Hinkson Creek Watershed Restoration Project

Collaborative Adaptive Management (CAM)

Physical Habitat GIS Data Development Technical Report

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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).

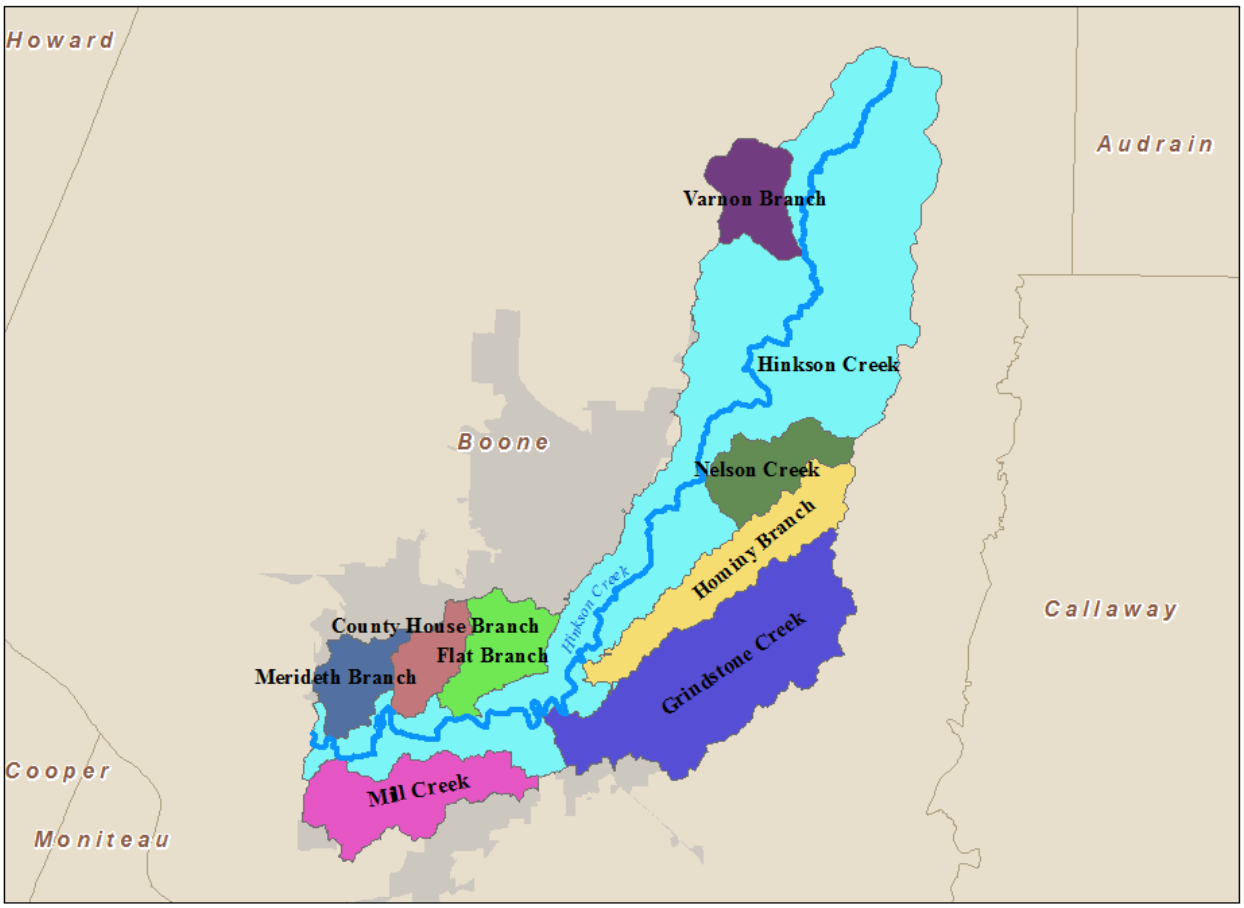

Figure 1. Watersheds that define the study area cover much of the Columbia metro area in central Boone County, Missouri.

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.

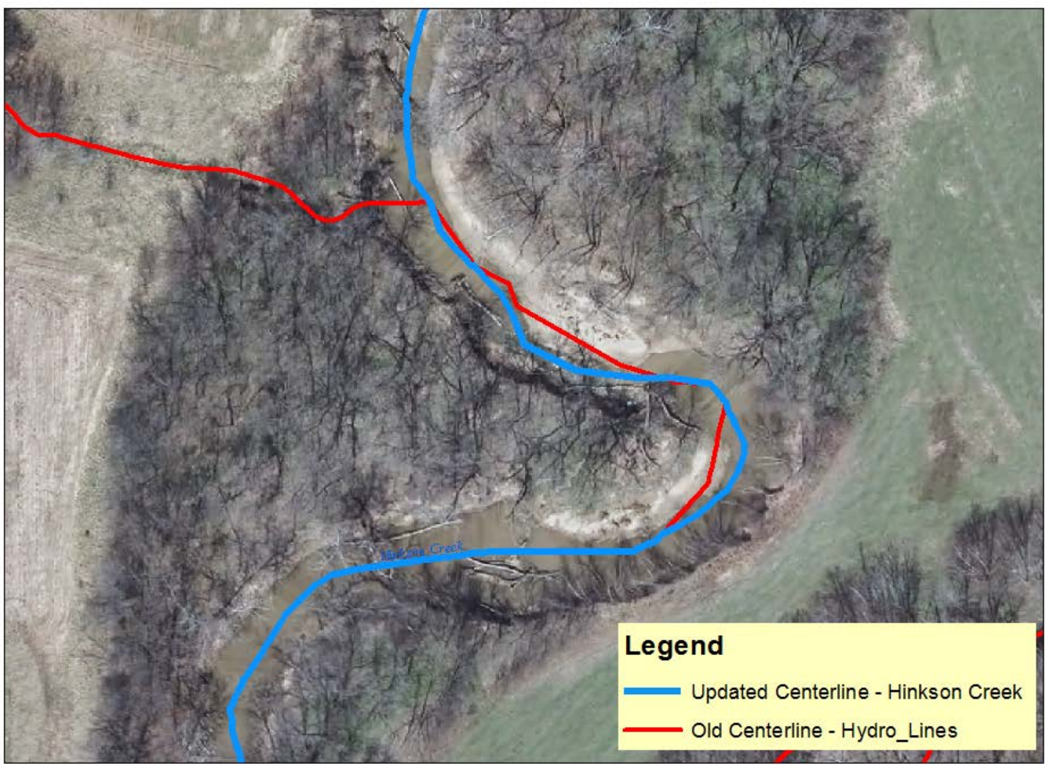

Figure 2. The centerline for Hinkson Creek was updated (blue) in places where old line work (red) did not reflect stream conditions in 2011.

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.

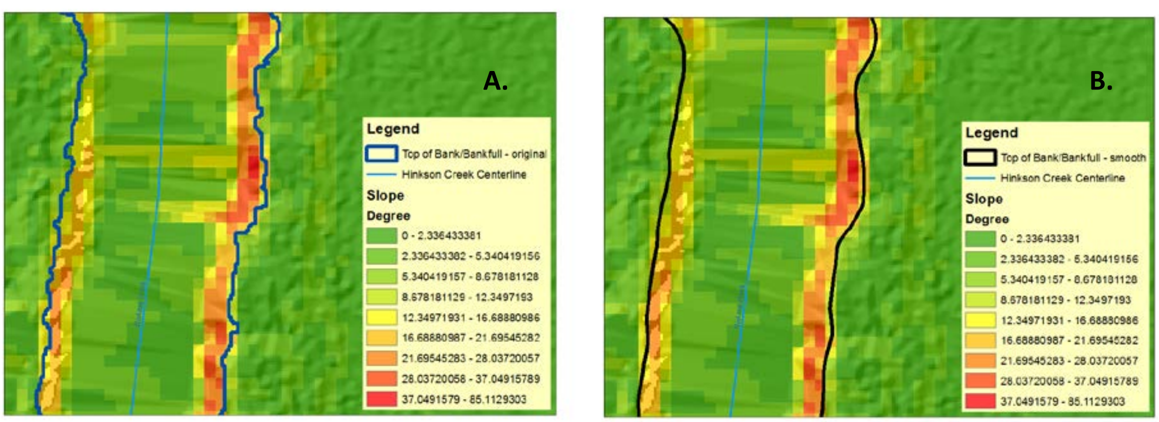

Figure 3. A) The original, pixel based polygon delineation of bankfull where the surrounding valley begins to slope down into stream channel. B) Smoothed bankfull polygon.

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.

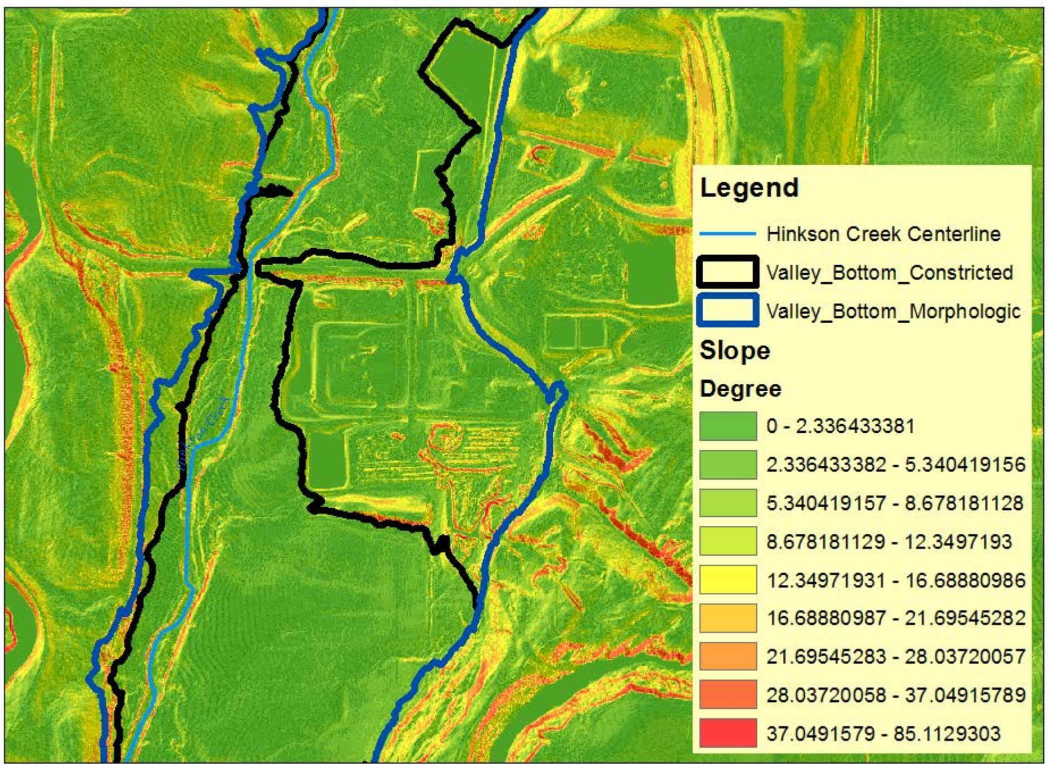

Figure 4. Location within the valley where constricted (black) valley is narrowed due to levee and road build. Morphological valley (blue) is considerably wider in some areas.

