.02	0.00
6.80	3.93	1.71	0.00	34.90	9.42	1.00	0.00
6.90	3.14	1.06	0.00	35.00	6.57	1.02	0.00
7.00	3.44	1.04	0.00	35.10	11.00	1.02	0.00
7.10	4.23	0.99	0.00	35.20	10.69	0.99	0.00
7.20	4.43	1.01	0.00	35.30	10.67	1.01	0.00
7.30	3.54	0.99	1.00	35.40	14.48	1.02	2.00
7.40	5.17	1.02	1.00	35.50	11.80	0.99	2.00
7.50	3.95	1.02	1.00	35.60	12.41	1.04	2.00
7.60	4.95	0.99	1.00	35.70	8.78	0.98	1.00
7.70	3.44	1.13	1.00	35.80	7.20	1.03	1.00
7.80	4.39	1.04	0.00	35.90	5.15	1.04	1.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
7.90	3.19	1.04	0.00	36.00	6.35	1.02	1.00
8.00	4.39	1.05	0.00	36.10	8.55	1.05	1.00
8.10	4.29	1.03	0.00	36.20	10.23	1.02	0.00
8.20	6.03	1.07	1.00	36.30	9.86	1.24	1.00
8.30	5.14	1.02	1.00	36.40	7.87	1.00	1.00
8.40		1.02	1.00	36.50	11.67	1.02	1.00
8.50	3.84	1.01	1.00	36.60	9.09	0.99	1.00
8.60	3.02	0.99	1.00	36.70	6.64	0.99	1.00
8.70	4.34	1.01	1.00	36.80	11.18	1.00	1.00
8.80	4.08	0.99	1.00	36.90	7.47	1.04	1.00
8.90	4.15	1.02	1.00	37.00	24.67	1.02	0.00
9.00	4.21	0.99	1.00	37.10	8.10	0.99	1.00
9.10	3.87	1.05	1.00	37.20	6.87	1.05	1.00
9.20	5.73	1.02	0.00	37.30	9.74	1.02	1.00
9.30	4.42	1.00	0.00	37.40	6.97	1.02	1.00
9.40	4.44	1.07	0.00	37.50	8.79	1.00	1.00
9.50	4.01	0.99	1.00	37.60	7.51	1.23	1.00
9.60	5.20	1.01	1.00	37.70	9.54	1.01	1.00
9.70	4.90	1.05	0.00	37.80	9.22	1.02	0.00
9.80	3.47	1.09	0.00	37.90	8.41	1.06	0.00
9.90	4.05	1.03	0.00	38.00	11.25	1.02	0.00
10.00	4.66	1.02	0.00	38.10	9.40	0.99	0.00
10.10	4.20	1.04	0.00	38.20	6.87	1.00	0.00
10.20	7.94	0.99	0.00	38.30	7.24	0.99	0.00
10.30	4.61	1.17	0.00	38.40	8.08	1.01	0.00
10.40	5.38	1.05	1.00	38.50	8.10	1.00	0.00
10.50	5.23	0.99	1.00	38.60	11.55	1.09	1.00
10.60	5.61	1.05	1.00	38.70	11.32	1.00	1.00

Table 23 (**cont.**). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
10.70	4.12	1.00	1.00	38.80	7.09	1.05	0.00
10.80	3.54	1.07	0.00	38.90	9.92	1.23	0.00
10.90	4.22	1.02	0.00	39.00	11.44	1.75	0.00
11.00	3.62	0.98	0.00	39.10	13.05	1.22	0.00
11.10	4.16	1.03	1.00	39.20	8.66	1.17	0.00
11.20	4.01	1.01	1.00	39.30	11.83	1.07	0.00
11.30	3.52	1.01	1.00	39.40	17.19	1.05	0.00
11.40	3.04	1.04	1.00	39.50	24.69	1.03	0.00
11.50	4.00	1.07	1.00	39.60	6.92	1.05	0.00
11.60	6.40	1.09	0.00	39.70	10.77	1.15	0.00
11.70	3.77	1.01	0.00	39.80	11.02	1.02	0.00
11.80	7.12	1.01	0.00	39.90	7.61	1.20	0.00
11.90	5.03	1.01	0.00	40.00	9.55	1.02	0.00
12.00	8.56	1.02	0.00	40.10	17.55	1.05	0.00
12.10	5.63	0.99	1.00	40.20	5.64	1.13	0.00
12.20	6.32	1.05	1.00	40.30	7.75	1.23	0.00
