Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

Gaging Station Report for:

Hydrological Monitoring of the Big Barren Creek Watershed, Mark Twain National Forest, Southeast Missouri

FINAL REPORT

Prepared by:
Marc R. Owen, M.S., Assistant Director, OEWRI
Shoukat Ahmed, Graduate Assistant, OEWRI
Robert T. Pavlowsky, Ph.D., Director, OEWRI

Assisted in the field by:
Matt Thies, Nick Bradley, Joe Nash, Hannah Adams, Grace Roman, Katy Reminga, Kayla Coonen, Triston Rice, Max Hillermann, and Tyler Pursley

Ozark Environmental and Water Resources Institute
Missouri State University
Temple Hall 343
901 South National Avenue
Springfield, MO 65897

Completed for:
Kelly Whitsett, Forest Hydrologist and Cave and Karst Program Manager
U.S. Forest Service
Mark Twain National Forest
401 Fairgrounds Road
Rolla, MO 65401

April 15, 2021

OEWRI EDR-21-002.0

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

SCOPE AND OBJECTIVES

Recent geomorphic instability in some headwater streams draining forest lands of the Missouri Ozarks has raised concerns among managers and other stakeholders. Increased flood frequency, bank erosion, and excessive gravel deposition in Ozarks streams over the last several decades can be related to a combination of factors including more frequent intense rainfall events, land management practices, riparian vegetation removal, and road network development (Jacobson, 2004; Hu et al., 2005; Pavlowsky et al., 2016; Bradley, 2017; Thies, 2017; Reminga, 2019). The United States Forest Service (USFS) is interested in understanding the hydrologic response of small, forested, headwater streams within the Mark Twain National Forest (MTNF) under different management conditions. The Collaborative Forest Landscape Restoration Program (CFLRP) is a 10-year program, which began in 2012, designed to restore 100,000 acres of shortleaf pine in the MTNF of southeast Missouri. This program uses multiple techniques, including prescribed fire, to help manage and restore the natural shortleaf pine/oak woodlands that once dominated the area. However, little is known about the impact of prescribed fire on local hydrology at timescales ranging from individual storm events that occur immediately after the burning season, to long-term changes in runoff as the vegetation begins to change and mature in restored forests.

The Big Barren Creek watershed is small (190.6 km^2), forested watershed located within the CFLRP and was selected for multi-year hydrological monitoring. The Big Barren Creek watershed has experienced increased flooding over the last decade that coincides with the USFS use of prescribed fire to reestablish shortleaf pines within the watershed. Furthermore, a section of Big Barren Creek within a two-kilometer designated Natural Area has a population of endangered mussels that the USFS wants to continue to protect (Finley et al., 2017). The goal of this project is to monitor the instantaneous discharge and water temperature of typical small streams within the MTNF under different management conditions. The specific objectives of this project are to: 1) install level logger gaging stations at 2^{nd}-3^{rd} order streams where upstream watershed areas have different burn histories and monitor stage throughout the length of the project; 2) develop discharge rating curves to calculate annual runoff volume and flow frequency analysis for each watershed; and 3) compare runoff characteristics of burned versus unburned watersheds. The purpose of this data report summarizes the site conditions at each gaging location and the methods used to estimate discharge at the original 14 stations that were installed in 2015-2016.

STUDY AREA

Big Barren Creek is a tributary of the Current River Basin (8-digit Hydrological Unit Code (HUC) #11010008) located in portions of Ripley, Oregon and Carter Counties in southeast Missouri (Figure 1). The watershed is located in the Salem Plateau physiographic subdivision of the Ozarks Highlands, is underlain by flat, Paleozoic age sedimentary rock, and is about 150 m higher in elevation than the Mississippi Alluvial Plain located just to the southeast (Adamski et al., 1995). Southeast Missouri has a temperate climate with a mean annual temperature of 14.4º C and mean annual precipitation around 112 cm in Carter County (Adamski et al., 1995). However, recent rainfall analysis shows an increase in annual rainfall that averages 136 cm per year since 2005 in the Big Barren Creek watershed (Pavlowsky et al., 2016). Land cover within the watershed is about 92% forested, with around 78% being National forest lands. The remainder of land use within the watershed are roads or small farms typically located along the valley bottom being used for pasture and hay production.

The majority of the streams within the Big Barren Creek watershed are ephemeral due to the underlying karst landscape where sinkholes, losing streams, and caves are common (Weary et al., 2014). Natural stream channels are typically multi-threaded, relatively wide and shallow, have silt-loam/cherty banks, gravel/cobble size bed material, and mature oak or pine trees growing on the bed (Thies, 2017). Along some privately-owned sections of the stream the channel has been channelized and forced into a single, relatively deep channel, which has caused incision upstream along the main channel and into the tributaries (Thies, 2017; Owen et al., 2018). Perennial sections of these streams are located within, or just downstream, of the Big Barren Creek Natural Area and the Cowards Hollow Natural Area which appear to be associated with a series of northeast trending faults (Weary et al., 2014; Figure 2).

Gaging station locations were selected along both the main stem of Big Barren Creek and distributed along smaller tributaries throughout the watershed. Gage locations within the smaller tributary watersheds drain almost entirely forest lands that have either been burned or unburned during the CFLRP project. However, sites such as SC and CH had some pasture on private land within the watershed. Additionally, CH is the only perennial tributary stream that was gaged. Drainage areas for the tributary sites ranged from 1.59-7.82 km^2. In an effort to better understand how flows are distributed downstream, gaging stations were installed along the main stem of Big Barren Creek, including two stations within the perennial natural area section. The drainage areas of the main stem sites had a mix of land uses from private lands, to burned and unburned public forest, ranging from 8.82-183.1 km^2.

METHODS

Gaging Stations

A total of 14 gaging stations were installed within the Big Barren Creek watershed in December 2015 (8 sites), January 2016 (2 sites), and September 2016 (4 sites) (Table 1 and Figure 2). Stage data was recorded every 5-minutes using Hobo U20L-04 Water Level Loggers (OEWRI 2016). The level loggers were installed inside a PVC pipe assembly and secured to 1-2 m staff gages that were installed at each site (Photos 1-3). As water rises in the pipe the level-logger uses the change in pressure to record changes in water level (Photo 4). An additional level logger was installed to measure barometric pressure used to compensate for barometric pressure changes. Raw data is downloaded periodically (≈ every 10 weeks) from the level loggers using the Hobo Waterproof Shuttle.

Discharge Rating Curve Development

Discharge rating curves were created at each site to estimate flows for each 5-minute stage reading over the monitoring period. Rating curves were developed by estimating discharge at various water surface elevations using Manning's equation and the continuity equation (Ward and Elliot, 1995). Channel capacity was measured from field-based channel/valley surveys, slope was calculated using 0.5 m spatial resolution LiDAR derived digital elevation models (DEMs), and Manning's roughness coefficient for the channel and floodplain from empirical equations. These data were all entered into hydraulics software for discharge calculations. Finally, regression equations were developed for discharge and stage relationships in Microsoft Excel software. Specific methods for each of these separate components are discussed below.

Channel Surveys

Cross-sectional surveys spanning the channel and floodplain were collected at each site in order to calculate the area of flow at various stages. Surveys were collected using either an autolevel or electronic total station perpendicular to the flow following standard protocols (Photo 5; Harrelson et al., 1994). Cross-sectional surveys were located immediately downstream of the gaging station at the glide-riffle interface and referenced to the stage gage erected at each site. The site at Highway J (HJ) is at a three-cell box culvert and the dimensions were measured using a tape. Channel cross-sections for each gaging station can be viewed in the *Gaging Station Information* section of this report.

Channel Slope

Channel slope is a primary variable required for hydraulic analysis. Slope values for this study were determined from available 0.5 m LiDAR DEMs. Elevation and distance values were collected from the DEM upstream and downstream of the cross-section location at between a 20-30 channel widths spacing (Rosgen, 1996). Slope values for each site are given in Table 2.

The slope of the box culvert was measured in the field using an autolevel and tape.

Manning's Roughness Coefficient

Manning's equation requires a roughness coefficient (*n*) value that is estimated for this study using the relative roughness method for the channel and a vegetation density method on the floodplain.

Channel "n"- This protocol estimates Manning's *n* using bed sediment size from standard pebble counts and the hydraulic radius (R) (Limerinos 1970). As water stage increase, the R value also increase, and Manning's "n" therefore changes with increasing depth (Table 2). Manning's roughness coefficient (*n*) for the channel was calculated using the following equation:

$$n = \frac{0.0926R^{1/6}}{1.16 + 2.0\log(R/d_{84})}$$

Where:
n = Manning's roughness coefficient
R = hydraulic radius (ft)
d_{84} = bed substrate diameter (ft) of the 84th percentile
* Note that values were converted to meters in tables

The diameter of bed and bar substrate is routinely measured using some variation of the Wolman pebble count method (Harrelson et al., 1994). Pebble counts were completed along 5-11 transects consisting of 6-10 samples each at the cross-section for a total of 30-90 samples using the blind touch method (Table 2). The "blind-touch" method is used to select samples where the worker steps to a location without looking down and reaches down to grab the first pebble touched with a pointed finger. A gravelometer was used to measure pebble diameter in one-half phi intervals. The minimum size of measured sediment using the gravelometer template is 2 mm. The largest size fraction measured by the gravelometer has a sieve diameter range of 128 to 180 mm or large cobbles. Beyond this size, a ruler is used to measure the B-axis diameter of the larger cobbles and boulders.

Floodplain "n"- This protocol estimates Manning's *n* using tree density, diameter, and floodplain topography (Tables 3-6; Arcement and Schnider, 1989). Manning's roughness coefficient (*n*) for the floodplain was calculated using the following equation:

$$n = n_0 V\, 1+(Veg_d)(C_*)(1.49/n_0)^2(1/2g)R^{4/3}$$

Where:
n = Manning's roughness coefficient
n_0 = Boundary roughness
Veg_d = Vegetation density (ft^2/ft^3)
R = hydraulic radius (ft)
C_* = Effective-drag coefficient (See Figure 4, Arcement and Schnider, 1989)
g = acceleration due to gravity = 32.2 (ft/s^2)
* Note that values were converted to meters in tables

Boundary roughness conditions (n0) for the floodplain was estimated using the following equation:

$$n_0 = (n_b + n_1 + n_2 + n_3 + n_4)m$$

Where:
n_b = base value for n
n_1 = surface irregularities
n_2 = floodplain shape and size variation = 0
n_3 = obstructions
n_4 = vegetation
m = degree of meandering = 1
* For more information about these values, see Arcement and Schnider, 1989

Tree Counts and Diameter Measurements

Vegetation density for the floodplain was estimated by sampling the floodplain along both banks at the gaging station location. Tree counts and diameter measurements were conducted along the cross-section across the floodplain by stretching a tape from the streambank to the valley wall. The length of the floodplain sampled varied by site. All trees were counted and the diameter at breast height was measured using a tree caliper within 10 m upstream and downstream of the tape. The width of the sample area was therefore the same at all sites (20 m, or 65.6 ft). Vegetation density of the sample area was calculated using the following equation:

$$Veg_d = h * \Sigma n_i d_i / hwl$$

$\Sigma n_i d_i$ = summation of number of trees multiplied by tree diameter (ft)
h = height of water above the floodplain (ft)
w = width of sample area (ft)
l = length of the sample area (ft)
* Note that values were converted to meters in tables

Velocity-Area Calculations

Channel survey data was then entered into the cross-section hydraulic analyzer spreadsheet tool (xsecAnalyzerVer17) developed by the NRCS (Moore, 2011). This program calculates channel hydraulic parameters, velocity, and discharge in 0.15 m (0.5 ft) increments and computes the channel separately from the floodplain. This program also calculates the channel Mannings roughness coefficient "n" using the Limerinos (1970) equation by the user entering the d_{84} bed substrate diameter from the pebble count. The floodplain "n" value must be provided by the user and for this project this was calculated using the vegetation density method described above (Arcement and Schnider, 1989). The site at Highway J (HJ) at a three-cell box culvert. Here the structures dimensions were measured, and discharge was estimated in HydraFlow Express software (Intelisolve 2006). Hydraulic parameters, velocities, and discharge for each gaging station can be viewed in the *Gaging Station Information* section of this report.

Flood Discharges

Modeling the highest flood flows at the gages in the larger main channel can be relatively difficult using a single cross-section. Therefore, a hydraulics model was used to get more accurate discharge estimates at the highest flood stages for five gage sites along the main channel at Highway J (HJ), Middle Big Barren (MBB), Upper Natural Area (UNA), Lower Natural Area (LNA), and Lower Big Barren (LBB). The RAS Mapper function of HEC-RAS 5.07 was used to estimate channel velocity for discharges that occur at overbank flood stages at each gage. The initial step to create the model was to delineate the stream centerline and both banks from a 1 m resolution LiDAR DEM (Ackerman, 2009; Dasanto et al., 2014). The total length of the stream segments evaluated ranged from 1.0 to 7.3 km (Figures 3-6). Due to the proximity of the UNA and the LNA, these two sites were analyzed within the same segment. Segments were divided into cross-sections spaced <100 m apart, with the total number ranging from 38 to 140 cross-sections for each site. A Manning's roughness coeffiecnt (n) of 0.16 was used for the floodplain, 0.08 for natural channels, and 0.045 for channelized segments (Ward and Elliot, 1995). Model results are reported for each gaging station in the *Gaging Station Information* section of this report.

Regression Equations

Rating curves were developed by plotting a best-fit line between Hobo stage (m) and discharge (m^3/s) in Microsoft Excel. The equation that represents the best-fit line was used to estimate discharge at various water depths from the Hobo stage recorders. For each site, a single log-log power function equation, or combination of power function equations, were used. The R^2 values for all equations used were >0.95. Additionally, flow measurements will be collected using a SonTek FlowTracker Acoustic Doppler velocity meter to verify and calibrate rating curves (Photo 6; OEWRI 2007). In some cases, the discharge that was calculated by the

hydraulic software was changed to match measured values. This was only necessary at the lower stages and it is noted on the rating tables for each site. Rating curves and regression equations for each gaging station can be viewed in the *Gaging Station Information* section of this report.

Water Year Data

Discharge data collected for this project will be presented in annual water year (WY) reports. The WY runs from October 1st to September 30th. The report will include both annual and daily data for each site. Information on the annual summary for each station will include annual statistics, annual rainfall, and comparison annual mean discharge to regional USGS gaging stations by drainage area. Annual graphs of 5-min temperature, stage, and discharge are included along with a flow duration curve at each site. Finally, a table showing the average daily discharge for the entire Water Year is also provided for each site.

LITERATURE CITED

Ackerman, P.E.C.T. (2009) HEC-GeoRAS: GIS Tools for Support of HEC-RAS using ArcGIS®. US Army Corps Eng. Hydrol. Eng. Center. Users Manual. Version 4.2. 244.

Adamski, J.C., J.C. Petersen, D.A. Friewald, J.V. Davis (1995) Environmental and Hydrologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma. U.S. Geological Survey Water-Resources Investigations Report 94-4022.

Arcement, G.J. and V.R. Schneider (1989) Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. U.S. Geological Survey Water-Supply Paper 2339.

Bradley, R.A. (2017) Geomorphic Disturbance and Anthropogenic Modifications in Big Barren Creek, Mark Twain National Forest, Southeast Missouri. Unpublished Masters Thesis, Department of Geography, Geology, and Planning, Missouri State University.

Dasanto, B.D., B. Pramudya, R. Boer, and Y. Suharnoto (2014) Effects of Forest Cover Change on Flood Characteristics in the Upper Citarum Watershed. J. Manaj. Hutan Trop. (Journal Trop. For. Manag. 20, 141–1.

Finley, J.M., A.D. Roberts, J. Hundley, J. Smith, and B.R. Simmons (2017) A Freshwater Mussel Survey of Big Barren Creek Natural Area, Carter County, Missouri. U.S. Fish and Wildlife Service, Columbia Fish and Wildlife Conservation Office and Columbia Ecological Services Field Office.