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.

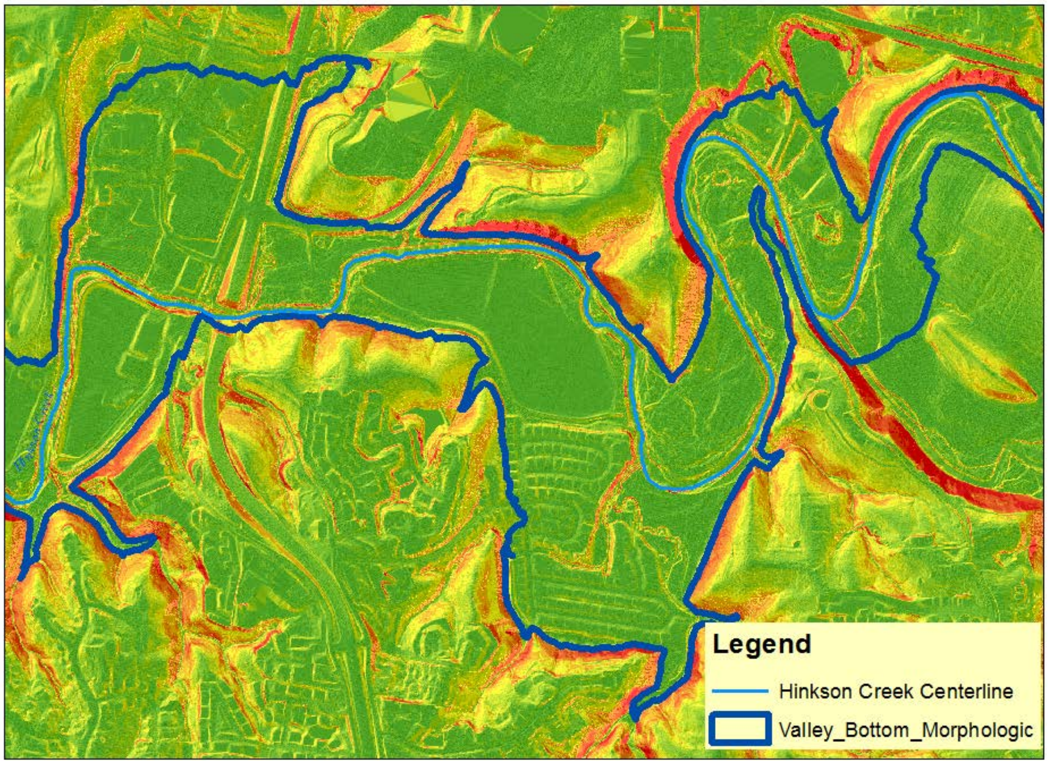

Figure 5. Morphological valley delineating bluff to bluff boundary.

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.

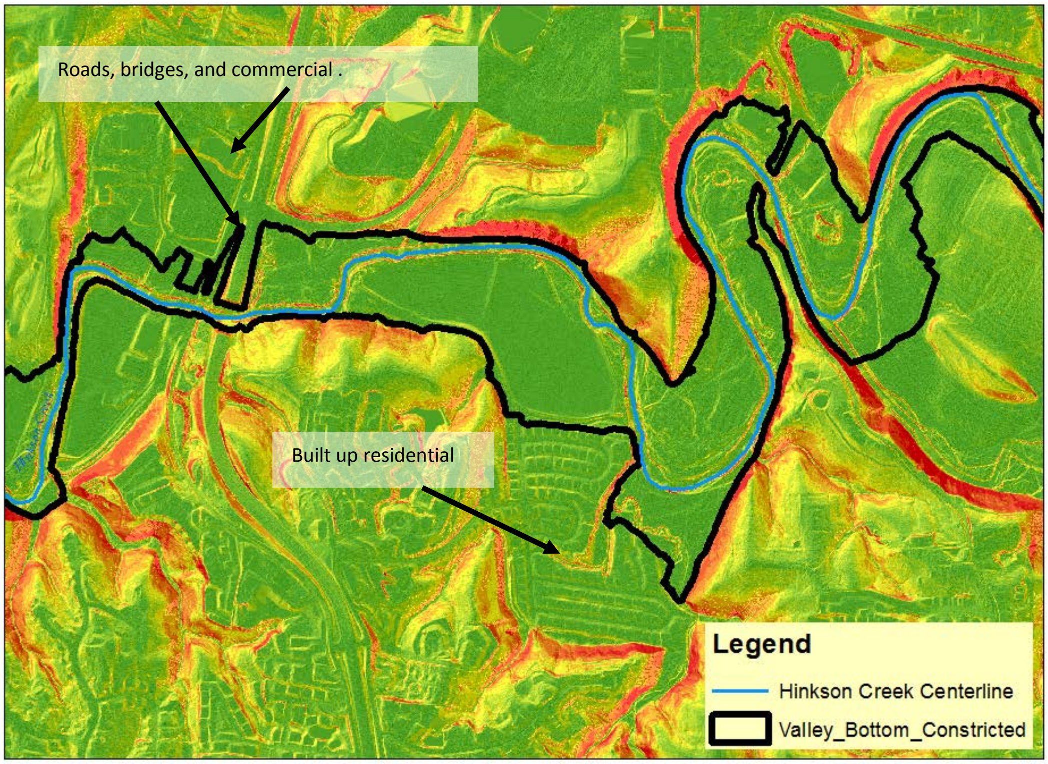

Figure 6. Valley is constricted due to roads, bridges, and built up residential and commercial properties.

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.

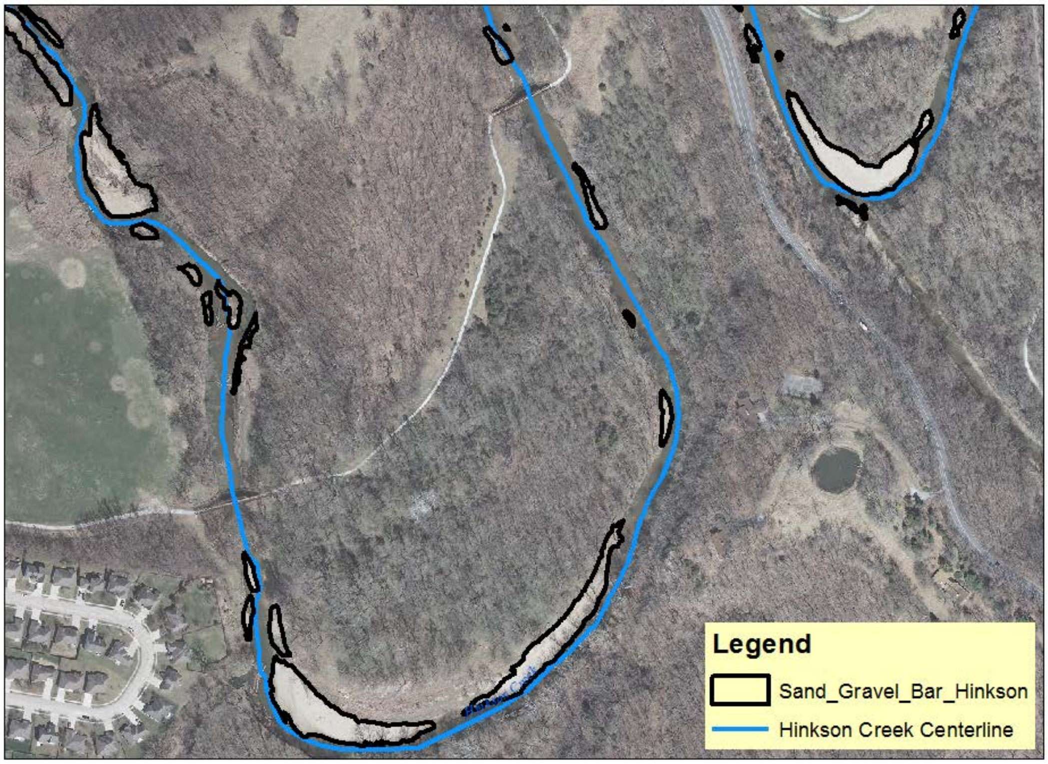

Figure 7. Sand and gravel bars were identified based on 2011 6" true color leaf-off imagery.

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.

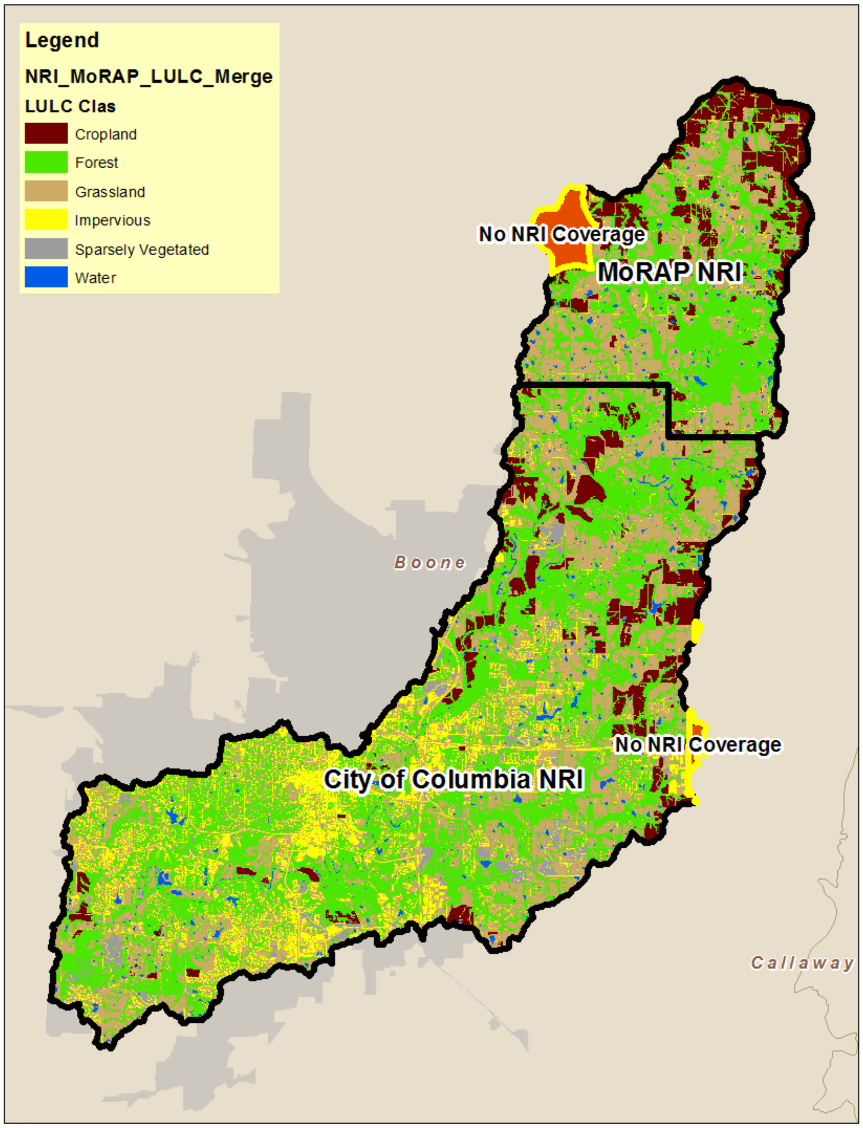

Figure 8. MoRAP created NRI-like LULC for the northern portion of the study area. The areas in red indicate where no LULC exists.