12.30	7.02	1.00	0.00	40.40	11.76	1.17	0.00
12.40	7.30	1.02	0.00	40.50	9.16	1.04	0.00
12.50	5.89	1.01	1.00	40.60	26.25	1.06	0.00
12.60	9.04	1.01	1.00	40.70	5.65	1.55	0.00
12.70	6.12	0.99	1.00	40.80	10.17	1.43	0.00
12.80	6.33	1.09	1.00	40.90	10.84	1.29	0.00
12.90	7.15	1.05	0.00	41.00	9.95	1.16	0.00
13.00	6.43	1.03	0.00	41.10	8.33	1.06	0.00
13.10	5.78	1.02	0.00	41.20	9.53	1.41	0.00
13.20	5.24	1.02	1.00	41.30	8.57	1.05	0.00
13.30	5.54	0.99	1.00	41.40	7.17	1.01	0.00
13.40	6.79	1.02	1.00	41.50	9.65	1.13	0.00

Table 23 (**cont.**). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
13.50	9.72	1.02	1.00	41.60	8.92	1.03	0.00
13.60	6.84	1.04	1.00	41.70	8.36	1.21	0.00
13.70	4.93	1.09	1.00	41.80	17.78	1.08	0.00
13.80	7.25	1.09	1.00	41.90	12.77	1.10	0.00
13.90	8.47	0.99	1.00	42.00	8.74	1.31	0.00
14.00	8.44	1.04	1.00	42.10	5.17	1.11	0.00
14.10	7.84	1.05	1.00	42.20	5.87	1.06	0.00
14.20	6.84	1.04	0.00	42.30	11.91	1.17	0.00
14.30	9.32	1.00	0.00	42.40	7.40	1.15	0.00
14.40	5.73	1.00	0.00	42.50	6.08	1.41	0.00
14.50	7.34	1.00	1.00	42.60	8.24	2.05	0.00
14.60	5.50	1.06	1.00	42.70	6.45	1.21	0.00
14.70	6.85	0.99	1.00	42.80	7.76	1.08	0.00
14.80	4.07	1.02	1.00	42.90	6.12	1.07	0.00
14.90	5.42	0.99	1.00	43.00	8.27	1.05	0.00
15.00		1.05	2.00	43.10	6.87	1.06	0.00
15.10	9.13	1.04	1.00	43.20	5.45	1.06	0.00
15.20	7.65	1.01	1.00	43.30	6.02	1.44	0.00
15.30	7.03	1.09	1.00	43.40	6.93	1.47	0.00
15.40	5.54	1.01	1.00	43.50	6.69	1.26	0.00
15.50	6.00	1.00	2.00	43.60	5.63	1.06	0.00
15.60	6.61	1.00	2.00	43.70	6.93	1.01	0.00
15.70	8.94	1.01	2.00	43.80	10.47	1.03	0.00
15.80	7.95	1.07	2.00	43.90	13.45	1.07	0.00
15.90	5.72	1.13	2.00	44.00	7.09	1.85	0.00
16.00	7.32	0.99	2.00	44.10	8.26	1.13	0.00
16.10	6.04	1.01	2.00	44.20	7.98	1.09	0.00
16.20	7.83	1.02	1.00	44.30	9.91	1.12	0.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
16.30	6.85	1.00	1.00	44.40	5.98	1.07	0.00
16.40	8.21	1.00	1.00	44.50	10.92	1.07	0.00
16.50	6.50	1.03	1.00	44.60	10.72	1.18	0.00
16.60	8.46	1.10	1.00	44.70	9.53	1.17	0.00
16.70	9.40	0.99	0.00	44.80	6.38	1.74	0.00
16.80	7.62	1.00	1.00	44.90	6.89	1.08	0.00
16.90	8.63	1.02	1.00	45.00	7.52	0.99	0.00
17.00	7.58	1.02	1.00	45.10	7.84	1.04	0.00
17.10	5.88	0.98	1.00	45.20	6.40	1.02	0.00
17.20	8.66	1.02	1.00	45.30	10.41	1.46	0.00
17.30	7.92	1.18	1.00	45.40	3.76	1.79	0.00
17.40	6.56	0.99	0.00	45.50	7.70	1.50	0.00
17.50	6.62	1.00	0.00	45.60	12.49	1.46	0.00
17.60	6.15	1.01	0.00	45.70	8.16	1.18	0.00
17.70	6.48	1.01	1.00	45.80	7.69	1.13	0.00