Harrelson, C.C., C.L. Rawlins, and J.P Potyondy (1994) Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RM-245, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, Fort Collins, CO.

Hu, Q., G.D. Wilson, X. Chen, and A. Akyuz (2005) Effects of Climate and Landcover Change on Stream Discharge in the Ozark Highlands, USA. Environmental Modeling and Assessment, 10:9-19.

Intelisolve (2006) Hydraflow Express User Manuel.

Jacobson, R.B. (2004) Downstream Effects of Timber Harvest in the Ozarks of Missouri. Toward Sustainability for Missouri Forests, U.S. Forest Service General Technical Report NC-239.

Limerinos, J.T. (1970) Determination of the Manning Coefficient from Measures Bed Roughness in Natural Channels. Geological Survey Water-Supply Paper 1898-B. United States Government Printing Office, Washington.

Moore, D. (2011) Using Mannings Equation with Natural Streams. NRCS Water Quality and Quantity Technology Development Team. Portland Oregon.

OEWRI (2007) Standard Operating Procedure for: Operation of the Son Tek/YSI FlowTracker Handheld ADV (Acoustic Doppler Velocimeter. Ozarks Environmental and Water Resources Institute, Missouri State University.

OEWRI (2016) Standard Operating Procedure for: Onset HOBO U20L-04 Water Level Logger and HOBO Waterproof Shuttle (U-DTW-1). Ozarks Environmental and Water Resources Institute, Missouri State University.

Owen, M.R., M.S. Thies, K.M. Geier R.T. Pavlowsky (2018). *Stream Crossing Inventory and Evaluation. Upper Big Barren Creek Watershed, Southeast Missouri*. OEWRI EDR-18-002. Completed for the U.S. Forest Service, January 26, 2018.

Pavlowsky R.T., M.R. Owen, and R.A. Bradley (2016). *Historical Rainfall Analysis for the Big Barren Creek Watershed, Southeast Missouri (1955-2015).* Prepared for U.S. Forest Service, Mark Twain National Forest, March 23, 2016.

Reminga, K.N. (2019) Historical Land Use Influence on Fine-Grained Sedimentation in Channel and Floodplain Deposits in a Forested Missouri Ozark Watershed. Unpublished Masters Thesis, Department of Geography, Geology, and Planning, Missouri State University.

Rosgen, D. L. (1996) Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Thies, M.S. (2017) Geomorphic Characteristics and Sediment Transport in Natural and Channelized Reaches of Big Barren Creek, Southeast Missouri. Unpublished Masters Thesis, Department of Geography, Geology, and Planning, Missouri State University.

Ward, A.D. and W.J. Elliot (1995) Environmental Hydrology. Lewis Publishers, Boca Raton, FL.

Weary, D.J., R.W. Harrison, R.C. Orndorff, R.E. Weems, J.S. Schindler, J.E. Repetski, and H.A. Pierce (2014) Bedrock Geologic Map of the Spring Valley, West Plains, and Parts of the Piedmont and Poplar Bluff 30'x60' Quadrangles, Missouri, Including the Upper Current River and Eleven Point River Drainage Basins. U.S. Geological Survey Scientific Investigations Map 3280.

TABLES

Table 1. Gaging station locations in the Big Barren Creek watershed.

Site Name	Site ID	Northing (m) NAD83,UTM15N	Easting (m) NAD83,UTM15N	Elevation (m)	Drainage Area (km2)	Stream Type	Burn History	Start Record	End Record
Tram Hollow	TH	4,080,612.536	660,800.255	257.10	1.59	Ephemeral	Unburned	12/17/2015	9/30/2019
Cowards Hollow	CH	4,077,436.497	671,184.193	201.49	2.19	Perennial	Burned	7/22/2016	9/30/2019
Upper Big Barren	UBB	4,082,297.631	660,727.701	253.46	2.51	Ephemeral	Burned	1/28/2016	9/30/2019
Barnes Hollow	BH	4,080,152.539	660,963.250	258.76	2.67	Ephemeral	Unburned	12/17/2015	9/30/2019
Upper Tributary	UT	4,081,698.540	660,910.259	247.92	4.19	Ephemeral	Burned	12/17/2015	9/30/2019
Wolf Pond	WP	4,084,372.539	665,468.255	232.65	5.13	Ephemeral	Burned	12/17/2015	9/30/2019
Polecat Hollow	PH	4,082,395.533	664,472.252	224.51	6.19	Ephemeral	Burned	12/17/2015	9/30/2019
South Prong Cedar	SPC	4,078,550.511	666,420.219	209.96	7.28	Ephemeral	Burned	12/17/2015	9/30/2019
Fools Catch	FC	4,081,865.521	669,811.222	196.79	7.82	Ephemeral	Unburned	12/17/2015	9/30/2019
Highway J	HYJ	4,081,730.799	661,557.484	245.46	8.82	Ephemeral	Mixed	9/9/2016	9/30/2019
Middle Big Barren	MBB	4,081,306.806	667,938.252	191.57	47.8	Ephemeral	Mixed	1/28/2016	9/30/2019
Upper Natural Area	UNA	4,080,307.787	672,375.327	163.74	103.6	Perennial	Mixed	9/9/2016	9/30/2019
Lower Natural Area	LNA	4,079,188.630	672,767.129	158.50	124.2	Perennial	Mixed	9/9/2016	9/30/2019
Lower Big Barren	LBB	4,074,388.720	681,374.962	121.83	186.1	Ephemeral	Mixed	9/9/2016	9/30/2019

Table 2. Slope, D84, and in-channel Manning's "n" values for gaging sites

Site Name	Channel Width (m)	Slope (m/m)	Pebble Count (n)	D84 (mm)	Manning's "n" Range for Channel	Average Channel "n" Value
Tram Hollow	15.0	0.00953	77	45	0.105-0.250	0.158
Cowards Hollow	11.1	0.01513	30	73	0.120-0.423	0.225
Barnes Hollow	18.7	0.00856	30	32	0.045-0.177	0.076
Upper Big Barren	8.4	0.00756	90	64	0.114-0.125	0.118
Wolf Pond	15.9	0.00665	90	64	0.118-0.252	0.155
Upper Tributary	16.6	0.00750	35	35	0.083-0.126	0.109
Polecat	16.0	0.00830	60	45	0.095-0.117	0.103
South Prong Cedar	20.3	0.00737	90	64	0.127-0.132	0.129
Fools Catch	14.1	0.00868	77	148	0.132-0.205	0.168
Middle Big Barren	22.3	0.00460	60	45	0.030-0.142	0.105
Upper Natural Area	35.7	0.00275	30	136	0.100-0.222	0.131
Lower Natural Area	38.5	0.00346	30	128	0.126-0.140	0.132
Lower Big Barren	46.9	0.00216	90	45	0.043-0.134	0.092

Table 3. Floodplain Tree Counts and Average Diameter at Breast Height (DBH) for gage sites

Site Name	Left Bank			Right Bank		
	Length (m)	# of Trees	Avg. Dia. (cm)	Length (m)	# of Trees	Avg. Dia. (cm)
Tram Hollow	NA	NA	NA	58	35	23.5
Cowards Hollow	39	21	29.1	15	6	24.5
Barnes Hollow	16	12	20.2	1.5	3	19.7
Upper Big Barren	20	32	30.1	32	35	27.1
Wolf Pond	29	10	33.6	6.0	1	59.3
Upper Tributary	55	32	29.0	11	2	43.5
Polecat	45	26	29.4	8.0	8	31.5
South Prong Cedar	46	20	28.0	11	4	20.0
Fools Catch	40	18	35.6	23	9	35.1
Middle Big Barren	19	8	24.9	19	16	24.0
Upper Natural Area	13	13	30.1	43	27	33.7
Lower Natural Area	11	19	30.6	115	51	28.2
Lower Big Barren	19	26	22.3	12	25	26.3

Table 4. Boundary roughness values (n0) for gage sites

Site Name	Left Bank							Right Bank						
	nb	n1	n2	n3	n4	m	n0	nb	n1	n2	n3	n4	m	n0
Tram Hollow	NA	NA	NA	NA	NA	NA	NA	0.02	0.008	0.0	0.025	0.075	1.0	0.128
Cowards Hollow	0.02	0.010	0.0	0.025	0.075	1.0	0.130	0.02	0.018	0.0	0.025	0.075	1.0	0.138
Barnes Hollow	0.02	0.003	0.0	0.020	0.075	1.0	0.118	0.02	0.003	0.0	0.005	0.065	1.0	0.093
Upper Big Barren	0.02	0.004	0.0	0.025	0.075	1.0	0.124	0.02	0.006	0.0	0.025	0.075	1.0	0.126
Wolf Pond	0.02	0.008	0.0	0.025	0.075	1.0	0.128	0.02	0.005	0.0	0.020	0.075	1.0	0.120
Upper Tributary	0.02	0.009	0.0	0.030	0.075	1.0	0.134	0.02	0.007	0.0	0.025	0.075	1.0	0.127
Polecat	0.02	0.005	0.0	0.025	0.075	1.0	0.125	0.02	0.005	0.0	0.025	0.075	1.0	0.125
South Prong Cedar	0.02	0.012	0.0	0.030	0.075	1.0	0.137	0.02	0.008	0.0	0.025	0.075	1.0	0.128
Fools Catch	0.02	0.008	0.0	0.025	0.075	1.0	0.128	0.02	0.002	0.0	0.025	0.075	1.0	0.122
Middle Big Barren	0.02	0.008	0.0	0.025	0.075	1.0	0.128	0.02	0.008	0.0	0.025	0.075	1.0	0.128
Upper Natural Area	0.02	0.017	0.0	0.028	0.085	1.0	0.150	0.02	0.017	0.0	0.028	0.085	1.0	0.150
Lower Natural Area	0.02	0.010	0.0	0.025	0.075	1.0	0.130	0.02	0.015	0.0	0.025	0.080	1.0	0.140
Lower Big Barren	0.02	0.010	0.0	0.025	0.075	1.0	0.130	0.02	0.010	0.0	0.025	0.075	1.0	0.130

n_b = base value for n
n_1 = surface irregularities
n_2 = floodplain shape and size variation = 0
n_3 = obstructions
n_4 = vegetation
m = degree of meandering = 1
* For more information about these values, see Arcement and Schnider, 1989

Table 5. Left Bank Manning's "n" values for gage sites

Site Name	Left Bank								
	Depth Over Floodplain	Length	FP Area	FP WP	FP R	FP Mean Depth	Veg. Density	C*	Floodplain
	(m)	(m)	(m2)	(m)	(m)	(m)	(m/m2)		"n"
Tram Hollow	0.75	NA	NA	NA	NA	NA	NA	NA	NA
Cowards Hollow	1.0	39	3.3	8.22	0.40	0.411	0.0024	16	0.135
Barnes Hollow	1.0	16	5.9	11.93	0.49	0.50	0.0023	19	0.131
Upper Big Barren	1.75	20	5.5	23.31	0.23	0.24	0.0072	17	0.137
Wolf Pond	1.0	29	3.9	25.02	0.16	0.16	0.0018	19	0.130
Upper Tributary	1.0	55	12.1	48.71	0.25	0.25	0.0026	18	0.139
Polecat	1.25	45	14.0	35.67	0.39	0.39	0.0026	16	0.134
South Prong Cedar	1.25	46	9.5	42.12	0.23	0.23	0.0019	18	0.140
Fools Catch	1.75	40	17.2	41.92	0.41	0.41	0.0024	16	0.136
Middle Big Barren	2.0	19	5.6	31.45	0.18	0.18	0.0016	19	0.130
Upper Natural Area	3.25	13	3.3	10.14	0.32	0.32	0.0046	18	0.161
Lower Natural Area	4.0	11	3.7	5.04	0.73	0.81	0.0078	12	0.168
Lower Big Barren	2.5	19	12.1	15.68	0.77	0.81	0.0047	11	0.154

FP = floodplain
WP = wetted perimeter
R = hydraulic radius
C* = Effective-drag coefficient (See Figure 4, Arcement and Schnider, 1989)

Table 6. Right Bank Manning's "n" values for gage sites

		Right Bank							
	Depth Over Floodplain	Length	FP Area	FP WP	FP R	FP Mean Depth	Veg Density	C*	Floodplain
Site Name	(m)	(m)	(m2)	(m)	(m)	(m)	(m/m2)		"n"
Tram Hollow	0.75	58	6.2	43.76	0.14	0.14	0.0022	20	0.130
Cowards Hollow	1.0	15	8.9	19.94	0.45	0.45	0.0015	16	0.135
Barnes Hollow	1.0	1.5	0.6	1.69	0.34	0.37	0.0006	20	0.118
Upper Big Barren	1.0	32	0.8	7.61	0.11	0.11	0.0046	19	0.129
Wolf Pond	1.0	6.0	3.2	7.52	0.43	0.43	0.0016	16	0.126
Upper Tributary	1.0	11	0.7	0.56	1.18	1.37	0.0012	7.0	0.134
Polecat	1.25	8.0	2.0	4.72	0.42	0.43	0.0048	16	0.142
South Prong Cedar	1.25	11	13.3	27.51	0.48	0.49	0.0011	15	0.133
Fools Catch	1.75	23	0.4	14.32	0.03	0.03	0.0021	19	0.122
Middle Big Barren	2.0	19	24.3	56.62	0.43	0.43	0.0031	16	0.139
Upper Natural Area	3.25	43	50.2	49.30	1.02	1.03	0.0032	9.0	0.167
Lower Natural Area	2.25	115	40.3	80.61	0.50	0.50	0.0019	14	0.135
Lower Big Barren	2.5	12	12.0	24.63	0.49	0.51	0.0086	14	0.160

FP = floodplain
WP = wetted perimeter
R = hydraulic radius
C* = Effective-drag coefficient (See Figure 4, Arcement and Schnider, 1989)

FIGURES

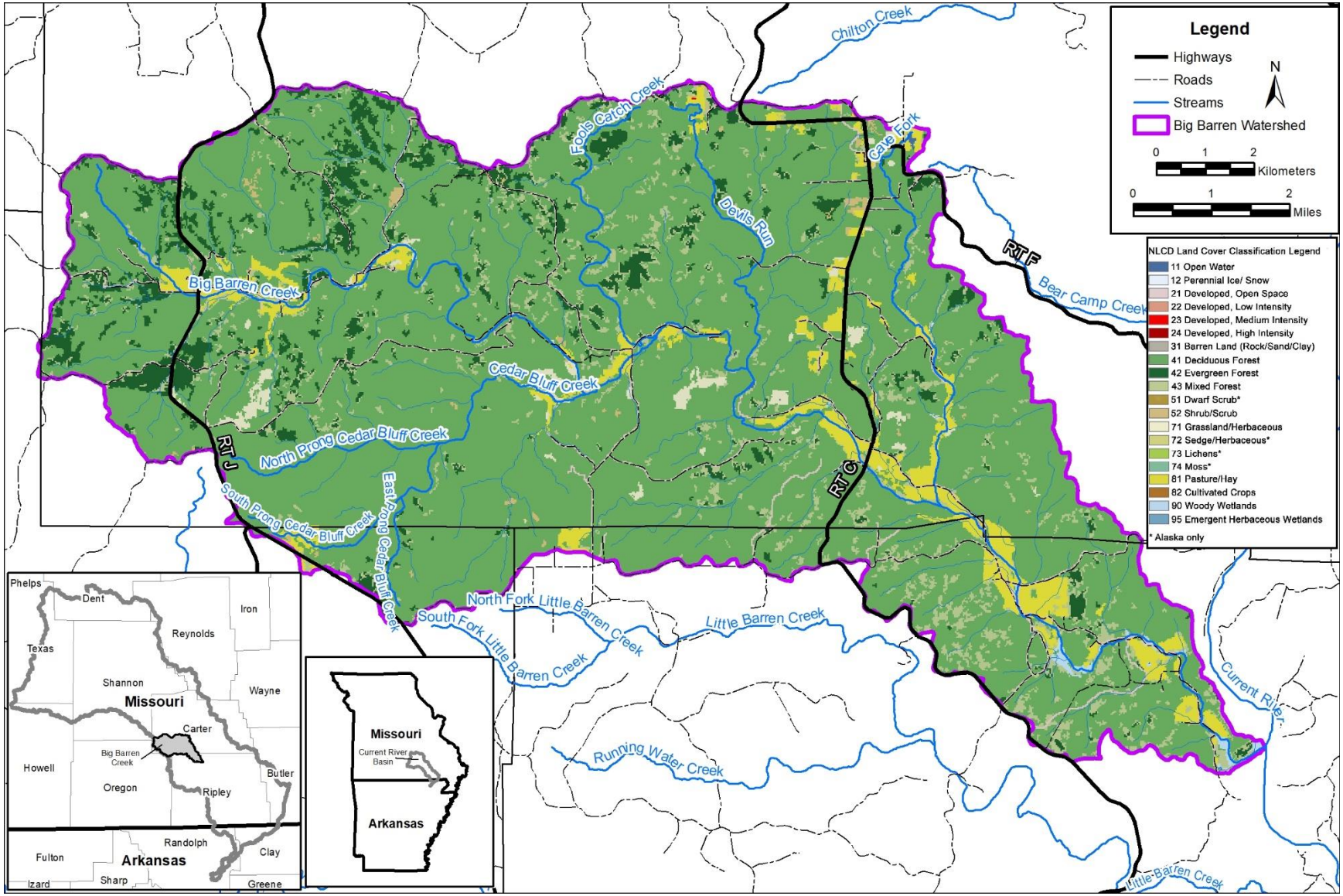

Figure 1. Location and land use (2016) of the Big Barren Creek watershed.