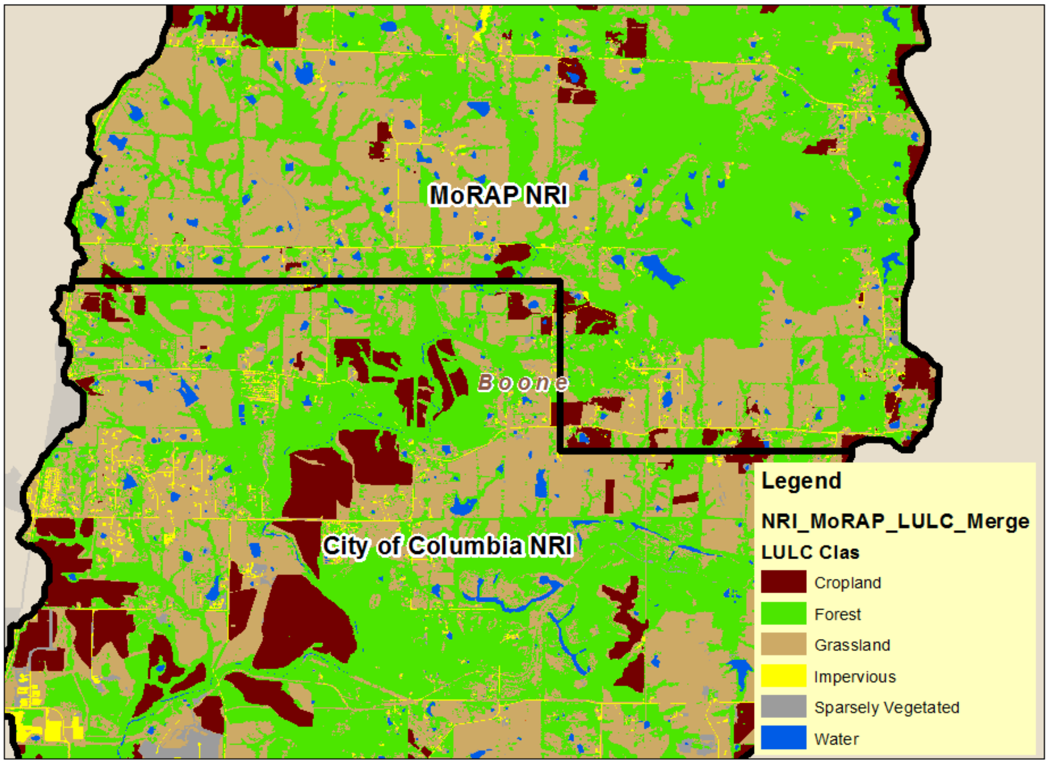

Figure 9. The addition of the MoRAP created LULC provided a virtually seamless LULC for the study area.

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.

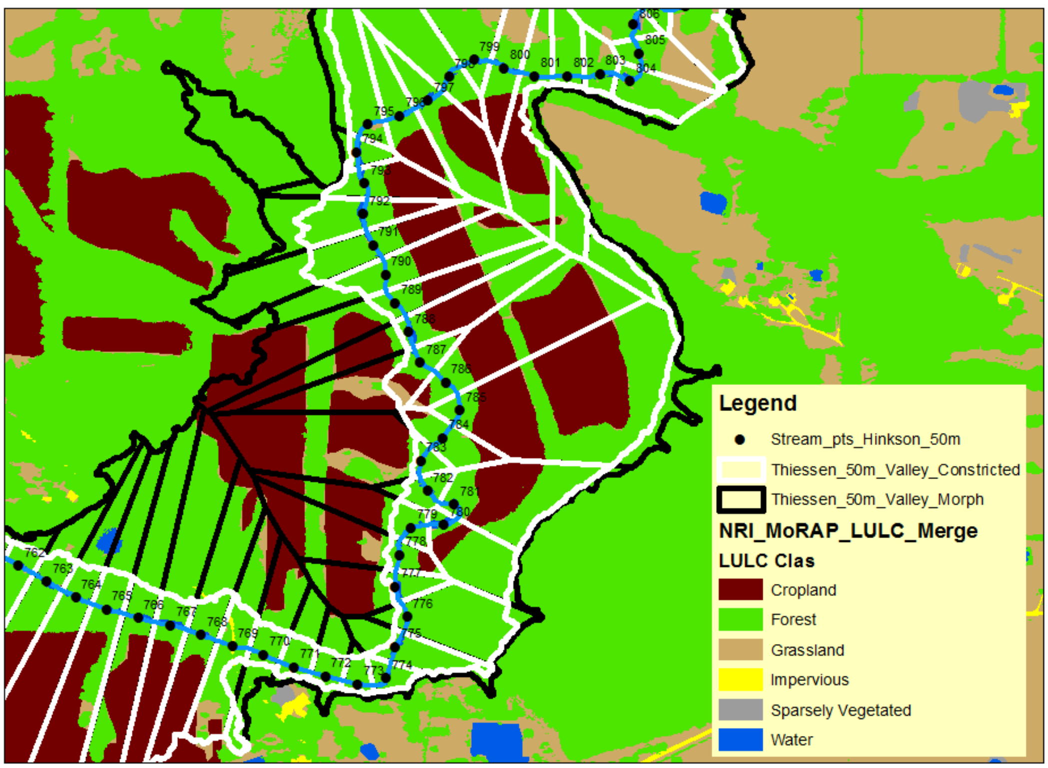

Figure 10. Theissen polygons based on stream points at 50 meter intervals vary greatly in size. Thiessen polygons were clipped to morphological (black) and constricted (white) valley boundaries.

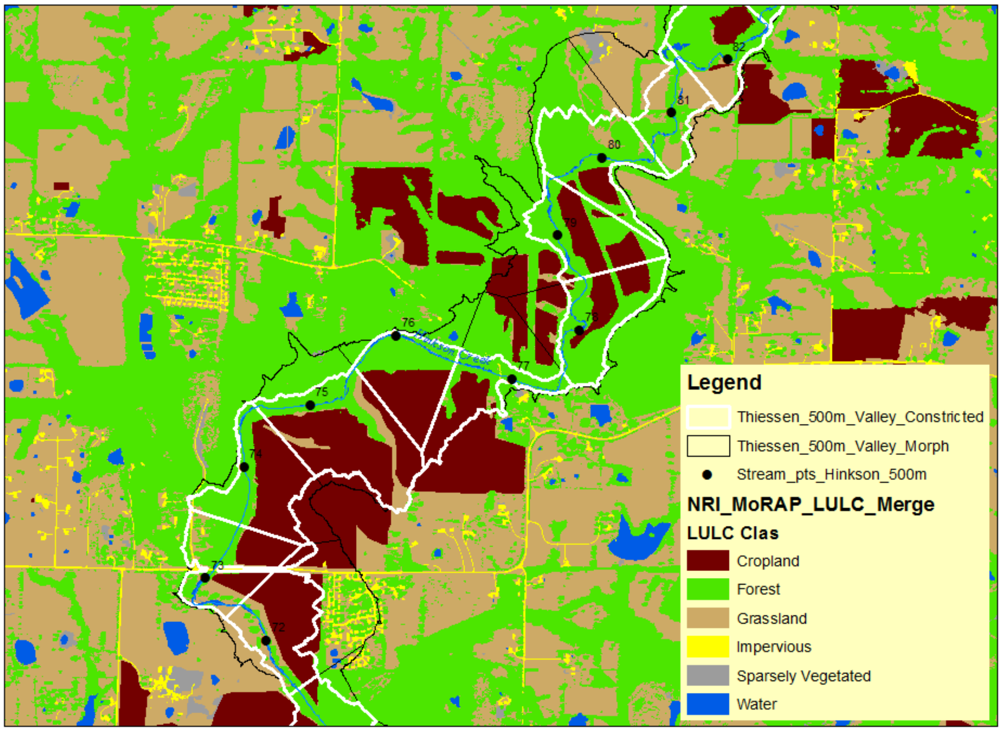

Figure 11. Theissen polygons based on stream points at 500 meter intervals were much more uniform in size compared to 50meter intervals (Figure 10). Theissen polygons were clipped to morphological (black) and constricted (white) valley boundaries.

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).