17.80	5.79	1.02	1.00	45.90	8.63	1.59	0.00
17.90	6.56	1.13	1.00	46.00	8.44	1.49	0.00
18.00	5.94	1.00	2.00	46.10	5.80	1.02	0.00
18.10	6.67	1.00	1.00	46.20	7.03	1.15	0.00
18.20	7.55	1.00	1.00	46.30	6.97	1.47	0.00
18.30	8.38	1.03	1.00	46.40	5.98	1.31	0.00
18.40	7.67	1.13	1.00	46.50	8.80	1.17	0.00
18.50	6.15	1.05	1.00	46.60	6.59	1.33	0.00
18.60	6.29	1.02	2.00	46.70	9.58	1.43	0.00
18.70	10.41	0.99	1.00	46.80	7.16	1.36	0.00
18.80	9.42	1.02	1.00	46.90	5.80	1.56	0.00
18.90	5.51	1.05	1.00	47.00	5.86	1.17	0.00
19.00	6.15	0.99	1.00	47.10	5.13	1.56	0.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
19.10	7.55	1.02	1.00	47.20	5.18	1.31	0.00
19.20	6.95	1.00	1.00	47.30	5.28	3.09	0.00
19.30	9.38	1.01	1.00	47.40	6.06	1.48	0.00
19.40	6.33	1.02	1.00	47.50	5.26	1.32	0.00
19.50	8.02	0.99	1.00	47.60	8.04	1.07	0.00
19.60	26.61	1.15	1.00	47.70	7.16	2.27	0.00
19.70	8.46	1.02	1.00	47.80	5.71	1.06	0.00
19.80	11.05	0.98	1.00	47.90	7.36	1.06	0.00
19.90	9.88	1.46	1.00	48.00	6.96	1.21	0.00
20.00	6.27	1.02	0.00	48.10	4.75	1.01	0.00
20.10	6.75	0.99	0.00	48.20	7.00	1.09	0.00
20.20	10.39	1.03	0.00	48.30	4.27	1.37	0.00
20.30	7.31	1.22	1.00	48.40	6.06	3.67	0.00
20.40	7.53	0.99	0.00	48.50	5.45	1.16	0.00
20.50	8.08	1.02	1.00	48.60	4.21	1.22	0.00
20.60	7.18	1.02	0.00	48.70	4.43	2.34	0.00
20.70	8.10	1.19	2.00	48.80	5.00	1.28	0.00
20.80	9.46	1.01	0.00	48.90	5.20	1.36	0.00
20.90	8.04	1.26	1.00	49.00	6.46	1.85	0.00
21.00	6.52	1.01	1.00	49.10	6.69	1.67	0.00
21.10	7.71	1.00	1.00	49.20	7.64	1.43	0.00
21.20	9.12	1.07	1.00	49.30	4.50	1.41	0.00
21.30	14.66	1.02	0.00	49.40	6.07	1.06	0.00
21.40	8.78	1.02	0.00	49.50	4.62	1.14	0.00
21.50	7.10	1.00	1.00	49.60	5.79	2.36	0.00
21.60	10.85	1.02	1.00	49.70	7.58	1.69	0.00
21.70	10.48	1.03	1.00	49.80	4.05	2.34	0.00
21.80	8.43	1.02	0.00	49.90	6.01	1.08	0.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
21.90	20.16	1.08	0.00	50.00	4.30	1.41	0.00
22.00	8.81	1.00	0.00	50.10	5.56	1.00	0.00
22.10	7.13	1.02	1.00	50.20	3.93	1.81	0.00
22.20	8.16	1.00	1.00	50.30	4.76	1.26	0.00
22.30	6.07	1.04	1.00	50.40		1.25	0.00
22.40	6.70	1.07	1.00	50.50	6.45	1.09	0.00
22.50	8.10	1.03	1.00	50.60	4.70	1.15	0.00
22.60	5.40	1.02	1.00	50.70	5.05	1.02	0.00
22.70	5.63	1.08	1.00	50.80	3.95	1.01	0.00
22.80	5.65	1.00	1.00	50.90	5.52	1.15	0.00
22.90	5.57	1.01	1.00	51.00	4.99	1.36	0.00
23.00	6.87	1.00	1.00	51.10	6.80	1.38	0.00
23.10	7.78	1.02	1.00	51.20	4.64	1.69	0.00
23.20	9.19	1.07	1.00	51.30	3.99	1.82	0.00