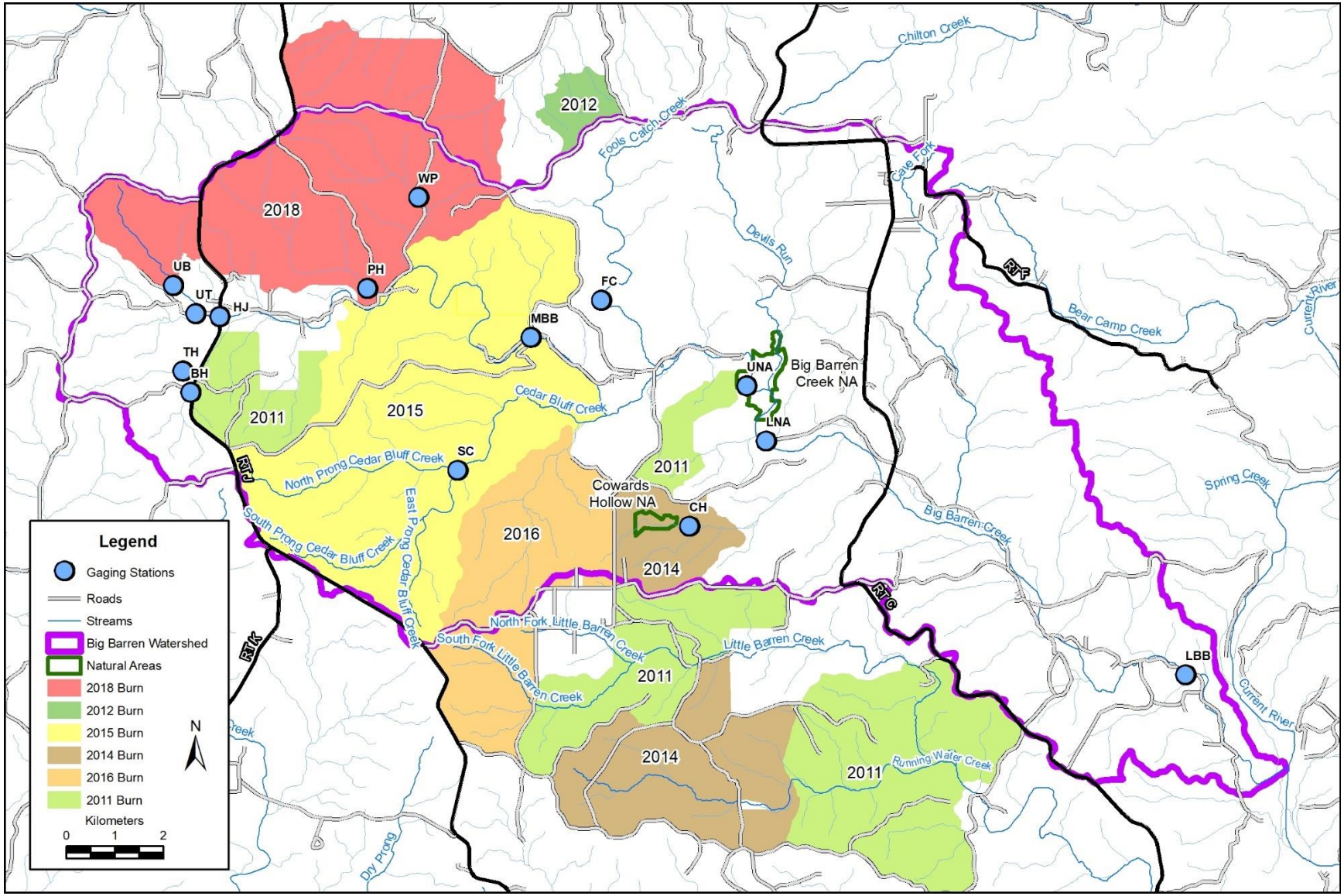

Figure 2. Hydrologic monitoring stations (2015-2019) with burn history.

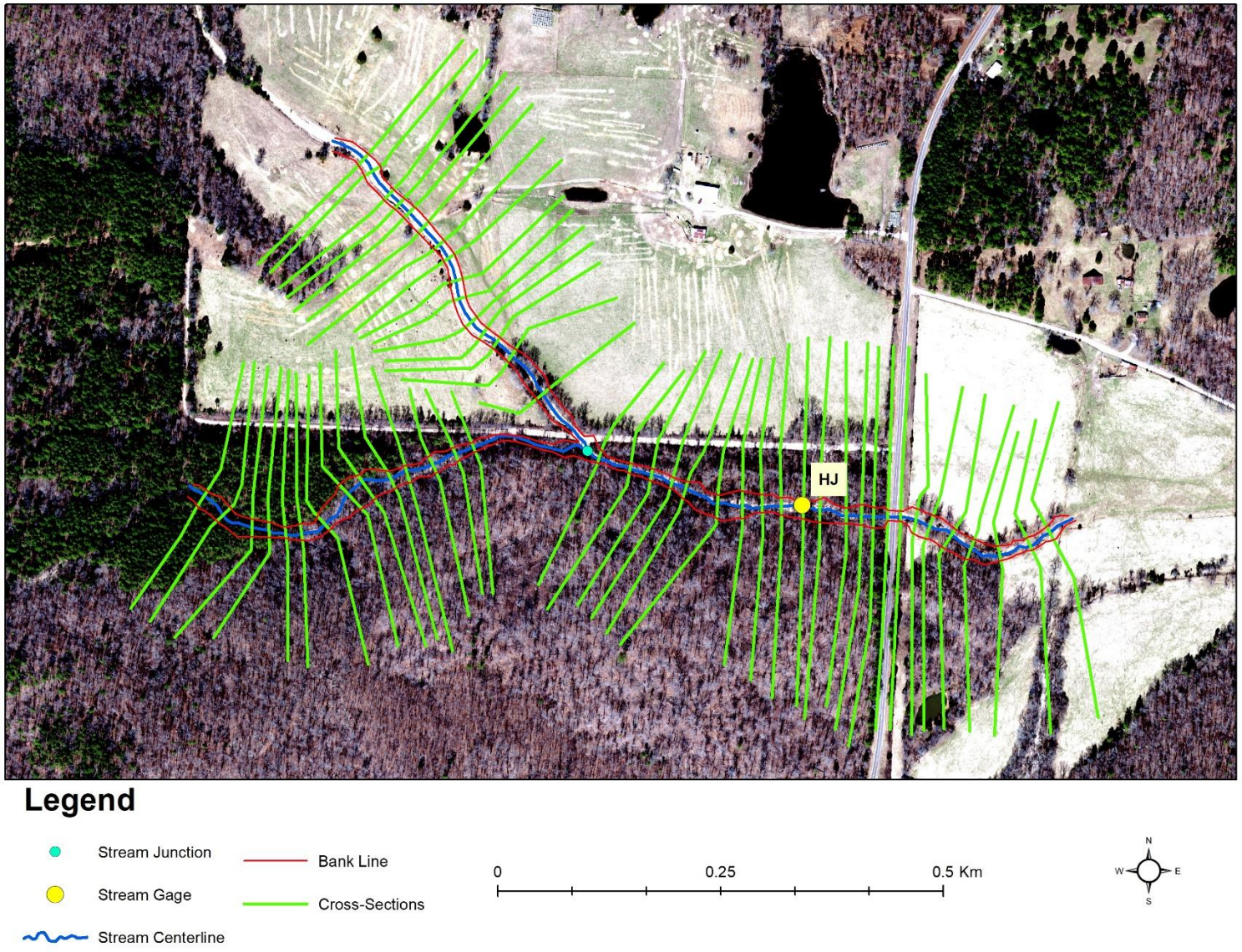

Figure 3. Highway J (HJ) HEC-RAS channel and cross-sections.

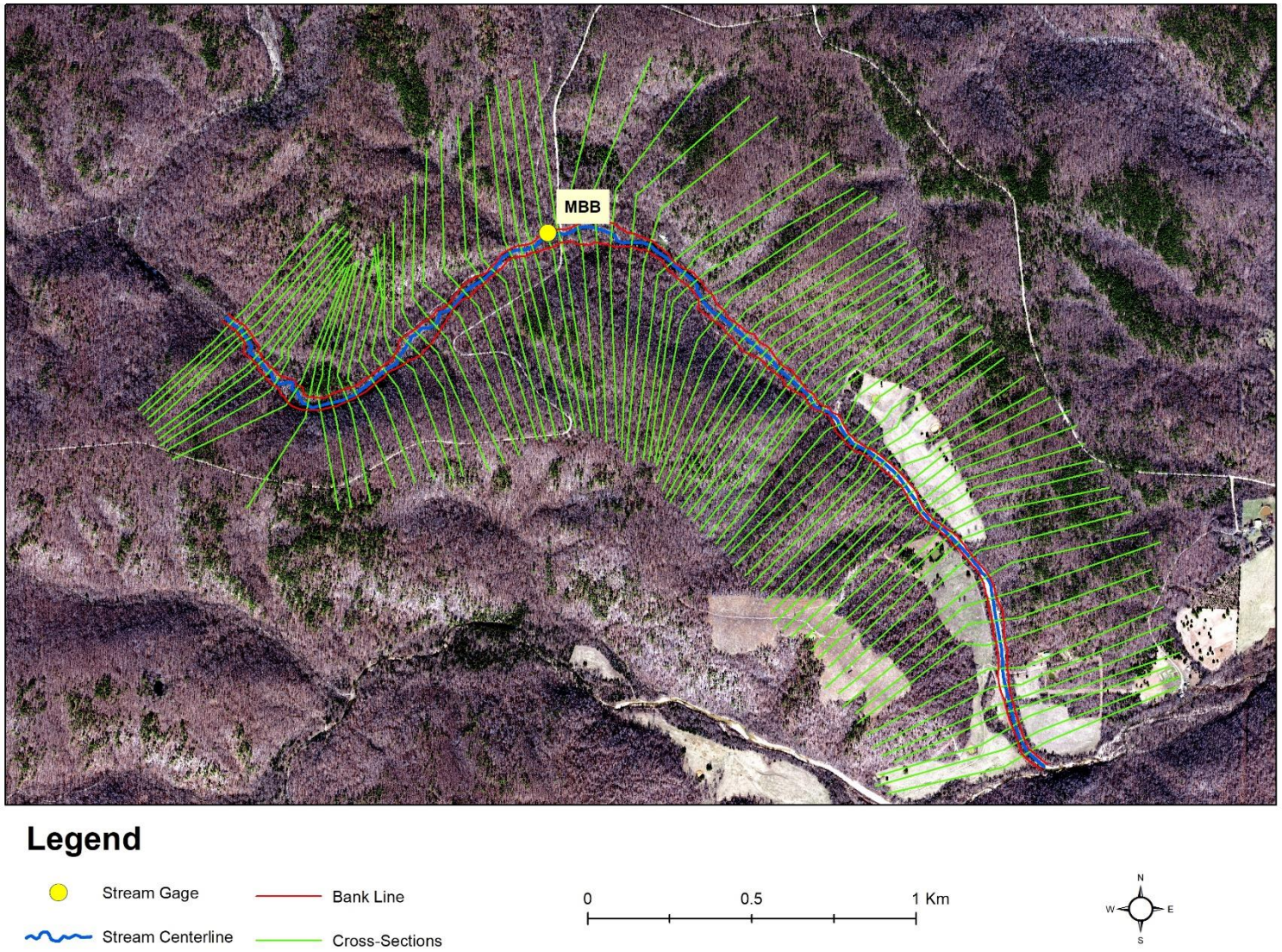

Figure 4. Middle Big Barren (MBB) HEC-RAS channel and cross-sections.

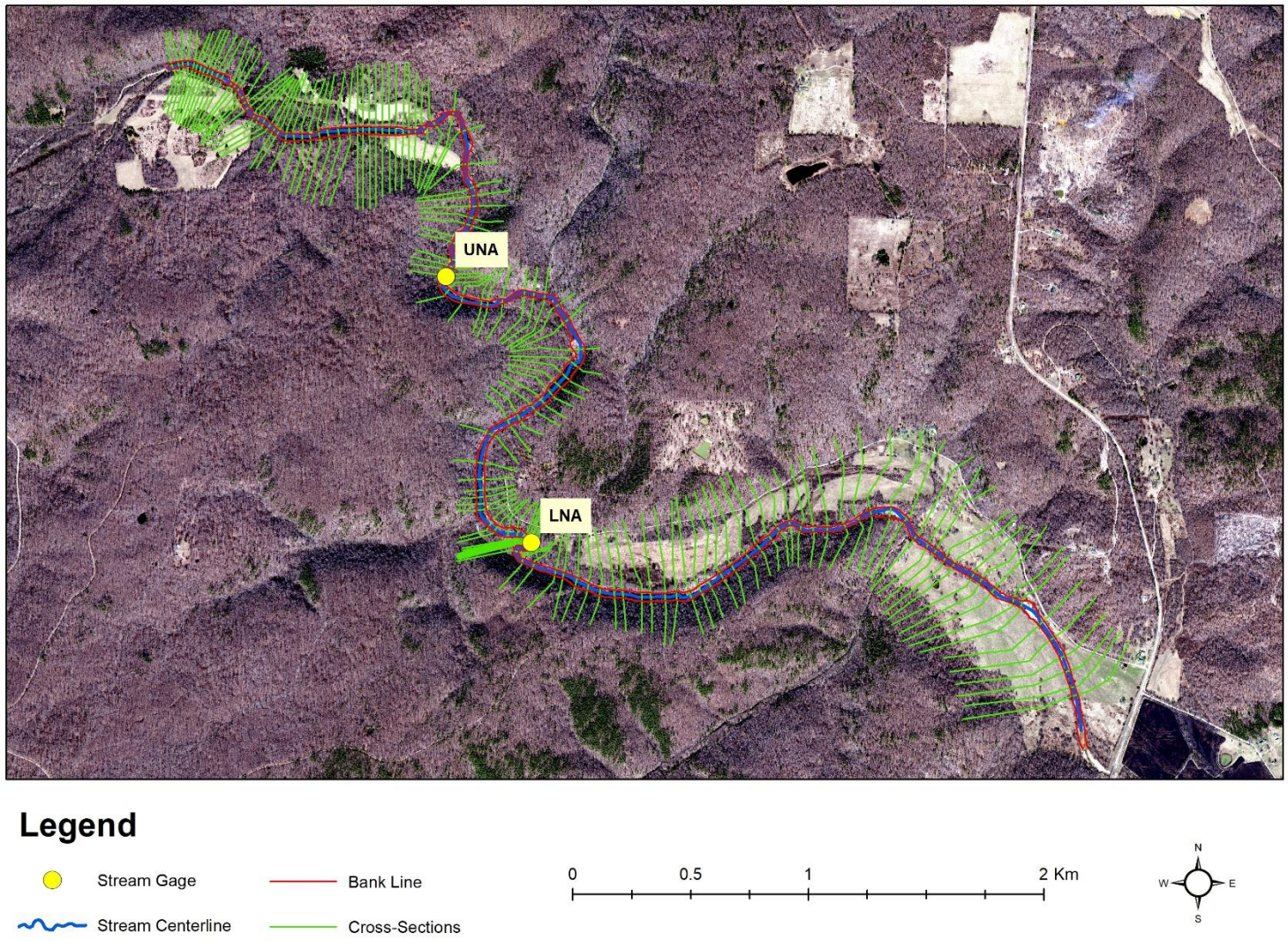

Figure 5. Upper Nautral Area (UNA) ans Lower Natural Area (LNA) HEC-RAS channel and cross-sections.