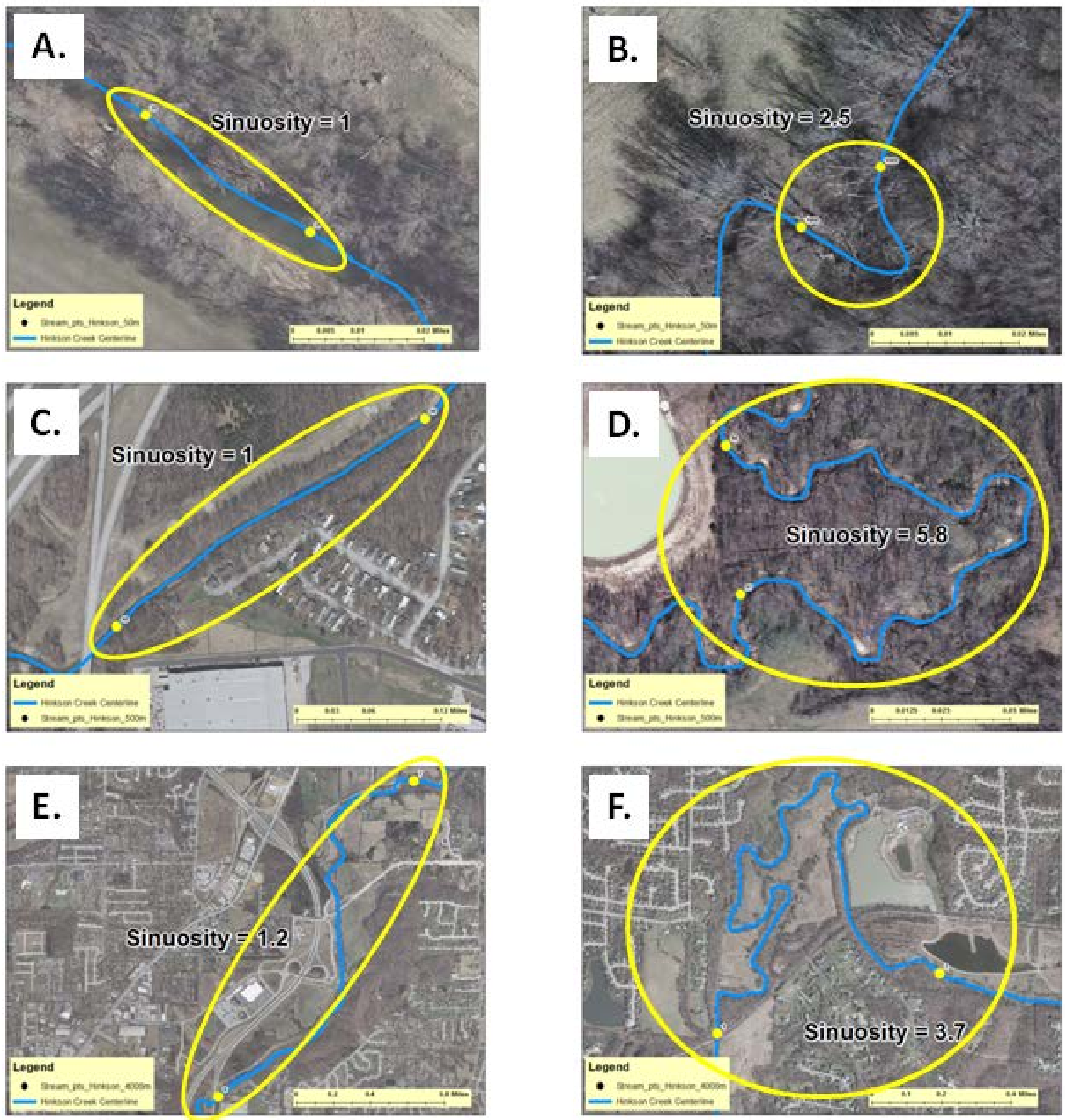

Figure 13. Shown is sinuosity at various scales. A) Sinuosity value of 1 between 50 meter points, indicating a straight section of the creek. B) Maximum sinuosity value of 2.5 within the 50 meter point dataset. C) Sinuosity value of 1 between 500 meter points. D) Maximum sinuosity value of 5.8 within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

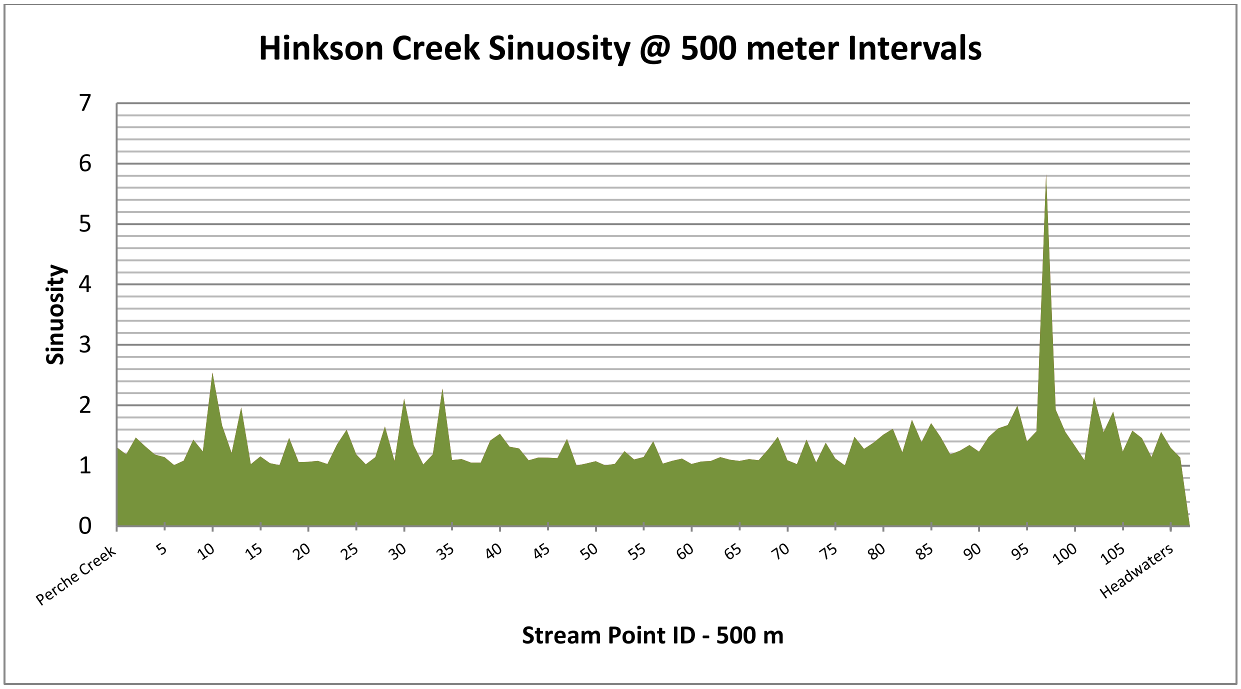

Figure 14. Longitudinal plot of sinuosity measures of Hinkson Creek at 500 meter point intervals. See Figure 23 for locator map of points at 500 meter intervals.

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.

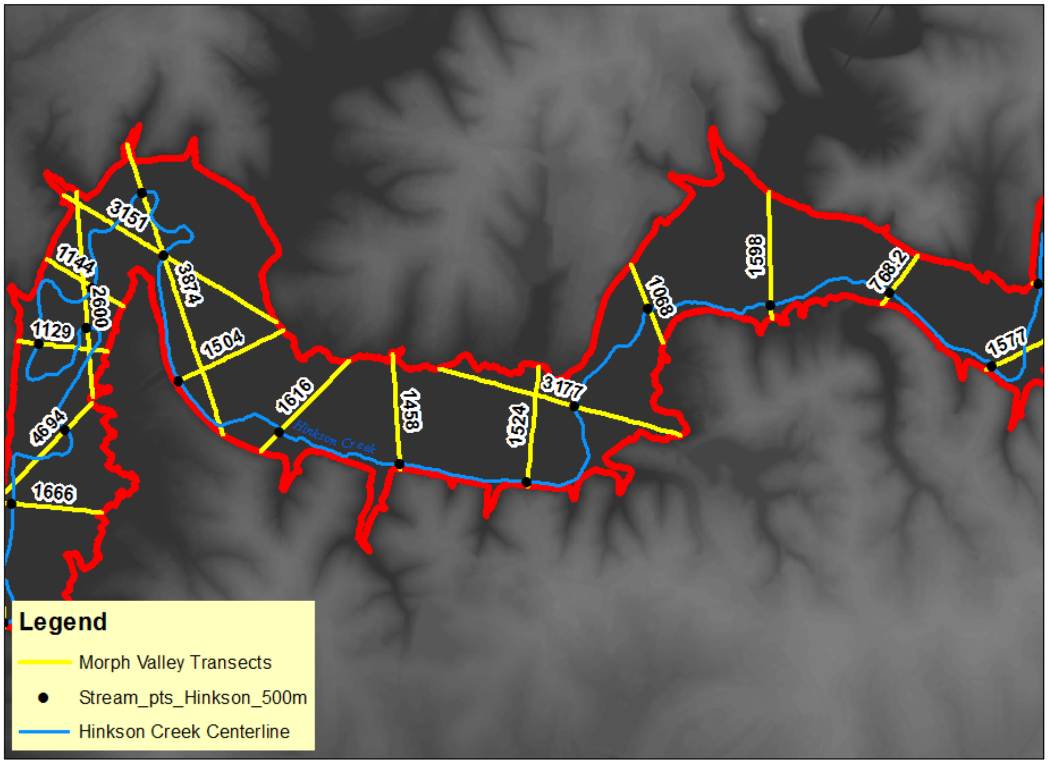

Figure 15. Transects perpendicular to the stream centerline were calculated for each point and clipped to both valley boundaries and the bankfull boundary to calculate width and applied to each point. Shown are transects clipped to the morphological valley boundary with width distances in feet on the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

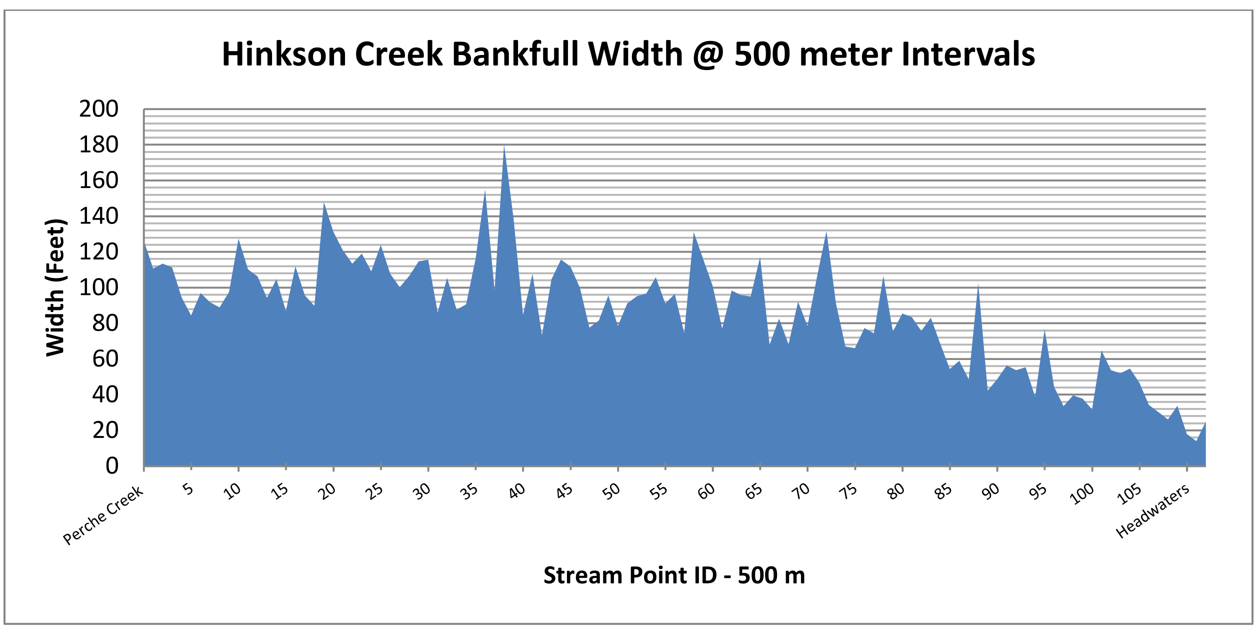

Figure 16. Longitudinal profile of Hinkson Creek bankfull width at 500 meter intervals shows decreasing width from the confluence with Perche Creek upstream to the headwaters. See Figure 23 for locator map of points at 500 meter intervals.