23.30	9.71	1.02	1.00	51.40	5.67	2.14	0.00
23.40	7.43	1.13	1.00	51.50	5.07	1.36	0.00
23.50	16.38	0.99	1.00	51.60	4.55	1.20	0.00
23.60	8.55	1.00	1.00	51.70	4.73	1.18	0.00
23.70	8.90	1.13	2.00	51.80	7.36	1.62	0.00
23.80	10.47	1.06	2.00	51.90	4.15	1.36	0.00
23.90	7.69	1.03	1.00	52.00	3.74	1.53	0.00
24.00	11.20	1.00	1.00	52.10	4.37	1.31	0.00
24.10	15.20	1.00	1.00	52.20	5.38	1.22	0.00
24.20	10.83	0.99	1.00	52.30	6.51	1.49	0.00
24.30	8.39	1.00	1.00	52.40	5.32	1.41	0.00
24.40	6.60	1.00	1.00	52.50	4.68	1.15	0.00
24.50	9.40	1.01	1.00	52.60	4.39	1.11	0.00
24.60	8.90	1.03	2.00	52.70	4.24	1.12	0.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
24.70	17.09	0.98	2.00	52.80	4.94	1.56	0.00
24.80	19.05	1.02	1.00	52.90	3.98	1.19	0.00
24.90	8.90	0.99	1.00	53.00	4.65	1.09	0.00
25.00	8.98	1.01	1.00	53.10	4.27	1.91	0.00
25.10	14.98	1.03	1.00	53.20	5.92	1.25	0.00
25.20	8.96	1.03	1.00	53.30	6.92	1.36	0.00
25.30	12.31	1.03	1.00	53.40	5.00	1.43	0.00
25.40	7.66	1.03	1.00	53.50	5.88	1.15	0.00
25.50	6.51	0.99	0.00	53.60	5.45	1.25	0.00
25.60	6.88	0.99	0.00	53.70	5.41	1.46	0.00
25.70	6.80	1.02	0.00	53.80	5.08	1.25	0.00
25.80	9.71	1.00	0.00	53.90	5.86	1.23	0.00
25.90	9.40	0.99	0.00	54.00	4.54	1.13	0.00
26.00	8.19	1.02	0.00	54.10	5.71	1.01	0.00
26.10	7.38	0.99	0.00	54.20	5.72	1.03	0.00
26.20	7.17	0.99	0.00	54.30	4.61	1.30	0.00
26.30	7.68	1.03	1.00	54.40	5.42	1.12	0.00
26.40	8.88	1.02	1.00	54.50	5.35	1.59	0.00
26.50	8.76	1.08	1.00	54.60	4.64	1.13	0.00
26.60	8.03	0.99	1.00	54.70	6.12	1.18	0.00
26.70	8.42	1.08	0.00	54.80	4.43	1.59	0.00
26.80	11.91	1.09	0.00	54.90	5.88	1.29	0.00
26.90	8.75	1.02	0.00	55.00	5.00	1.50	0.00
27.00	8.19	1.09	0.00	55.10	5.30	1.09	0.00
27.10	8.68	0.99	0.00	55.20	3.98	1.28	0.00
27.20	7.73	1.01	2.00	55.30	5.48	1.34	0.00
27.30	11.38	1.00	2.00	55.40	6.25	1.25	0.00
27.40	17.35	1.03	2.00	55.50	5.03	1.30	0.00

Table 23 (**cont**.). Appendix C. Channel geometry metrics. Width:depth ratio is bankfull width to relative thalweg depth. Sinuosity was calculated by MoRAP during Phase I PHA. Bedrock indicates zero, one or two banks showing presence of bedrock.

Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock	Stream Distance (km)	Width:Depth Ratio (m/m)	Sinuosity	Bedrock
27.50	11.10	0.99	2.00	55.60	5.94	1.16	0.00
27.60	10.69	0.99	1.00	55.70	5.70	1.05	0.00
27.70	14.15	1.25	1.00	55.80	4.95	1.04	0.00
27.80	9.59	1.13	0.00	55.90	5.32	1.13	0.00
27.90	9.68	1.02	0.00	56.00	3.24	0.00	0.00
28.00		0.99	1.00				