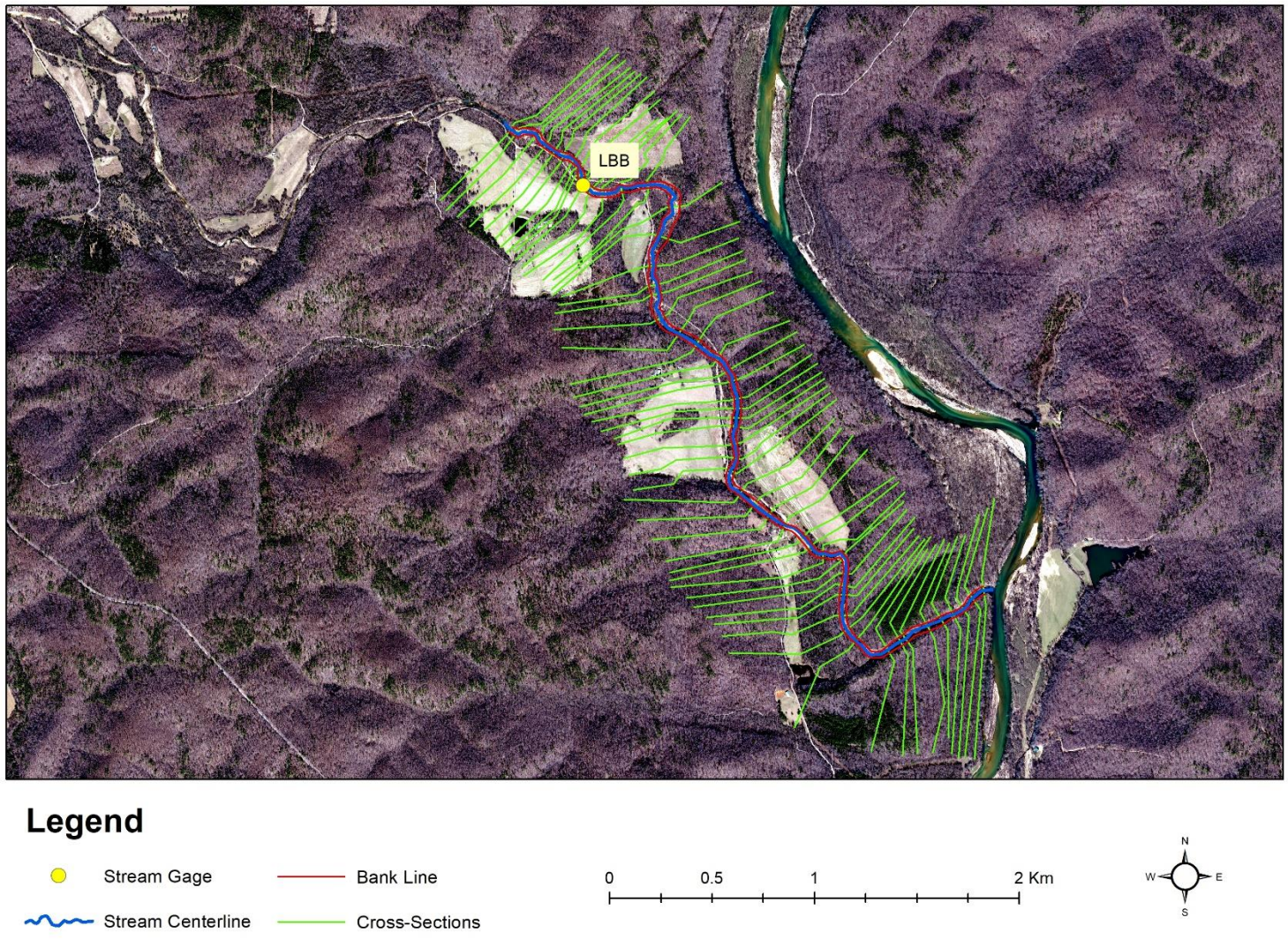

Figure 6. Lower Big Barren (LBB) HEC-RAS channel and cross-sections.

PHOTOS

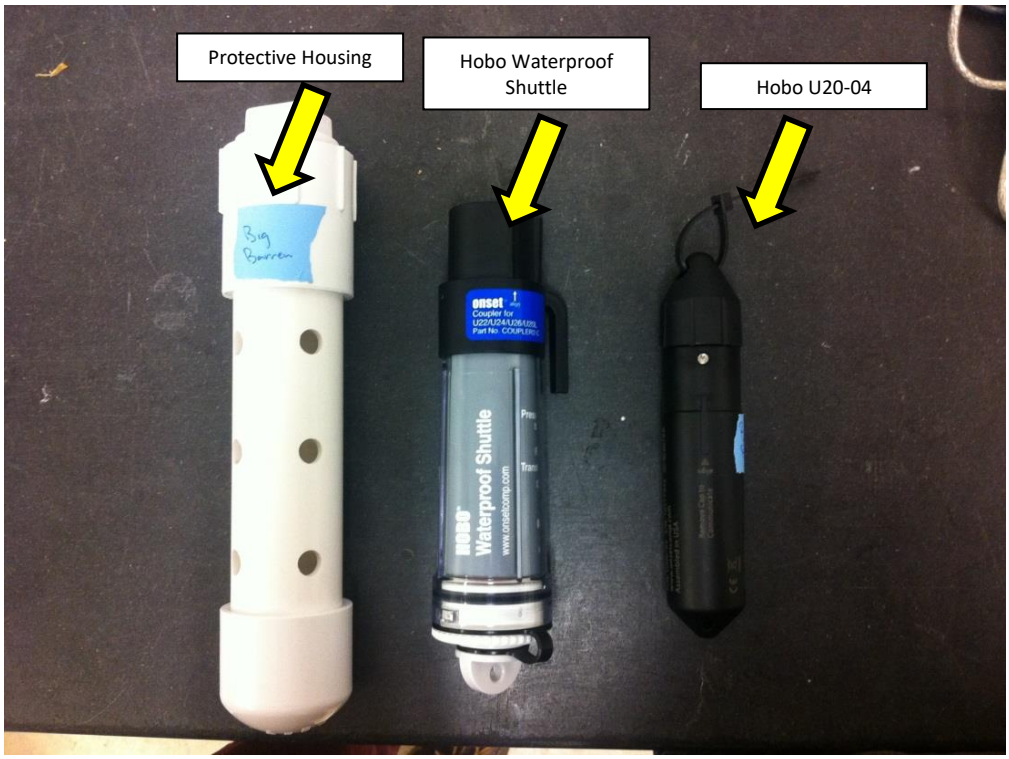

Photo 1. Example of the Hobo U20-04 water level stage recorder, shuttle, and protective housing used for this project.

Photo 2. Water level stage recorder and staff gage installed at Barnes Hollow (12/14/2015).

Photo 3. Water level stage recorder attached to stage gage at Barnes Hollow (12/14/2015).


Photo 4. Looking upstream at the Fools Catch gaging station during flow conditions (05/05/2017).

Photo 5. Looking upstream at the Fools Catch gaging station during no-flow conditions (12/14/2015).

Photo 6. Collecting discharge measurements with SonTek FlowTracker at the Fools Catch gaging station for calibrating rating curves (05/05/2017).

GAGING STATION INFORMATION

Tram Hollow (1.59 km^2)

Site Name:	Tram Hollow
Site ID:	TH
Location Description:	Gage is located approximately 250 m upstream of the confluence with Barnes Hollow Tributary in Carter County
Northing (m) UTM Zone 15N:	4,080,612.536
Easting (m):	660,800.255
Elevation (m):	257.10
Stream Name:	Tram Hollow Tributary
Type:	Ephemeral
River KM:	0.25
Drainage Area (km2):	1.59
Date Installed:	12/17/2015
Burn History:	Unburned

Photo 7. Looking downstream at Tram Hollow (December 14, 2015).

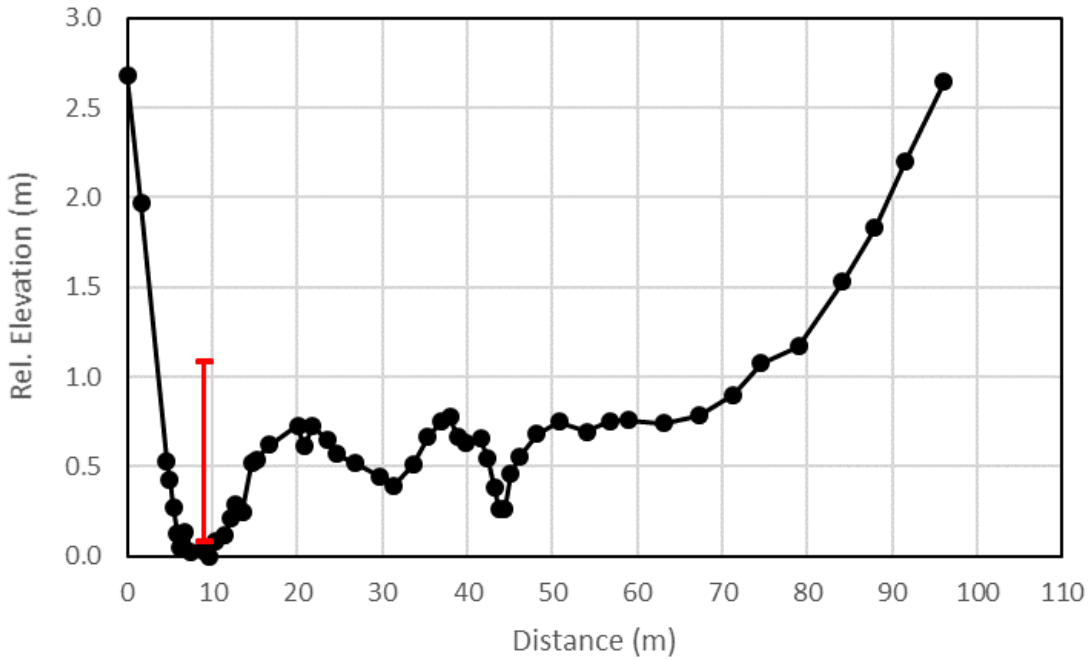

Figure 7. Cross-section at the Tram Hollow.

Table 7. Rating table for the Tram Hollow.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.71	1.66	1.75	87.4	85.4	1.02	84.8	1.03	0.123	107.8	1.23
1.46	1.41	1.50	66.7	81.6	0.82	81.1	0.82	0.122	73.1	1.10
1.21	1.16	1.25	46.9	77.5	0.61	77.0	0.61	0.122	44.7	0.95
0.96	0.91	1.00	28.6	69.9	0.41	69.6	0.41	0.121	23.2	0.81
0.71	0.66	0.75	12.1	54.4	0.22	54.1	0.22	0.119	8.80	0.73
0.46	0.41	0.50	4.07	19.0	0.21	18.8	0.22	0.105	2.23	0.55
0.21	0.16	0.25	1.16	7.04	0.17	6.98	0.17	0.250	0.14	0.12
0.16	0.11	0.20							0.006	

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = measured

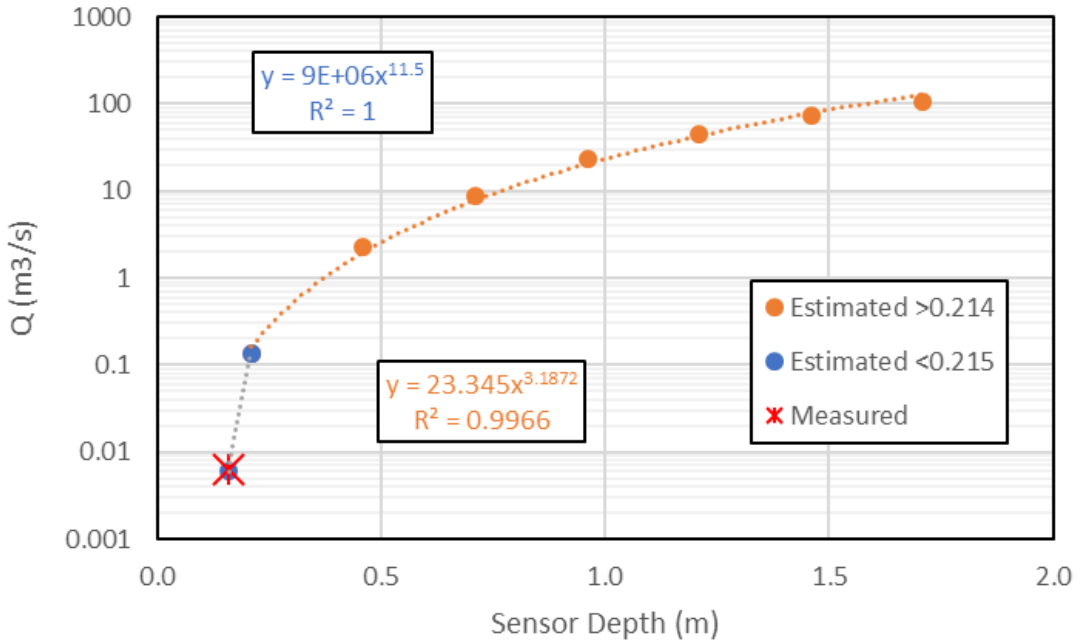

Figure 8. Rating curves for the Tram Hollow.

Table 8. Rating equations for Tram Hollow.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.215	Power[1]	8,519,019.683	11.499520
>0.214	Power[1]	23.344705	3.187168

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Cowards Hollow (2.19 km^2)

Site Name:	Cowards Hollow
Site ID:	CH
Location Description:	Gage is located approximately 2.0 km downstream of US National Forest Road 3145 on the main stem of Cowards Hollow Tributary in Carter County
Northing (m) UTM Zone 15N:	4,077,436.497
Easting (m)	671,184.193
Elevation (m):	201.49
Stream Name:	Cowards Hollow Tributary
Type:	Perennial
River KM:	4.02
Drainage Area (km2):	2.19
Date Installed:	7/22/2016
Burn History:	Burned

Photo 8. Looking upstream at Cowards Hollow gage (May 5, 2017).