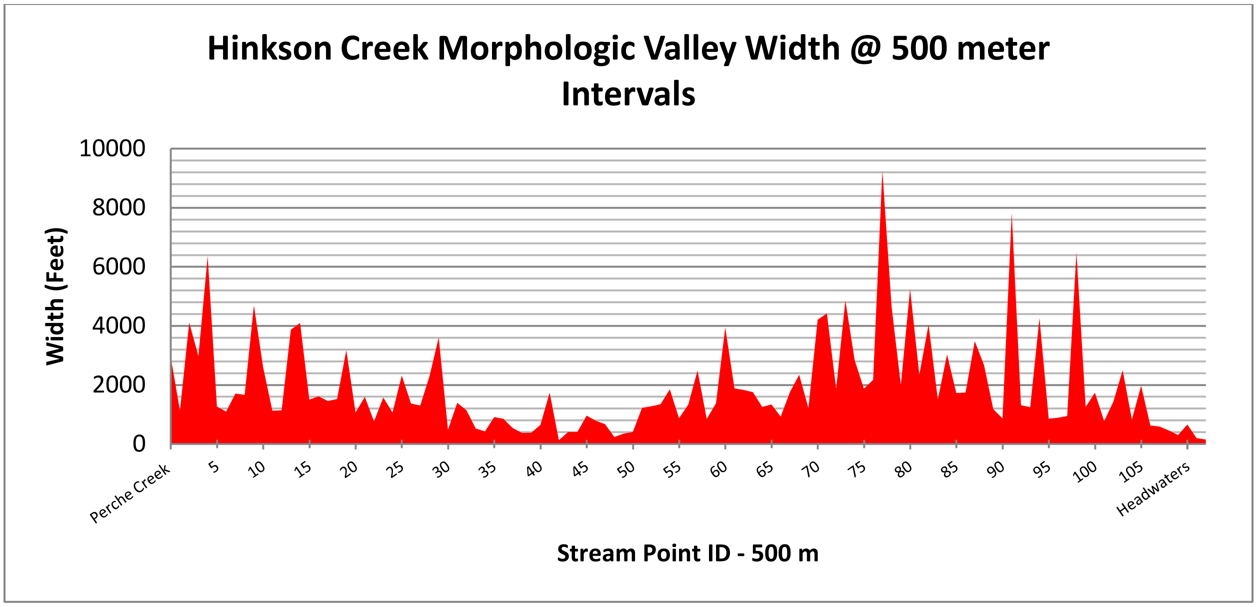

Figure 17. Width of Hinkson Creek morphologic valley at 500 meter intervals. See Figure 23 for locator map of points at 500 meter intervals.

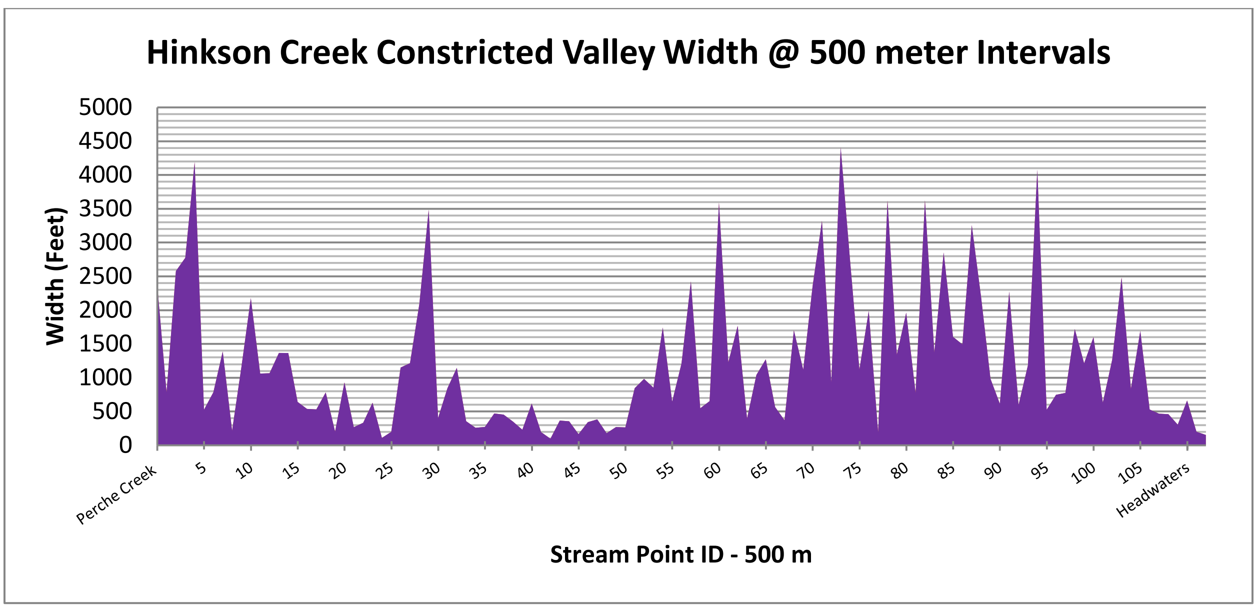

Figure 18. Width of Hinkson Creek constricted valley at 500 meter intervals. See Figure 23 for locator map of points at 500 meter intervals.

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.

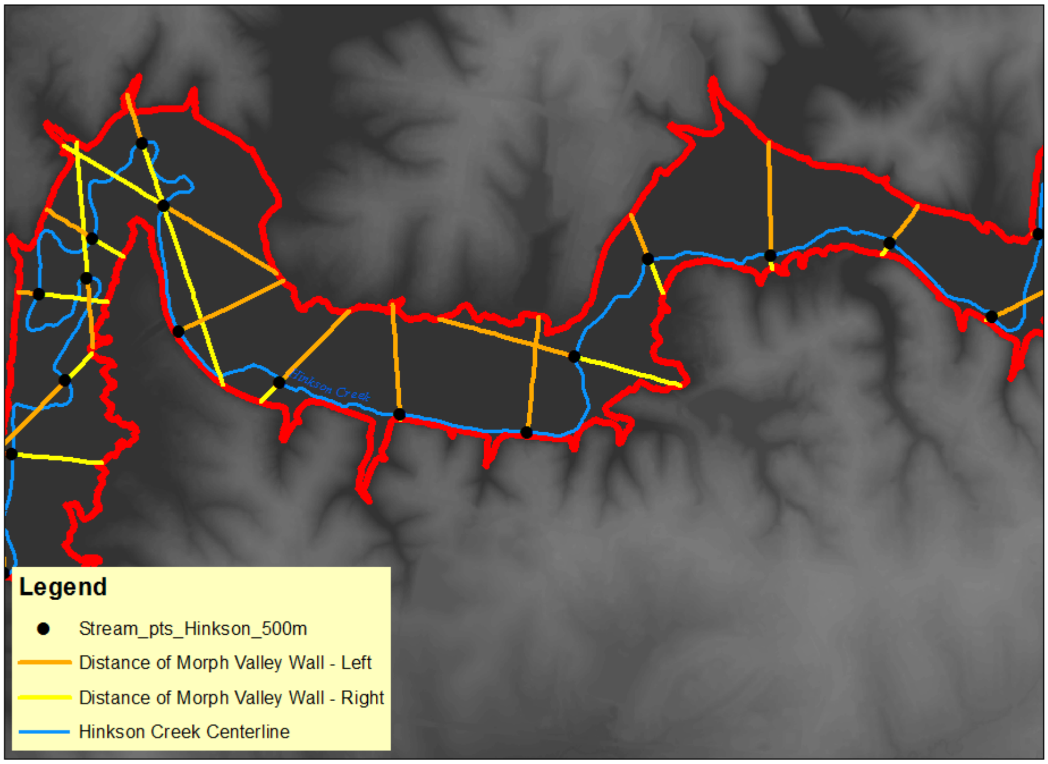

Figure 19. Perpendicular transects used to calculate valley widths were cut in half using the stream centerline and distance from centerline to right and left side valley boundaries were calculated and applied to each point. Due to sinuosity within the valley, these values may be more or less meaningful.

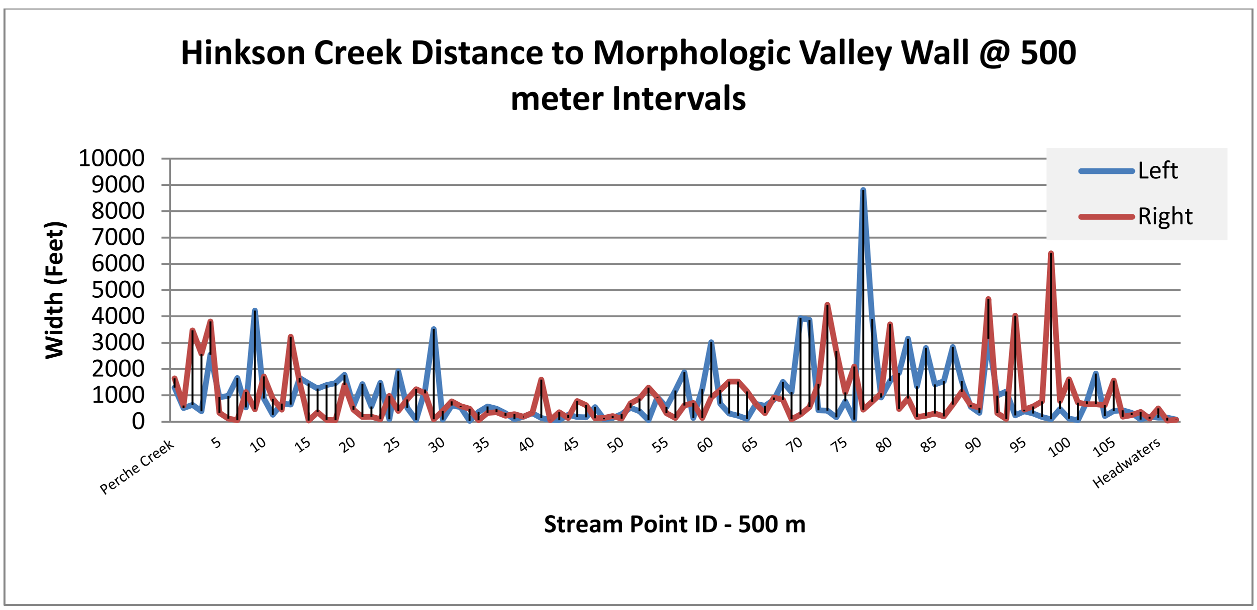

Figure 20. Distance to morphologic valley wall from Hinkson Creek centerline at 500 meter intervals. Red line line represents distance from right side of stream to valley boundary and blue line represents distance from left side of stream to valley boundary based on navigation upstream from confluence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

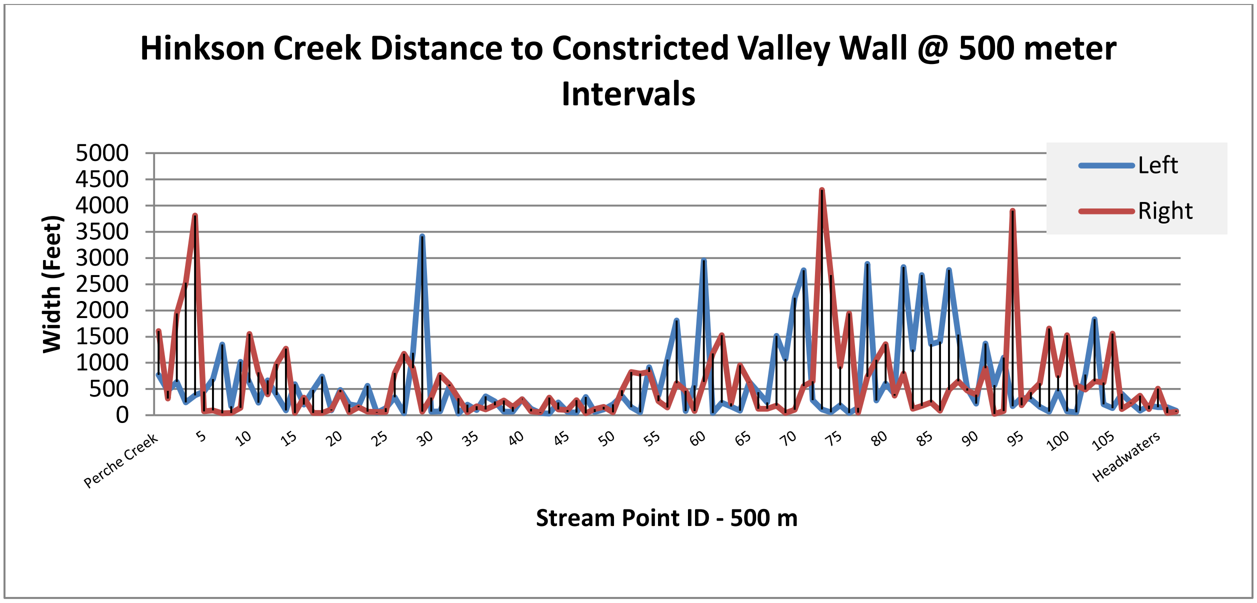

Figure 21. Distance to constricted valley wall from Hinkson Creek centerline at 500 meter intervals. Red line line represents distance from right side of stream to valley boundary and blue line represents distance from left side of stream to valley boundary based on navigation upstream from confluence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

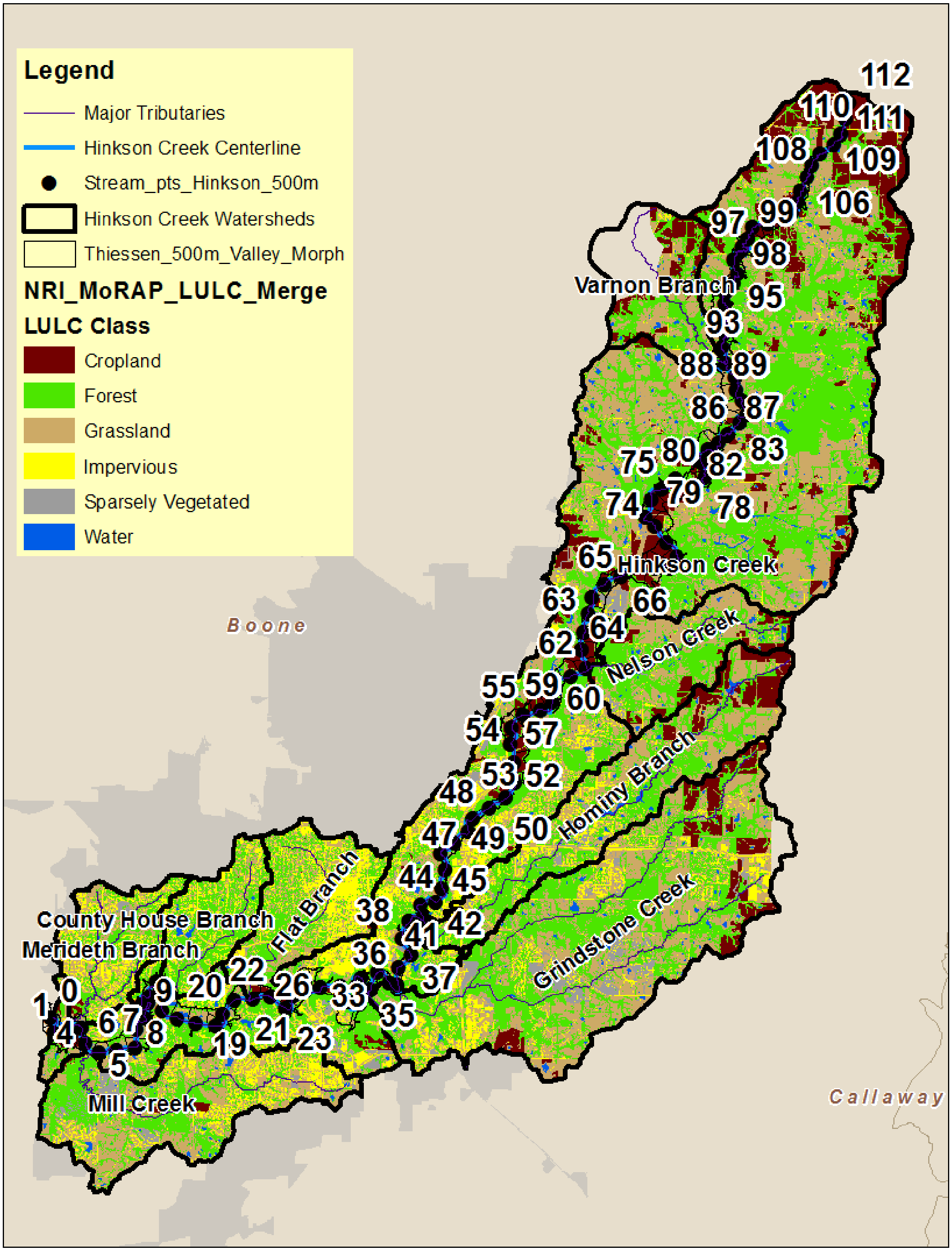

Figure 23. LULC summarized at 500 meter intervals at morphologic valley extent. Numbers represent ID of stream points and thiessen polygons at 500 meter intervals along stream centerline.

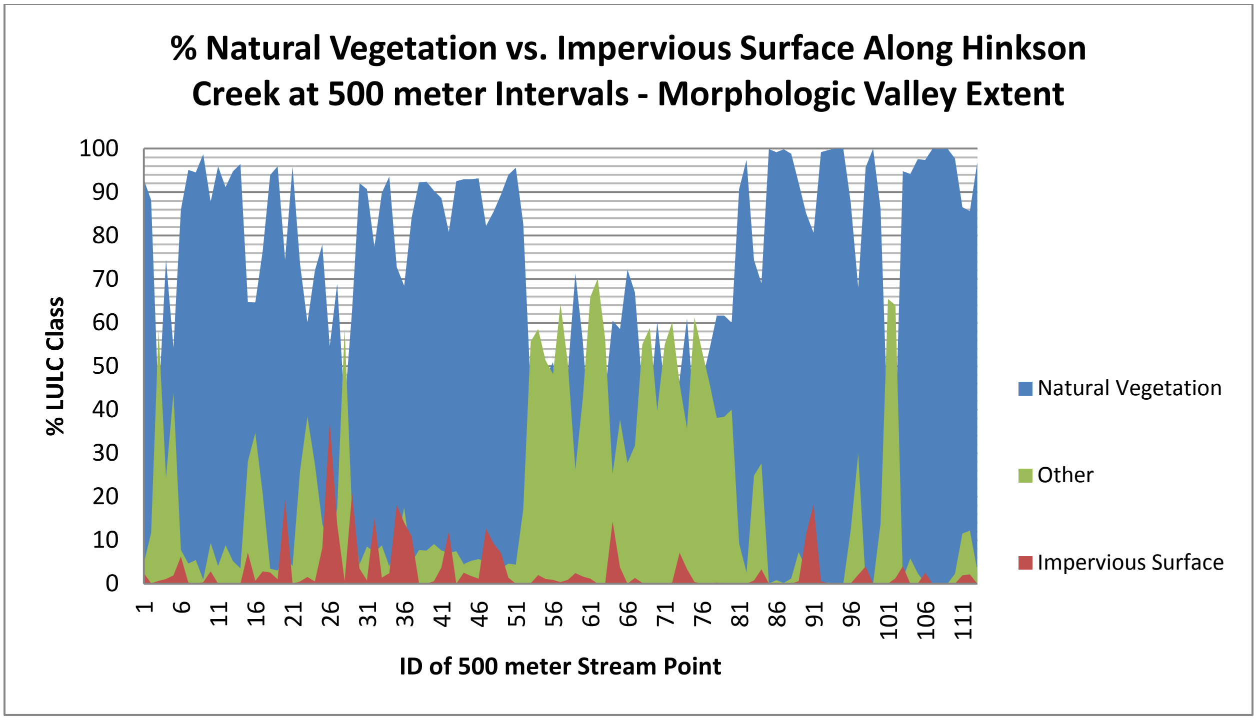

Figure 24. Chart illustrating LULC composition within thiessen polygons at 500 meter intervals within the morphologic valley. Spikes in impervious surface mostly occur along lower portions of stream. While natural vegetation (grass and forest) drops just below mid-point of the stream, but typically comprises 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%.