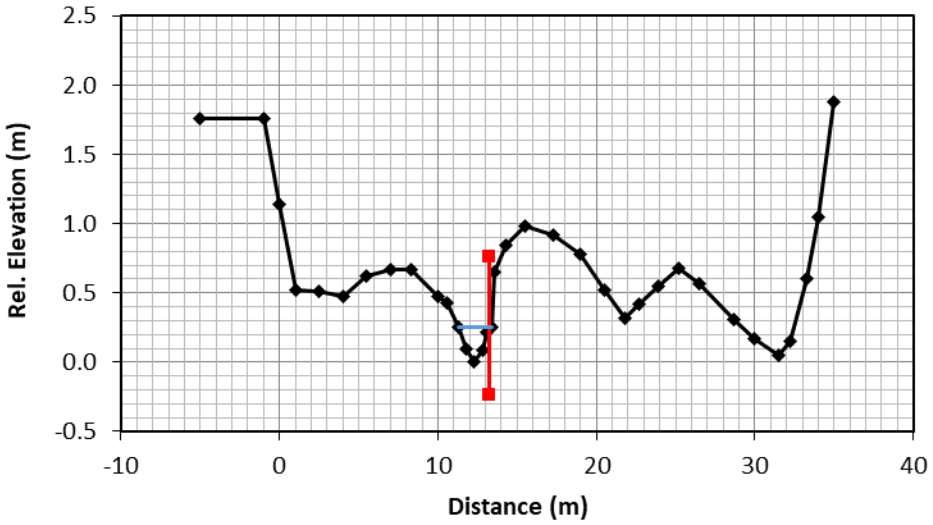

Figure 9. Location of the Cowards Hollow gage in Carter County.

Table 9. Rating table for the Cowards Hollow gage site.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.49	1.57	1.25	24.4	35.4	0.69	34.4	0.71	0.131	21.6	0.89
1.24	1.32	1.00	7.09	15.8	0.45	15.3	0.46	0.120	5.88	0.83
0.99	1.07	0.75	3.53	13.8	0.26	13.3	0.26	0.132	1.53	0.43
0.74	0.82	0.50	0.98	5.46	0.18	5.21	0.19	0.423	0.09	0.10
0.49	0.57	0.25	0.27	2.17	0.13	2.10	0.13	0.125	0.01	0.25
0.24	0.32	0.00	0.0	0.0	0.00	0.0	0.00	0.423	0.00	0.00

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = changed based on measurement

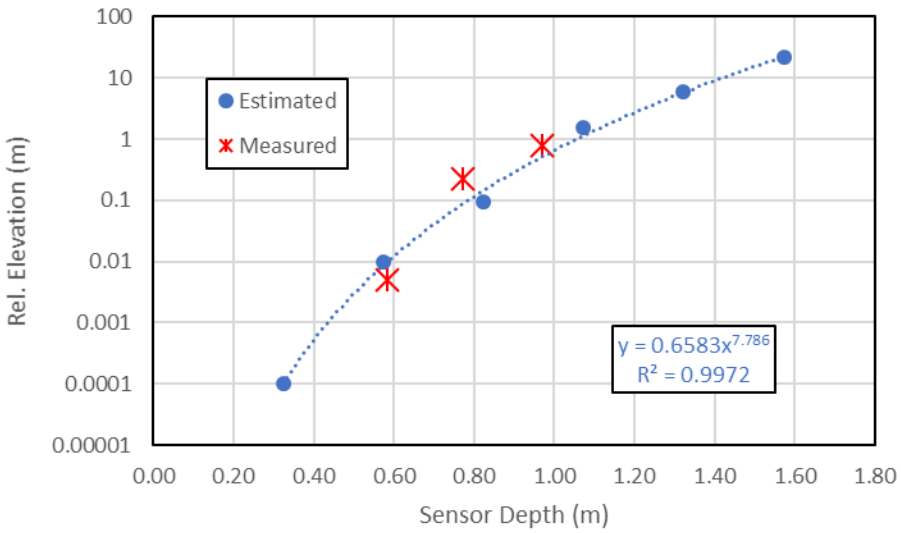

Figure 10. Rating curve for the Cowards Hollow gage site.

Table 10. Rating equation for Cowards Hollow gage site

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
0.24-1.57	Power	0.658286	7.78599191

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Upper Big Barren (2.51 km^2)

Site Name:	Upper Big Barren
Site ID:	UBB
Location Description:	Gage is located approximately 850 m upstream of Carter County Road 174
Northing (m) UTM Zone 15N:	4,082,297.631
Easting (m):	660,727.701
Elevation (m):	253.46
Stream Name:	Big Barren Creek
Type:	Ephemeral
River KM:	42.4
Drainage Area (km2):	2.51
Date Installed:	1/28/2016
Burn History:	Burned

Photo 9. Looking upstream at the Upper Big Barren (January 28, 2016).

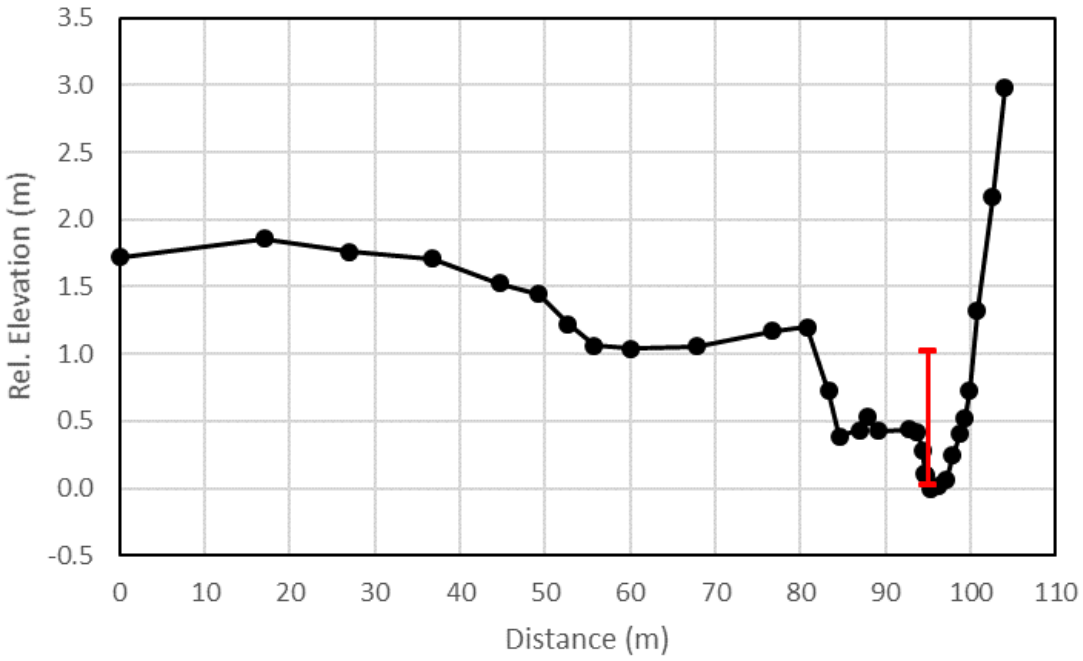

Figure 11. Cross-section for the Upper Big Barren.

Table 11. Rating table for the Upper Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.98	1.97	2.00	72.2	103.1	0.70	102	0.71	0.128	63.8	0.88
1.73	1.72	1.75	48.0	77.5	0.62	77.0	0.62	0.127	42.1	0.88
1.48	1.47	1.50	32.5	55.7	0.58	55.2	0.59	0.125	28.1	0.86
1.23	1.22	1.25	19.8	48.8	0.41	48.4	0.41	0.124	15.7	0.79
0.98	0.97	1.00	10.7	18.8	0.57	18.4	0.58	0.114	9.12	0.85
0.73	0.72	0.75	6.35	16.9	0.38	16.7	0.38	0.114	3.92	0.62
0.48	0.47	0.50	2.40	14.5	0.16	14.4	0.17	0.125	0.78	0.32
0.23	0.22	0.25							0.030	

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = adjusted

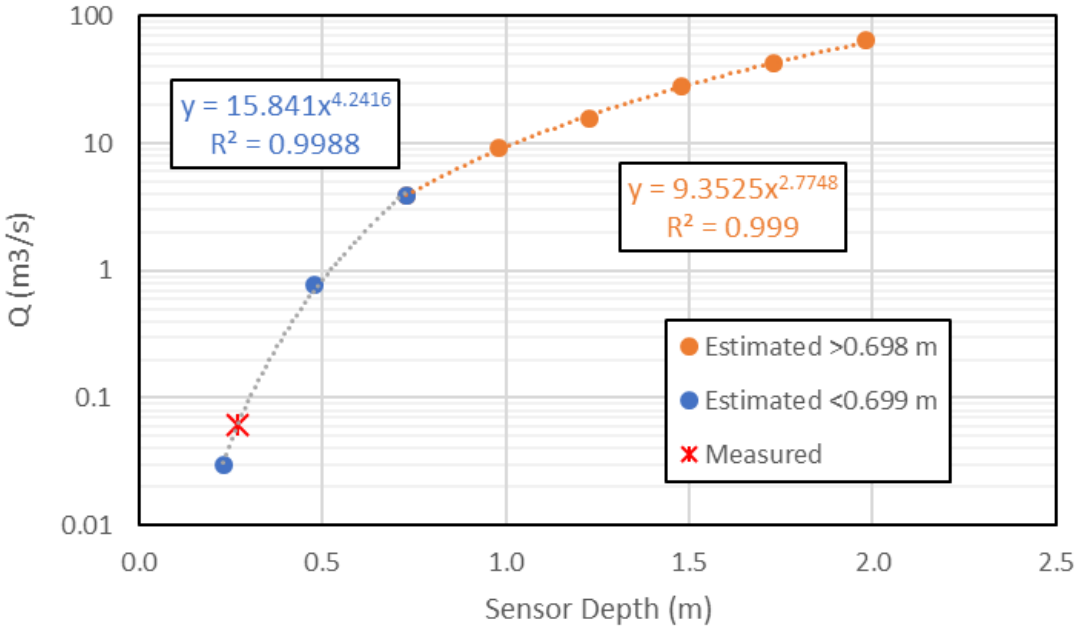

Figure 12. Rating curves for the Upper Big Barren.

Table 12. Rating equations for the Upper Big Barren.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.699	Power[1]	15.840876	4.241575
>0.698	Power[1]	9.352472	2.774801

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Barnes Hollow (2.67 km^2)

Site Name:	Barnes Hollow
Site ID:	BH
Location Description:	Gage is located approximately 100 m upstream of US National Forest Road 3150 in channelized section of the main stem of Barnes Hollow Tributary in Carter County
Northing (m) UTM Zone 15N:	4,080,152.539
Easting (m):	660,963.250
Elevation (m):	258.76
Stream Name:	Barnes Hollow Tributary
Type:	Ephemeral
River KM:	2.35
Drainage Area (km2):	2.67
Date Installed:	12/17/2015
Burn History:	Unburned

Photo 10. Looking upstream at BH gage (December 14, 2015).

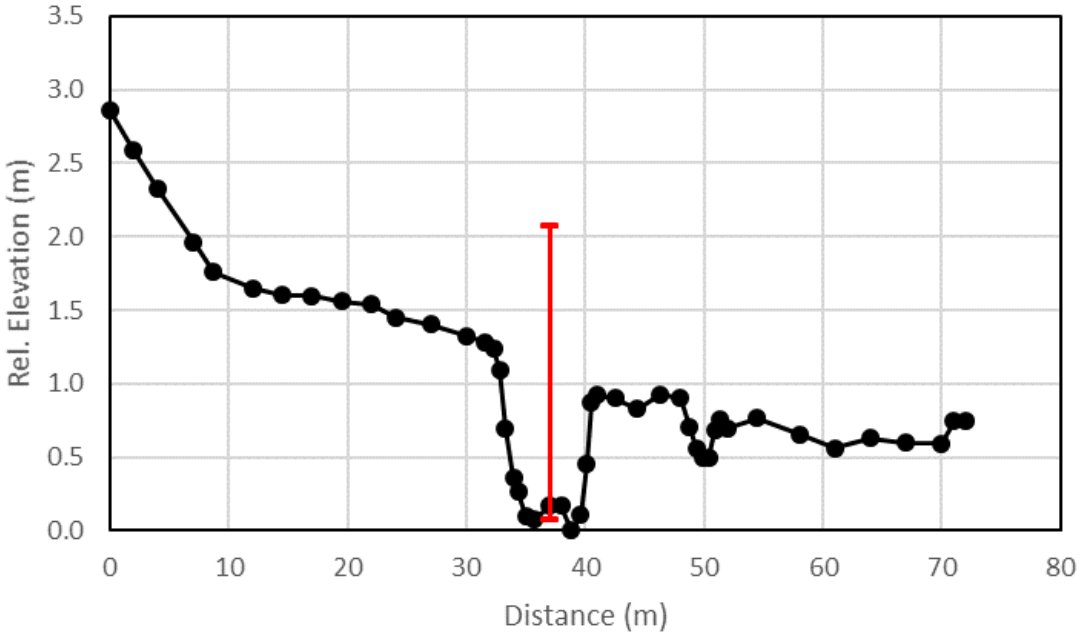

Figure 13. Cross-section for the Barnes Hollow.

Table 13. Rating table for the Barnes Hollow.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg D (m)	*"n"*	Q (m3/s)	Velocity (m/s)
0.88	0.86	0.87	4.81	9.75	0.49	9.26	0.52	0.045	6.59	1.37
0.76	0.74	0.75	3.90	7.55	0.52	7.16	0.54	0.045	4.84	1.24
0.51	0.49	0.50	2.19	6.66	0.33	6.44	0.34	0.056	1.61	0.74
0.26	0.24	0.25	0.70	5.45	0.13	5.35	0.13	0.177	0.09	0.12
0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.056	0.00	0.00

WP = wetted perimeter
R = hydraulic radius
Q = discharge

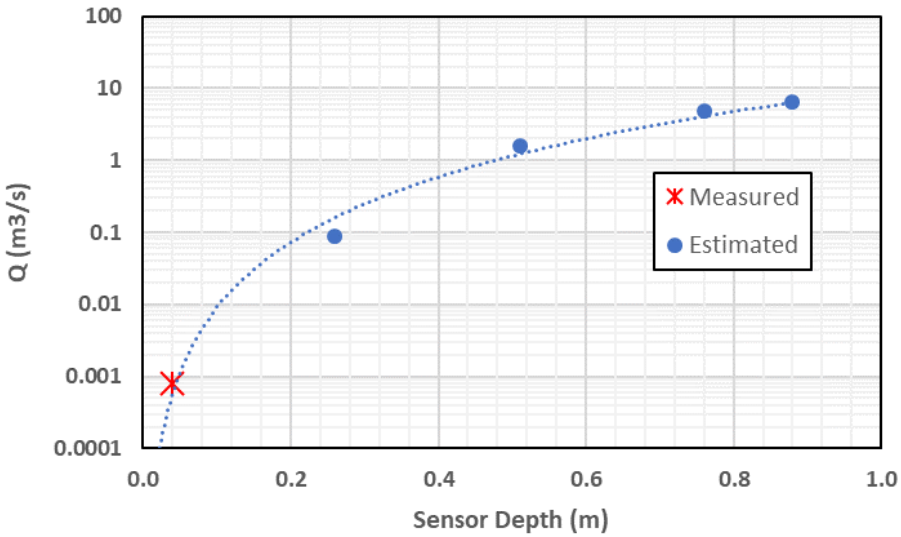

Figure 14. Rating curve for the Barnes Hollow.

Table 14. Rating equation for the Barnes Hollow.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)	R^2
0.00-0.86	Power[1]	9.320198	3.012376	0.996

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Upper Tributary (4.19 km^2)

Site Name:	Upper Tributary
Site ID:	UT
Location Description:	Gage is located approximately 150 m upstream of the confluence with Big Barren Creek along Carter County Road 174.
Northing (m) UTM Zone 15N:	4,081,698.540
Easting (m):	660,910.259
Elevation (m):	247.92
Stream Name:	Unnamed Tributary to Big Barren Creek
Type:	Ephemeral
River KM:	0.15
Drainage Area (km2):	4.19
Date Installed:	12/17/2015
Burn History:	Unburned

Photo 11. Looking downstream at the Upper Tributary gage location (December 14, 2015).

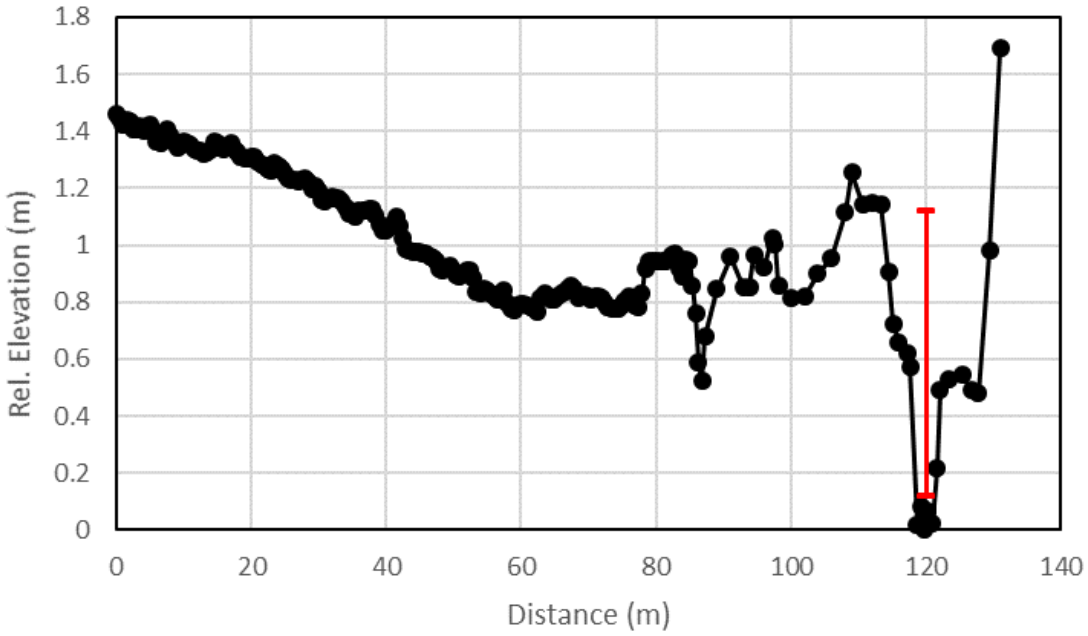

Figure 15. Cross-section for the Upper Tributary.

Table 15. Rating table for the Upper Tributary.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.37	1.38	1.50	69.4	131.3	0.53	131	0.53	0.127	42.1	0.61
1.12	1.13	1.25	39.3	105.6	0.37	105	0.37	0.127	22.0	0.56
0.87	0.88	1.00	16.7	79.1	0.21	78.6	0.21	0.126	9.42	0.56
0.62	0.63	0.75	4.59	16.1	0.28	15.7	0.29	0.109	3.52	0.77
0.37	0.38	0.50	1.58	6.24	0.25	6.00	0.26	0.083	1.07	0.68
0.12	0.13	0.25	0.60	3.48	0.17	3.37	0.18	0.118	0.13	0.21

WP = wetted perimeter
R = hydraulic radius
Q = discharge

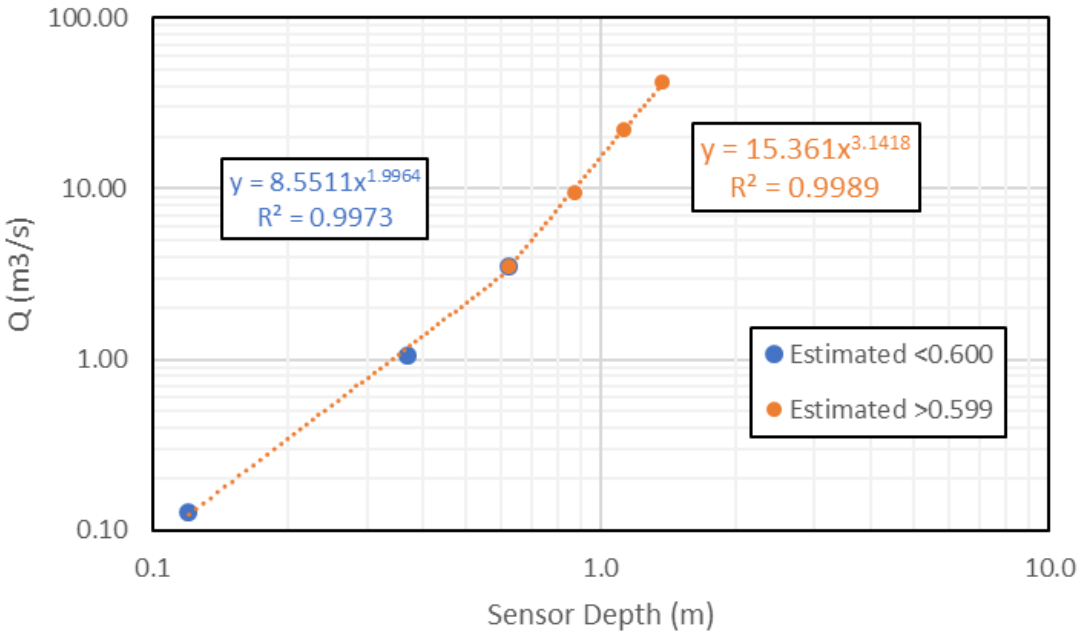

Figure 16. Rating curves for the Upper Tributary.

Table 16. Rating equations for the Upper Tributary.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.600	Power[1]	8.551122	1.996356
>0.599	Power[1]	15.361256	3.141773

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Wolf Pond (5.13 km^2)

Site Name:	Wolf Pond
Site ID:	WP
Location Description:	Gage is located approximately 40 m downstream of Carter County Road J-173.
Coordinate System	UTM Zone 15N
Northing (m) UTM Zone 15N:	4,084,372.539
Easting (m)	665,468.255
Elevation (m)	232.65
Stream Name:	Wolf Pond Tributary
Type:	Ephemeral
River KM:	1.9
Drainage Area (km2):	5.13
Date Installed:	12/17/2015
Burn History:	Burned

Photo 12. Looking upstream at the Wolf Pond Tributary (December 15, 2015).

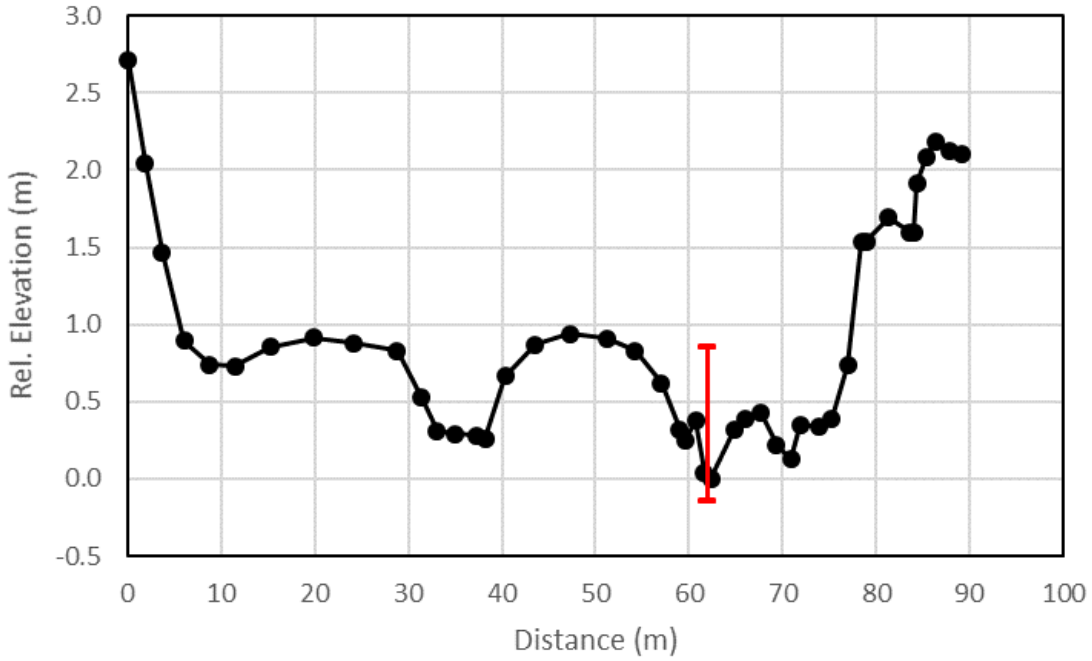

Figure 17. Cross-section for the Wolf Pond Tributary.

Table 17. Rating table for the Wolf Pond Tributary.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
2.11	2.14	2.00	103.3	83.7	1.23	82.9	1.25	0.126	131.3	1.27
1.86	1.89	1.75	82.8	82.1	1.01	81.4	1.02	0.126	93.7	1.13
1.61	1.64	1.50	63.2	75.4	0.84	74.8	0.85	0.125	62.5	0.99
1.36	1.39	1.25	44.7	73.8	0.61	73.3	0.61	0.125	36.7	0.82
1.11	1.14	1.00	26.6	72.2	0.37	71.8	0.37	0.126	17.2	0.65
0.86	0.89	0.75	12.6	37.7	0.34	37.4	0.34	0.118	6.14	0.49
0.61	0.64	0.50	5.24	26.1	0.20	25.9	0.20	0.252	0.69	0.13
0.36	0.39	0.25	0.64	5.72	0.11	5.65	0.11	0.126	0.10	0.16
0.19	0.22	0.08							0.001	

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = measured

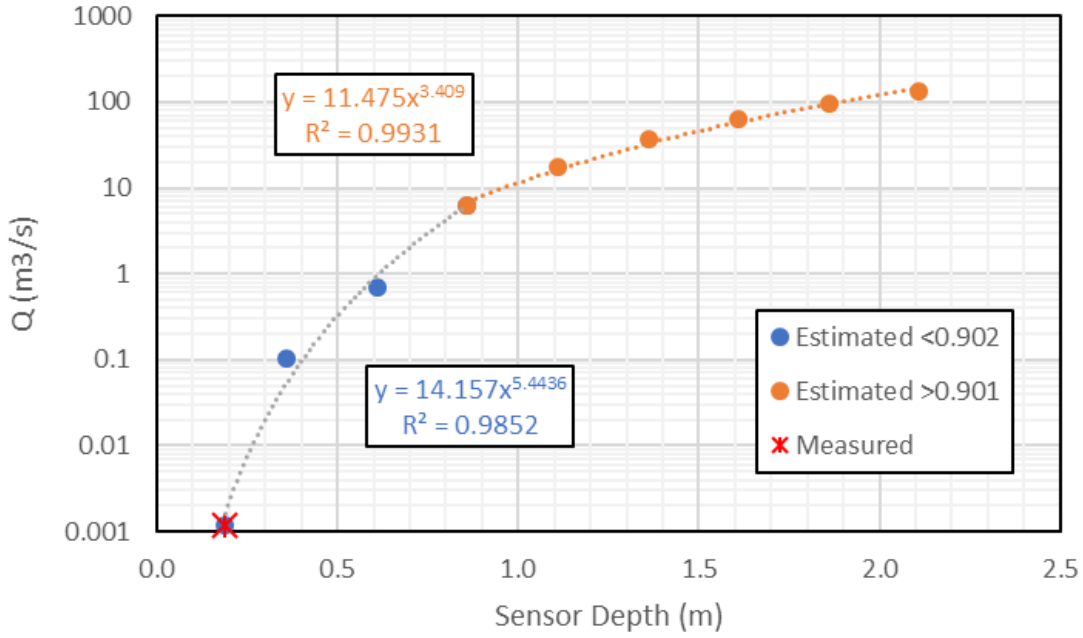

Figure 18. Rating curves for the Wolf Pond Tributary.

Table 18. Rating equations for the Wolf Pond Tributary.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.902	Power[1]	14.157063	5.443613
>0.901	Power[1]	11.474501	3.408988

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Polecat Hollow (6.19 km^2)

Site Name:	Polecat Hollow
Site ID:	PH
Location Description:	Gage is located 600 m upstream of Carter County Road J-173
Northing (m) UTM Zone 15N:	4,082,395.533
Easting (m):	664,472.252
Elevation (m):	224.51
Stream Name:	Polecat Hollow Tributary
Type:	Ephemeral
River KM:	0.6
Drainage Area (km2):	6.19
Date Installed:	12/17/2015
Burn History:	Burned

Photo 13. Looking upstream at Polecat Hollow (December 15, 2015).

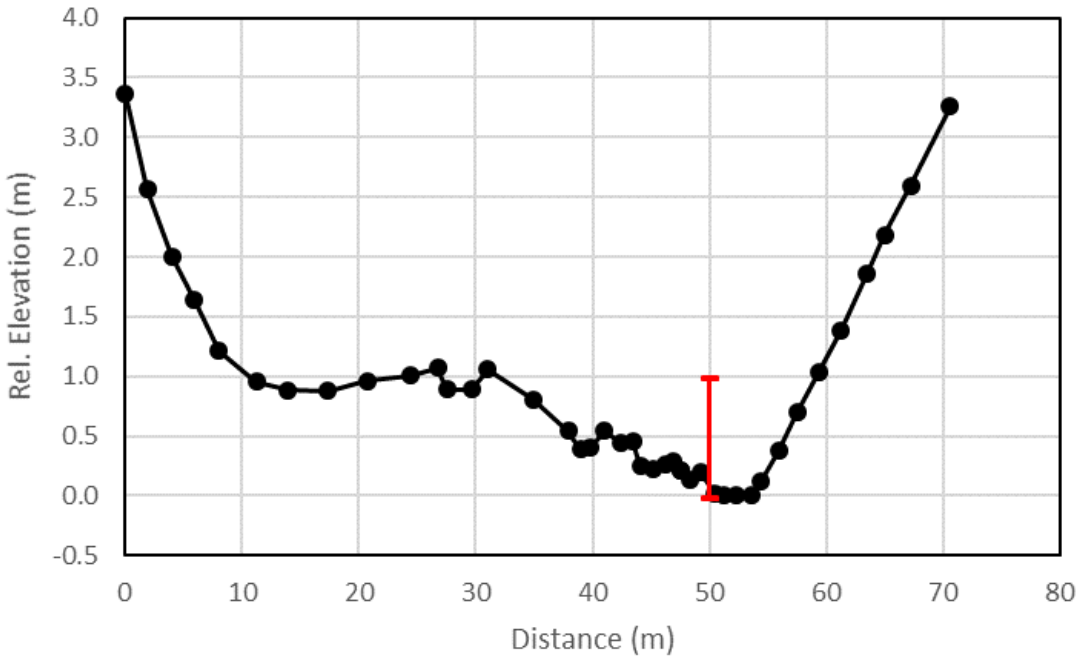

Figure 19. Cross-section for the Polecat Hollow.