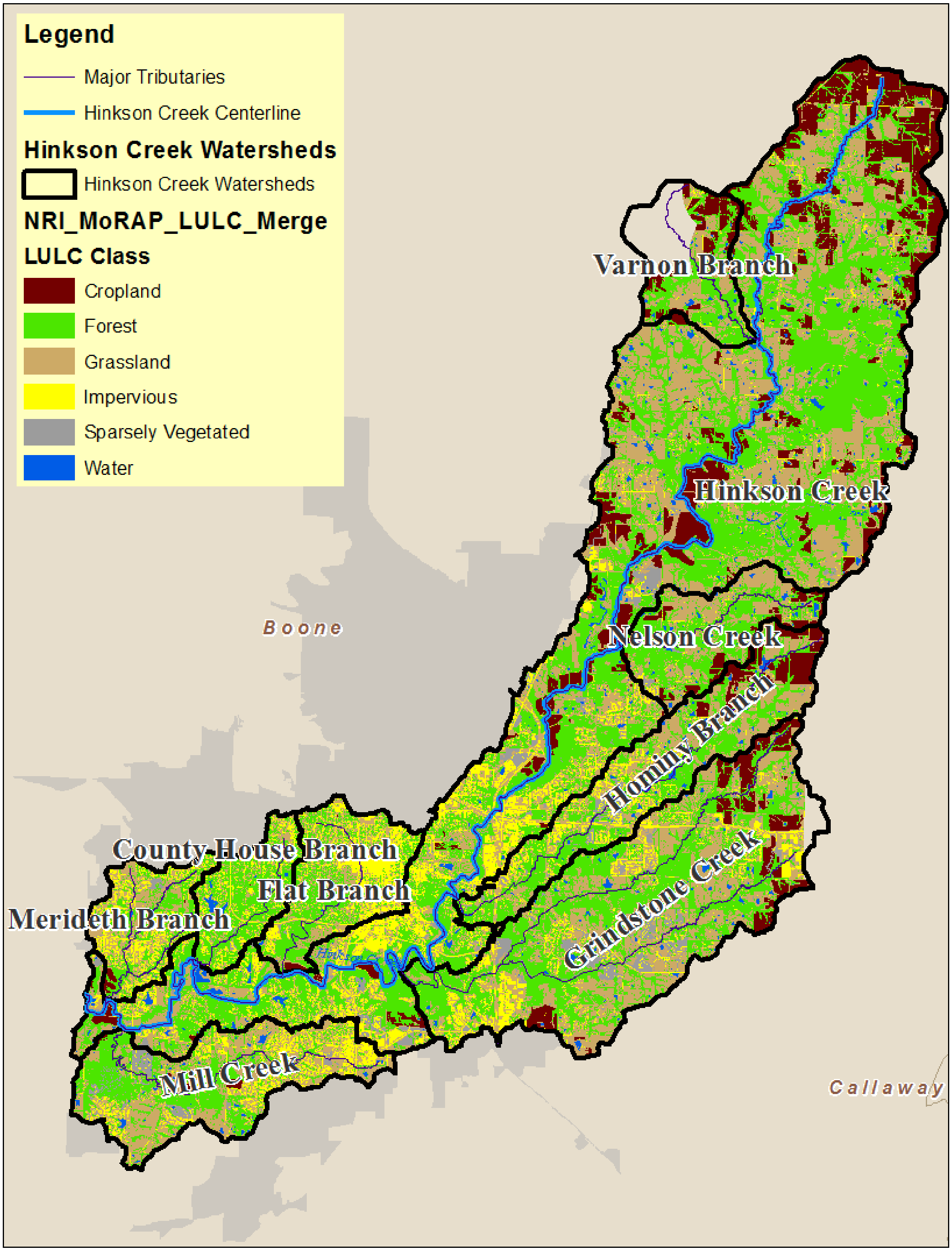

Figure 25. Watersheds and LULC within Hinkson Creek study area.

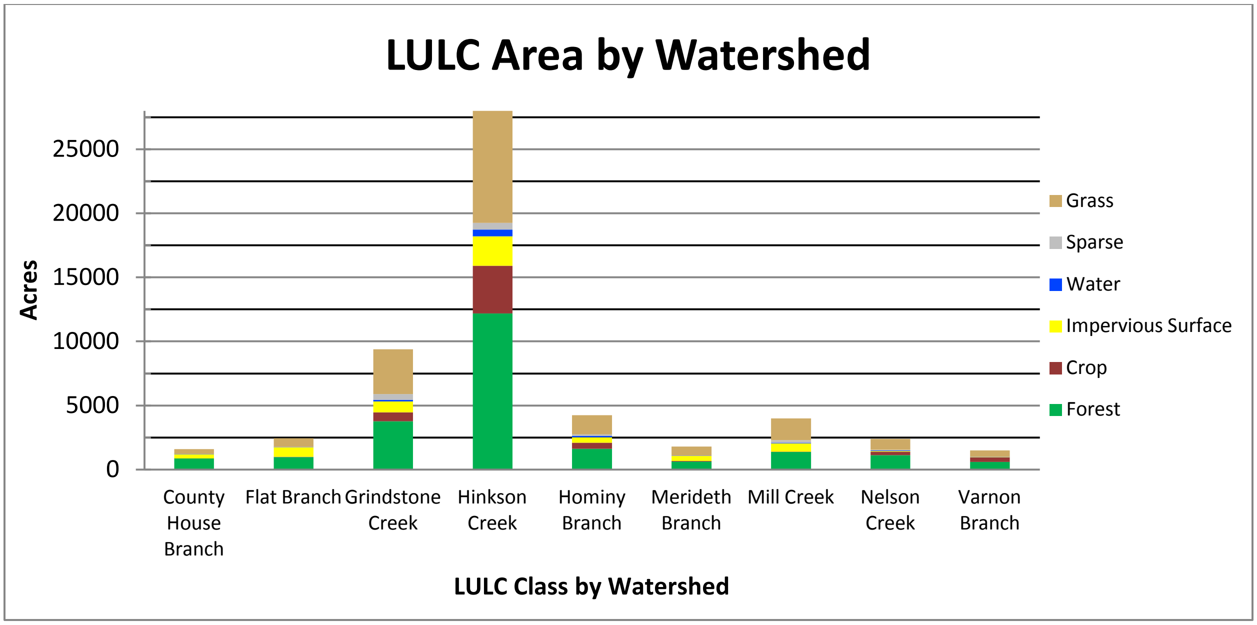

Figure 26. Area of LULC within each watershed in acres.

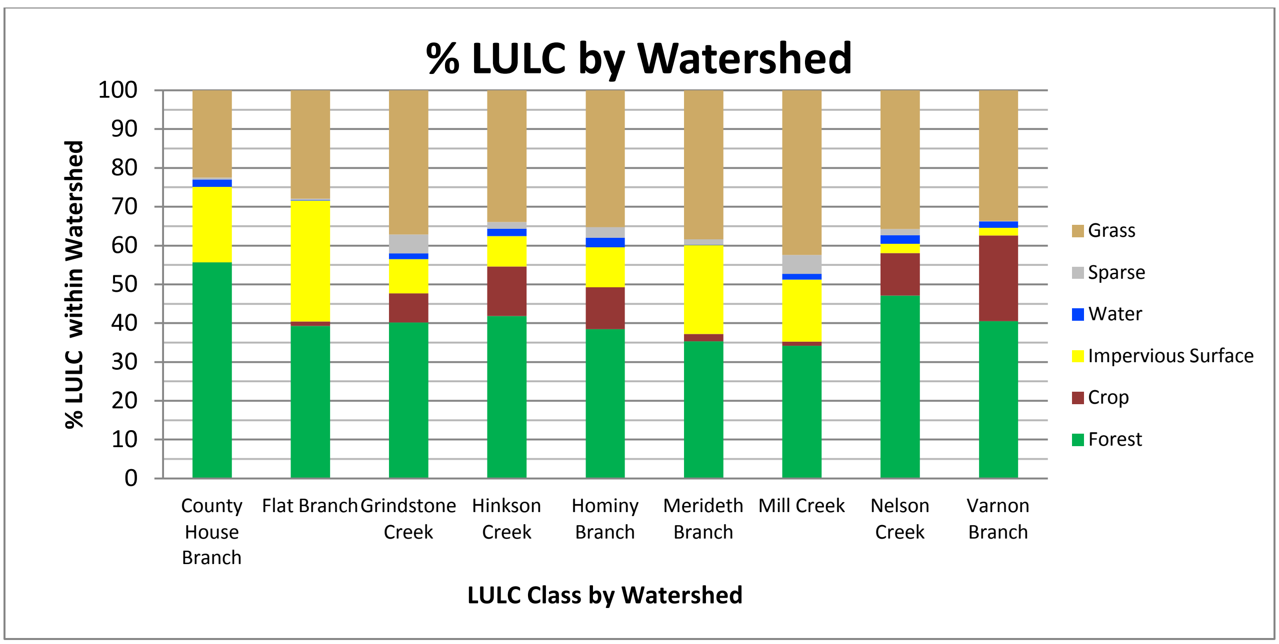

Figure 27. Percent LULC class within each watershed.

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.

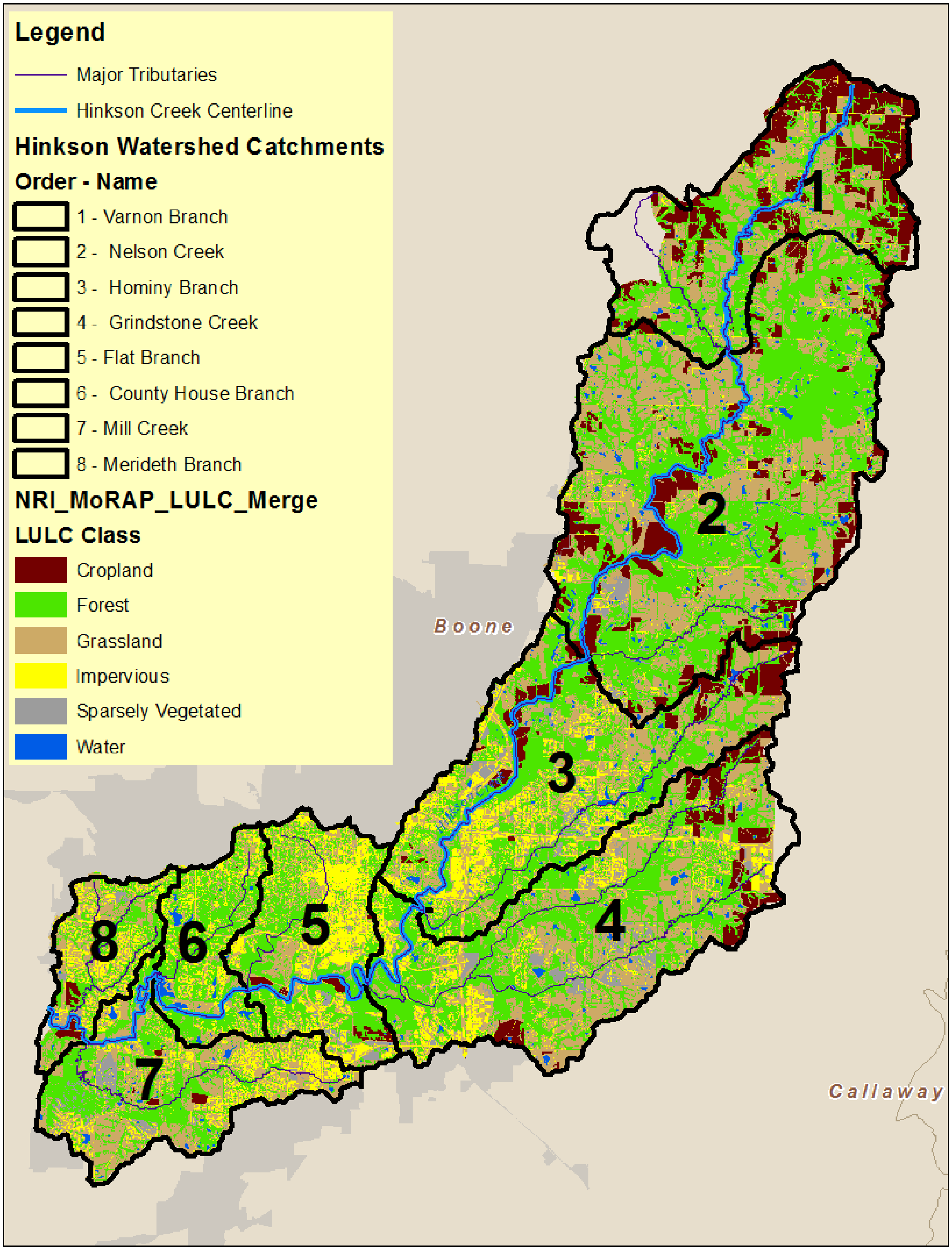

Figure 28. "Catchments" developed to calculate cumulative upstream LULC composition statistics at major tributaries of Hinkson Creek. Watersheds were divided at major tributaries based on fine scale catchments and lumped into broader watershed catchments. Catchments were numbered arbitrarily starting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