Table 19. Rating table for the Polecat Hollow.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
2.03	2.01	2.00	72.0	60.5	1.19	60.1	1.20	0.122	120.2	1.67
1.78	1.76	1.75	57.3	58.0	0.99	57.6	0.99	0.121	87.9	1.54
1.53	1.51	1.50	43.1	55.5	0.78	55.2	0.78	0.120	60.3	1.40
1.28	1.26	1.25	29.7	53.0	0.56	52.7	0.56	0.120	37.6	1.27
1.03	1.01	1.00	17.1	44.3	0.39	44.1	0.39	0.117	20.5	1.20
0.78	0.76	0.75	9.60	22.4	0.43	22.3	0.43	0.098	9.61	1.00
0.53	0.51	0.50	4.57	17.5	0.26	17.4	0.26	0.095	2.59	0.57
0.28	0.26	0.25	1.30	9.74	0.13	9.70	0.13	0.061	0.50	0.38
0.03	0.01	0.00							0.001	

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = Adjusted

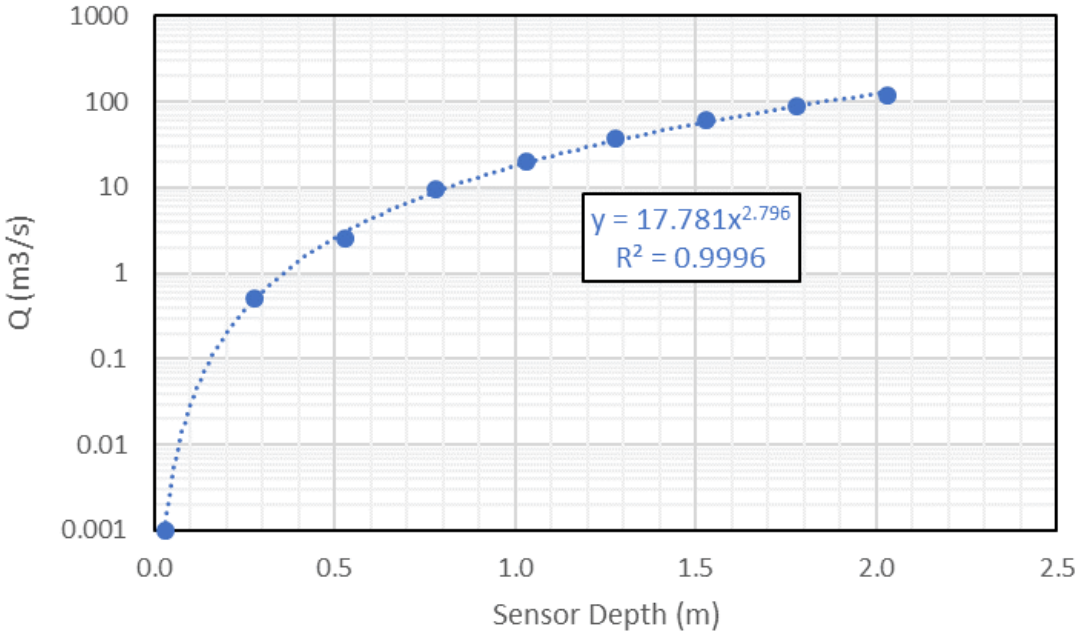

Figure 20. Rating curves for the Polecat Hollow.

Table 20. Rating equations for Polecat Hollow.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<2.04	Power[1]	17.780673	2.795989

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

South Prong Cedar Bluff Creek (7.28 km^2)

Site Name:	South Prong Cedar Bluff Creek
Site ID:	SPC
Location Description:	Gage is located approximately 150 m upstream of the confluence with North Prong Cedar Bluff Creek.
Northing (m) UTM Zone 15N	4,078,550.511
Easting (m)	666,420.219
Elevation (m)	209.96
Stream Name:	South Prong Cedar Bluff Creek
Type:	Ephemeral
River KM:	0.15
Drainage Area (km2):	7.28
Date Installed:	12/17/2015
Burn History:	Burned

Photo 14. Looking upstream at South Prong Cedar Bluff Creek gage (October 15, 2015).

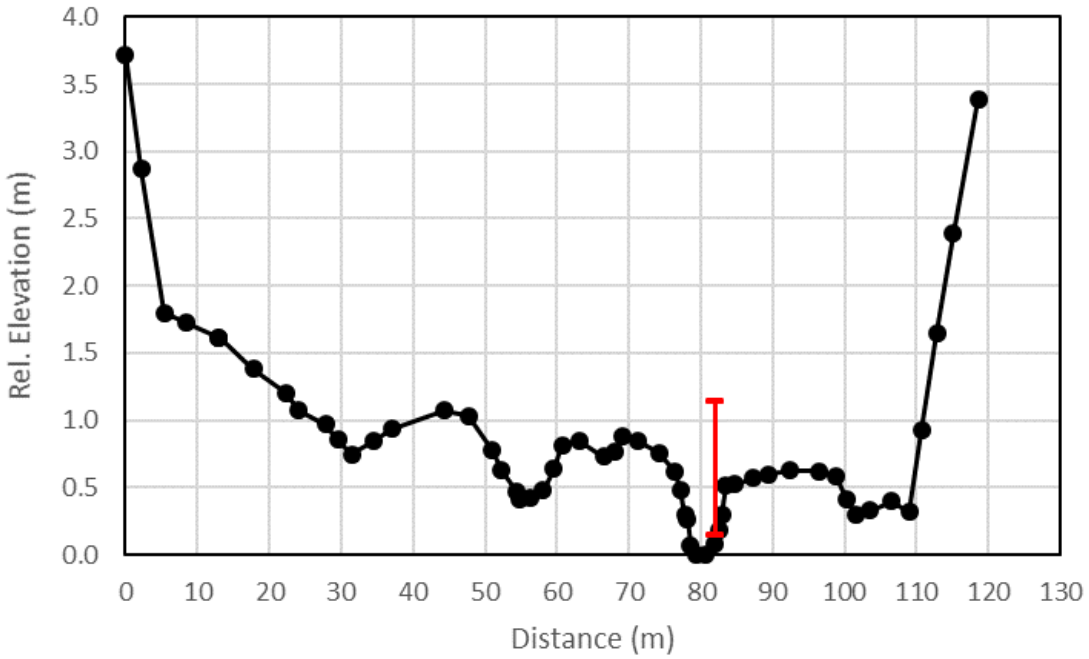

Figure 21. Cross-section for the South Prong Cedar Bluff Creek.

Table 21. Rating table for the **South Prong Cedar Bluff Creek**.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg D (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.69	1.61	1.75	98.9	106.3	0.93	106	0.94	0.134	80.9	0.82
1.44	1.36	1.50	73.8	97.5	0.76	97.0	0.76	0.133	53.6	0.73
1.19	1.11	1.25	50.3	91.0	0.55	90.6	0.55	0.133	31.3	0.62
0.94	0.86	1.00	28.7	76.9	0.37	76.5	0.37	0.132	15.0	0.52
0.69	0.61	0.75	12.7	46.6	0.27	46.4	0.27	0.127	5.33	0.42
0.44	0.36	0.50	3.93	20.9	0.19	20.7	0.19	0.128	1.12	0.29
0.17									0.021	

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = measured

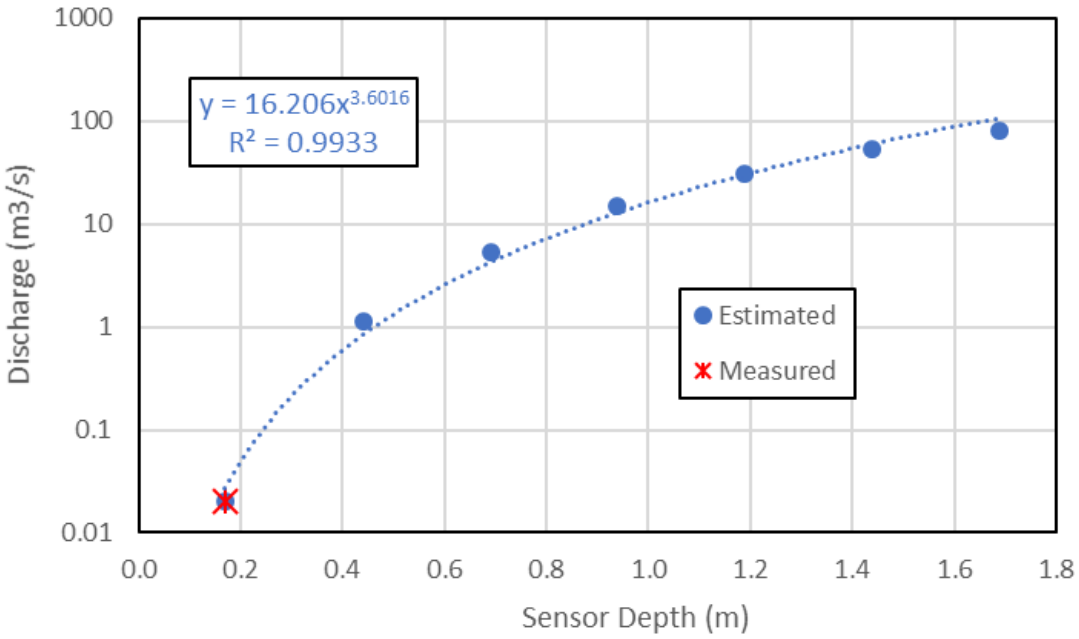

Figure 22. Rating curve for the South Prong Cedar Bluff Creek.

Table 22. Rating equations for South Prong Cedar Bluff Creek.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<1.70	Power[1]	16.206209	3.601633

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Fools Catch (7.82 km^2)

Site Name:	Fools Catch
Site ID:	FC
Location Description:	Gage is located approximately 2.5 km upstream of the confluence with Big Barren Creek in Carter County
Northing (m) UTM Zone 15N:	4,081,865.521
Easting (m):	669,811.222
Elevation (m):	196.79
Stream Name:	Fools Catch Tributary
Type:	Ephemeral
River KM:	2.5
Drainage Area (km2):	7.82
Date Installed:	12/17/2015
Burn History:	Unburned

Photo 15. Looking downstream at Fools Catch (December 14, 2015).

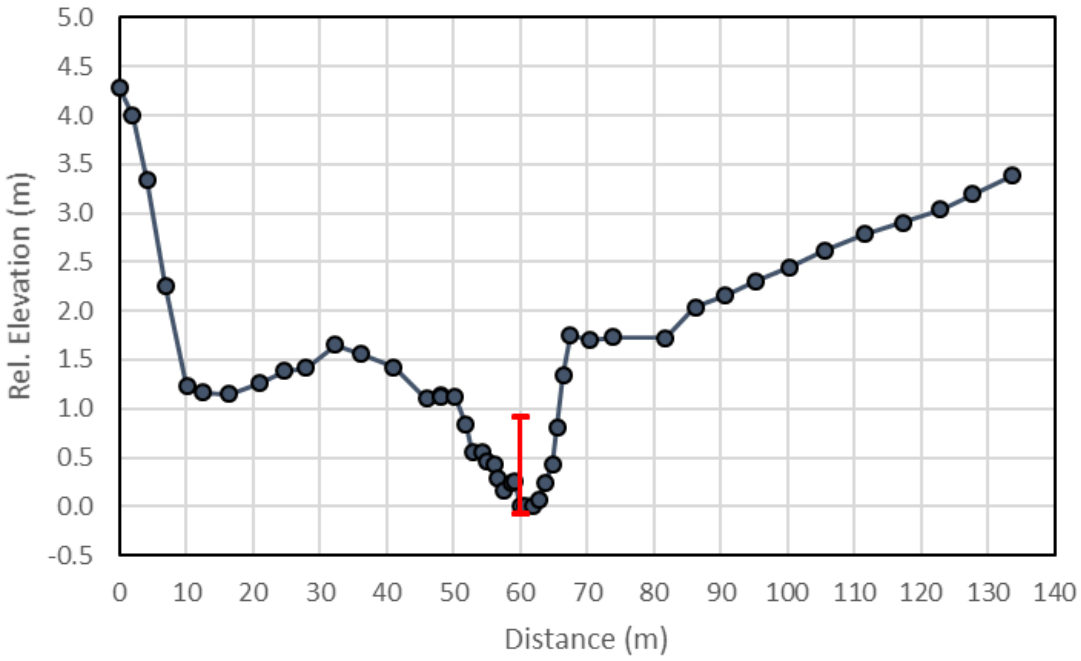

Figure 23. Cross-section for the Fools Catch.

Table 23. Rating table for the Fools Catch.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
1.94	1.92	2.00	58.3	78.7	0.74	78.1	0.75	0.121	58.0	0.99
1.69	1.67	1.75	39.3	73.9	0.53	73.3	0.54	0.123	34.3	0.87
1.44	1.42	1.50	25.0	49.3	0.51	48.8	0.51	0.124	19.0	0.76
1.19	1.17	1.25	14.9	33.6	0.44	33.2	0.45	0.132	8.91	0.59
0.94	0.92	1.00	9.56	15.3	0.63	15.0	0.64	0.205	3.22	0.33
0.41	0.39	0.47	2.7	10.0	0.27	9.9	0.27	0.800	0.127	0.05

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = measured

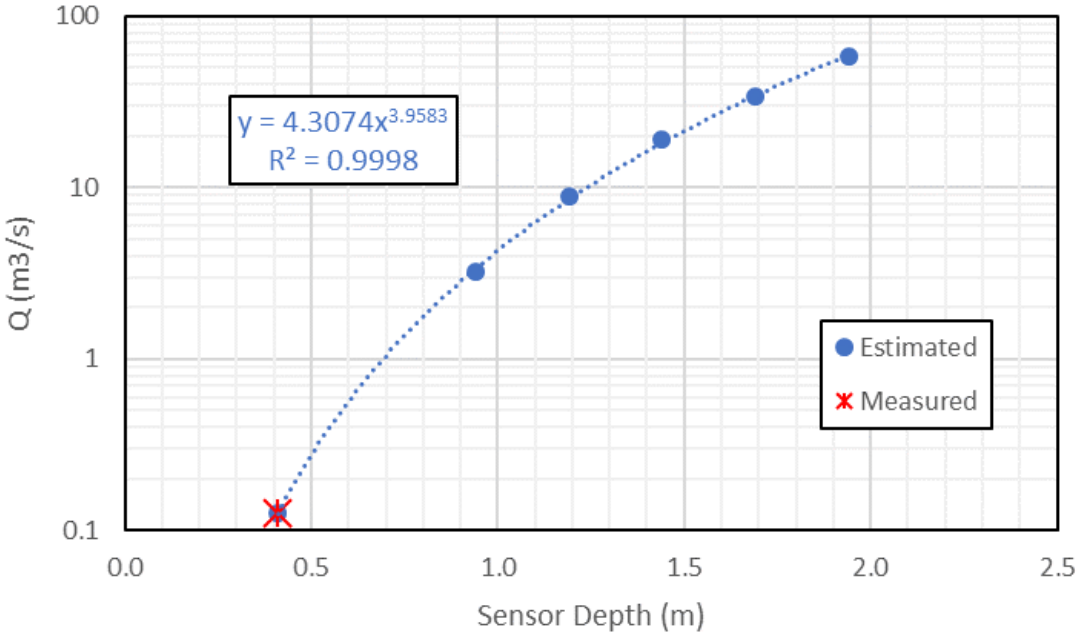

Figure 24. Rating curve for the Fools Catch.

Table 24. Rating equations for Fools Catch.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
0.00-0.570	Power[1]	1.7898	2.5393

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: $y = b*x^m$

Highway J (8.82 km^2)

Site Name:	Highway J
Site ID:	HYJ
Location Description:	Gage is located on the upstream side of State Highway J box culvert in Carter County
Northing (m) UTM Zone 15N	4,081,730.799
Easting (m)	661,557.484
Elevation (m)	245.46
Stream Name:	Main stem Big Barren Creek
Type:	Ephemeral
River KM:	41.1
Drainage Area (km2):	8.82
Date Installed:	9/8/2016
Burn History:	Mixed

Photo 16. Looking upstream at the Highway J (December 19, 2016).

Table 25. Culvert Dimensions for Highway J.