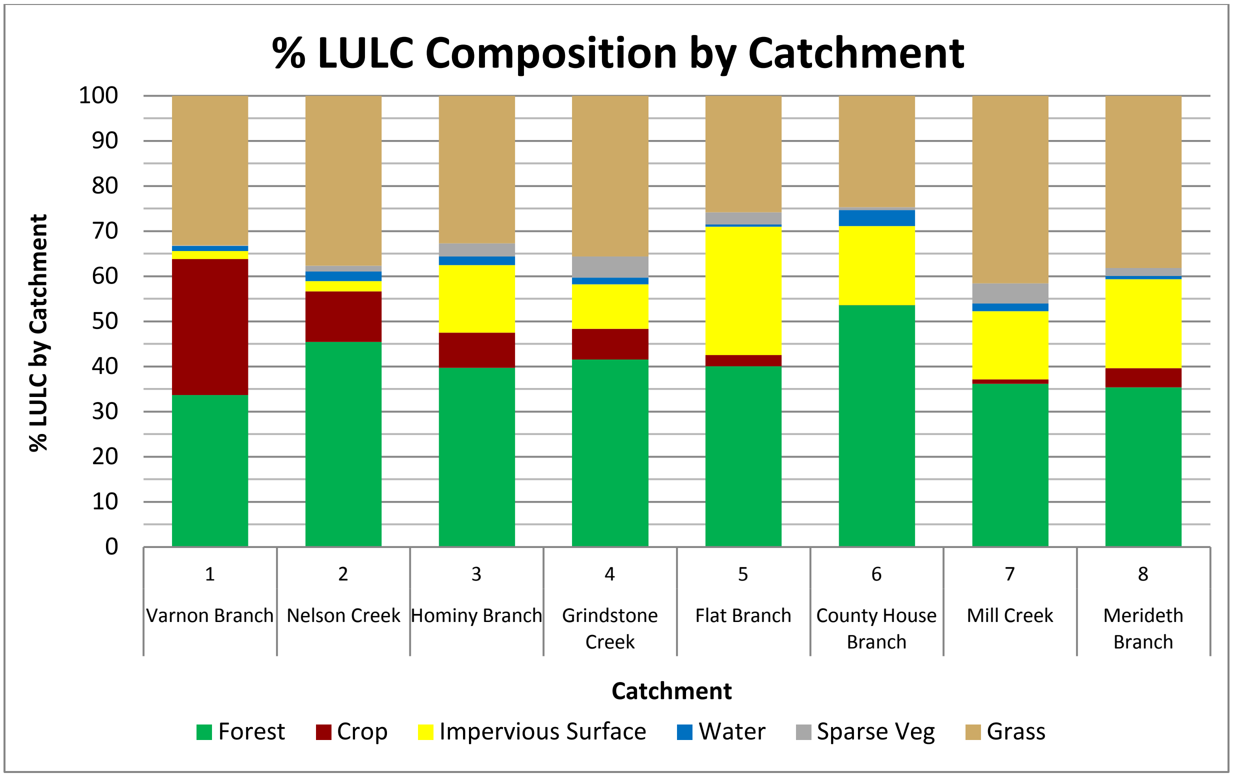

Figure 29. Percent LULC composition within each catchment. Note the dominance of the forest and grass cover types in all catchments, the increase in impervious cover from catchmentsa 3 to 8, and decrease in crop cover type from catchments 1 through 8.

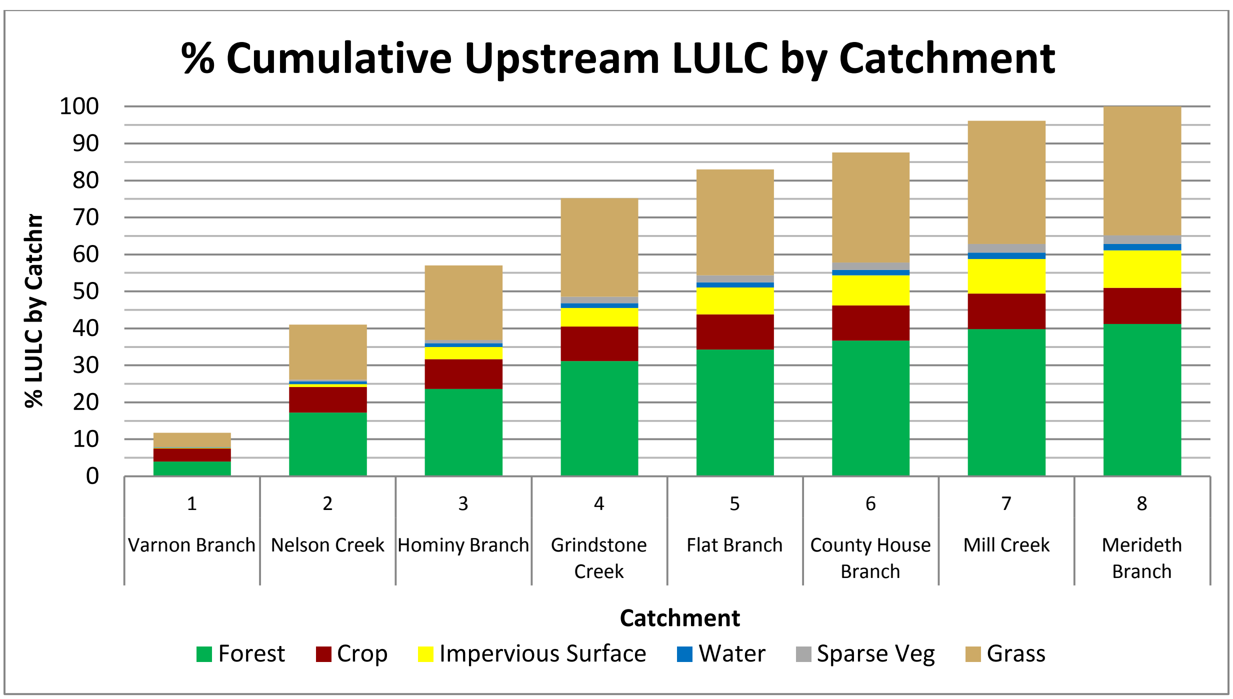

Figure 30. Percent cumulative upstream LULC by catchment shows the contribution of each catchment toward total land cover values for the entire watershed, progressively moving downstream. Note the gradual addition of all forest, grass, and imperverios in a downstream direction. Crop, water, and sparse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

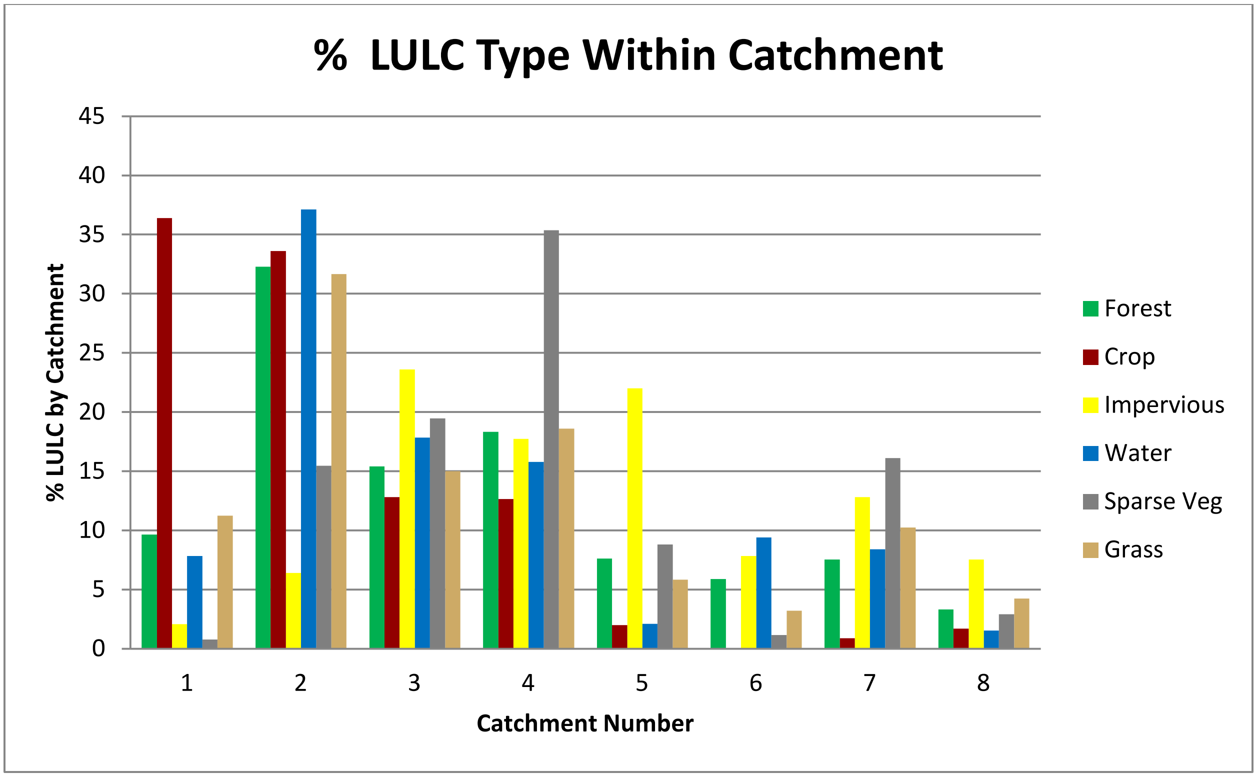

Figure 31. Percent of each LULC type by catchment relative to total area for each LULC type. This chart illustrates the percentage of the total area of a single cover type that exists within each catchment. Note that over 35% of all crop exists in catchment one and over 60% of all impervious surface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