Type = Box culvert
Number of Barrels = 3
Height = 1.83 m
Width = 3.01 m
Length = 14.63 m
Slope = 0.63%
Material = Concrete
Manning's n = 0.012

Table 26. Rating table for Highway J.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Q (m3/s)
2.38	2.38	2.38	113.28
2.01	2.01	2.01	84.96
1.52	1.52	1.52	56.64
1.22	1.22	1.22	28.32
0.93	0.93	0.93	14.16
0.40	0.40	0.40	2.83
0.13	0.13	0.13	1.42
0.05	0.05	0.05	0.28
0.03	0.03	0.03	0.14

Q = discharge

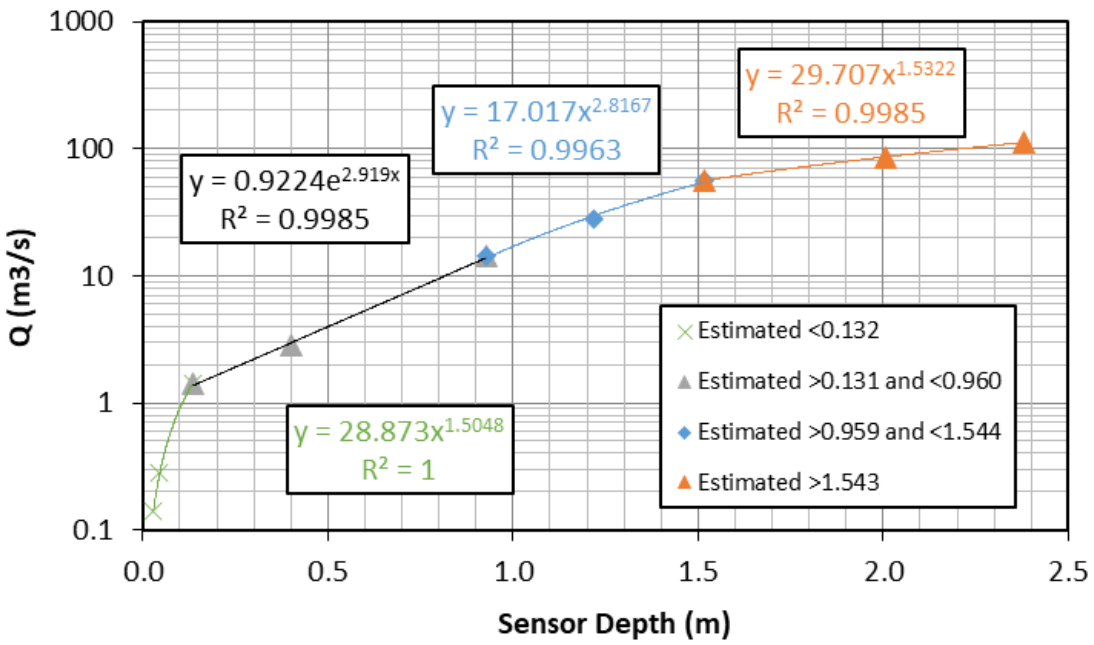

Figure 25. Rating curves for the Highway J gage site.

Table 27. Rating equations for Highway J gage site

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.132	Power[1]	28.873261	1.504764
>0.131 and <0.960	Exponential[2]	0.922433	18.52211*
>0.959 and <1.544	Power[1]	17.016719	2.816676
>1.543	Power[1]	29.706803	1.532200

y = discharge (m^3/s)
x = sensor depth (m)

1. Power function: y = b*x^m
2. Exponential: y = b*m^x

* Ln = 2.918965

Middle Big Barren (47.8 km^2)

Site Name:	Middle Big Barren
Site ID:	MBB
Location Description:	Gage is located approximately 70 m upstream of the low water crossing at US National Forest Road 3146 (Bearpen Road) near the confluence with Bearpen Hollow Tributary.
Northing (m) UTM Zone 15N:	4,081,306.806
Easting (m):	667,938.252
Elevation (m):	191.57
Stream Name:	Big Barren Creek (main stem)
Type:	Ephemeral
River KM:	29.1
Drainage Area (km2):	47.8
Date Installed:	1/28/2016
Burn History:	Mixed

Photo 17. Looking downstream toward Bearpen Road from MBB gage (March 7, 2016).

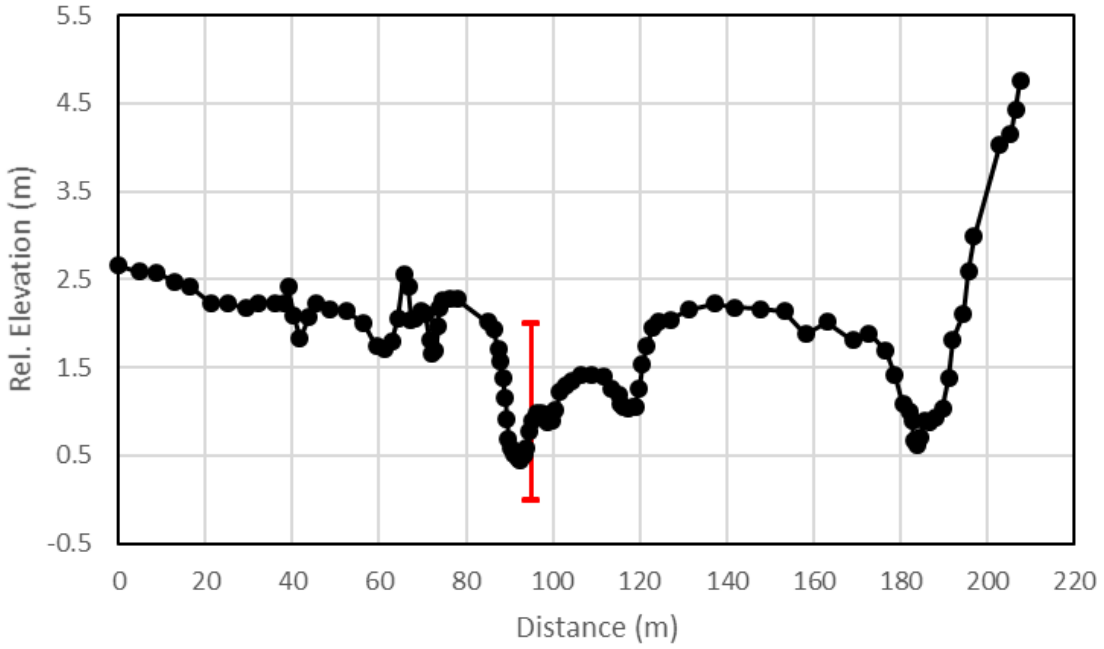

Figure 26. Cross-section for the Middle Big Barren.

Table 28. Rating table for the Middle Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg D (m)	*"n"*	Q (m3/s)	Velocity (m/s)
2.11	2.00	2.00	49.0	88.6	0.55	87.6	0.56	0.117	38.0	0.78
1.86	1.75	1.75	31.7	55.5	0.57	54.8	0.58	0.111	23.3	0.74
1.61	1.50	1.50	19.6	46.3	0.42	45.7	0.43	0.110	11.5	0.59
1.36	1.25	1.25	9.98	30.8	0.32	30.3	0.33	0.105	4.28	0.43
1.11	1.00	1.00	3.76	18.3	0.21	18.1	0.21	0.119	0.78	0.21
0.86	0.75	0.75	1.13	6.71	0.17	6.60	0.17	0.142	0.17	0.15
0.61	0.50	0.50	0.04	1.41	0.03	1.41	0.03	0.030	0.01	0.20
0.56	0.45	0.45	0.0	0.0	0.00	0.0	0.00	0.142	0.002	0.00

WP = wetted perimeter
R = hydraulic radius
Q = discharge
Yellow = adjusted

Table 29. Rating table from HEC-RAS for the Middle Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Q (m3/s)
2.74	2.72	2.81	142
3.55	3.53	3.62	283
4.42	4.40	4.49	425
5.21	5.19	5.28	566

Q = discharge

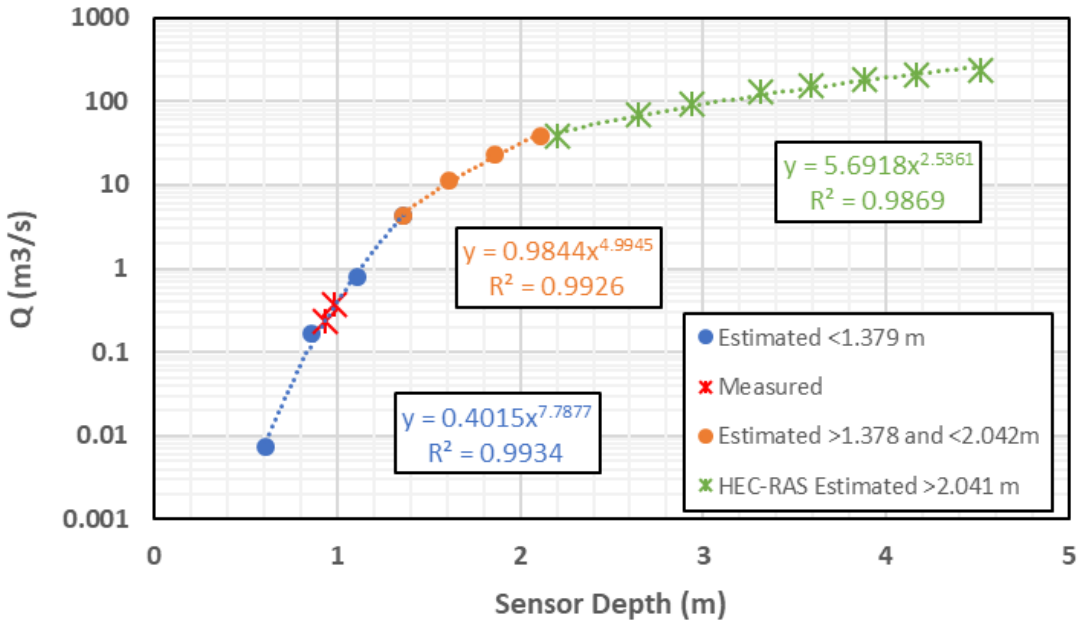

Figure 27. Rating curves for the Middle Big Barren.

Table 30. Rating equations for Middle Big Barren

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
	Power[1]		
	Power[1]		
	Power[1]		

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Upper Natural Area (103.6 km^2)

Site Name:	Upper Natural Area
Site ID:	UNA
Location Description:	Gage is located within the US Forest Service Big Barren Creek Natural Area 0.65 km upstream of the confluence with Devils Run.
Northing (m) UTM Zone 15N	4,080,307.787
Easting (m)	672,375.327
Elevation (m)	163.74
Stream Name:	Big Barren Creek (main stem)
Type:	Perennial
River KM:	21.1
Drainage Area (km2):	103.6
Date Installed:	9/8/2016
Burn History:	Mixed

Photo 18. Riffle downstream of Upper Natural Area gage (Sept. 10, 2016).

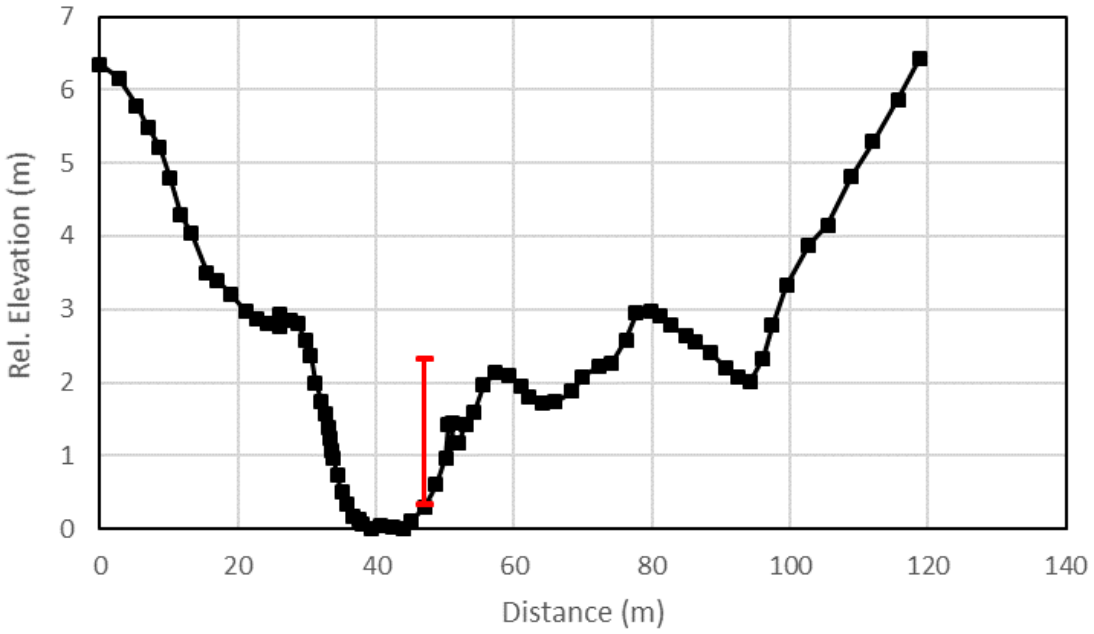

Figure 28. Cross-section for the Upper Natural Area.

Table 31. Rating table for the Upper Natural Area.

Sensor Depth (m)	**Staff Gage (m)**	**Depth (m)**	**Area (m2)**	**WP (m)**	**R (m)**	***"n"***	**Q (m3/s)**	**Velocity (m/s)**	**Cor. Fact.**	**New Q (m3/s)**
1.20	1.17	1.50	20.7	20.9	0.99	0.100	14.1	0.68	1.0	14.1
0.95	0.92	1.25	16.0	18.0	0.89	0.102	8.34	0.52	0.50	4.17
0.70	0.67	1.00	11.9	16.2	0.74	0.128	3.98	0.33	0.21	0.83
0.45	0.42	0.75	8.09	14.7	0.55	0.222	1.28	0.16	0.03	0.04

WP = wetted perimeter
R = hydraulic radius
Q = discharge

Table 32. Rating table from HEC-RAS for the Upper Natural Area.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Q (m3/s)
1.27	1.24	1.57	14.2
1.71	1.68	2.01	28.3
3.55	3.52	3.84	141.6
4.86	4.83	5.15	283.2
5.84	5.81	6.14	424.8
6.70	6.67	6.99	566.4

Q = discharge

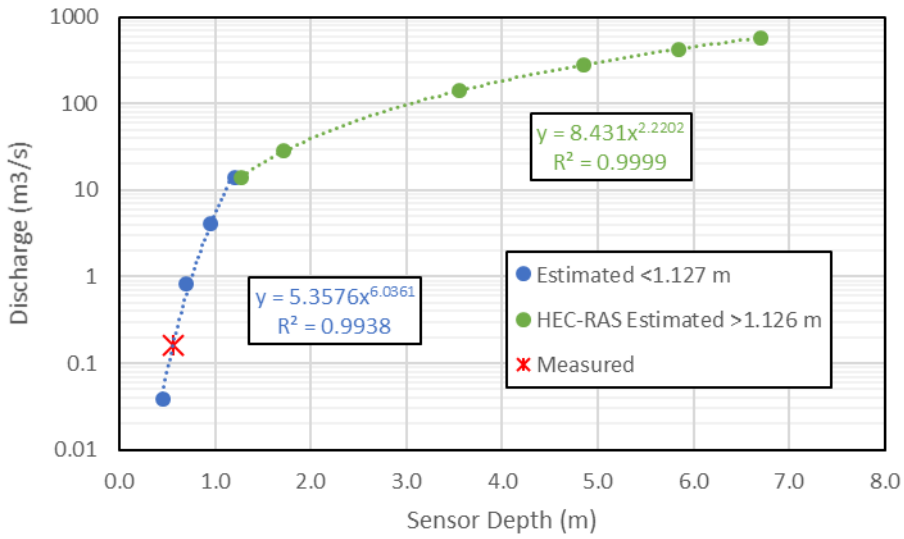

Figure 29. Rating curves for the Upper Natural Area.

Table 33. Rating equations for Upper Natural Area.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<1.127	Power[1]	5.357621	6.036103
>1.126	Power[1]	8.430961	2.220232

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Lower Natural Area (124.2 km^2)

Site Name:	Lower Natural Area
Site ID:	LNA
Location Description:	Gage is located along the main channel of Big Barren Creek within the US Forest Service Big Barren Creek Natural Area approximately 300 m downstream of the confluence with the Devils Horn tributary, 60 m off Carter County C-167.
Northing (m) UTM Zone 15N:	4,079,188.630
Easting (m):	672,767.129
Elevation (m):	158.50
Stream Name:	Big Barren Creek (main stem)
Type:	Perennial
River KM:	18.8
Drainage Area (km2):	124.2
Date Installed:	9/8/2016
Burn History:	Mixed

Photo 19. Looking upstream at the Lower Natural Area gage (May 05, 2017).

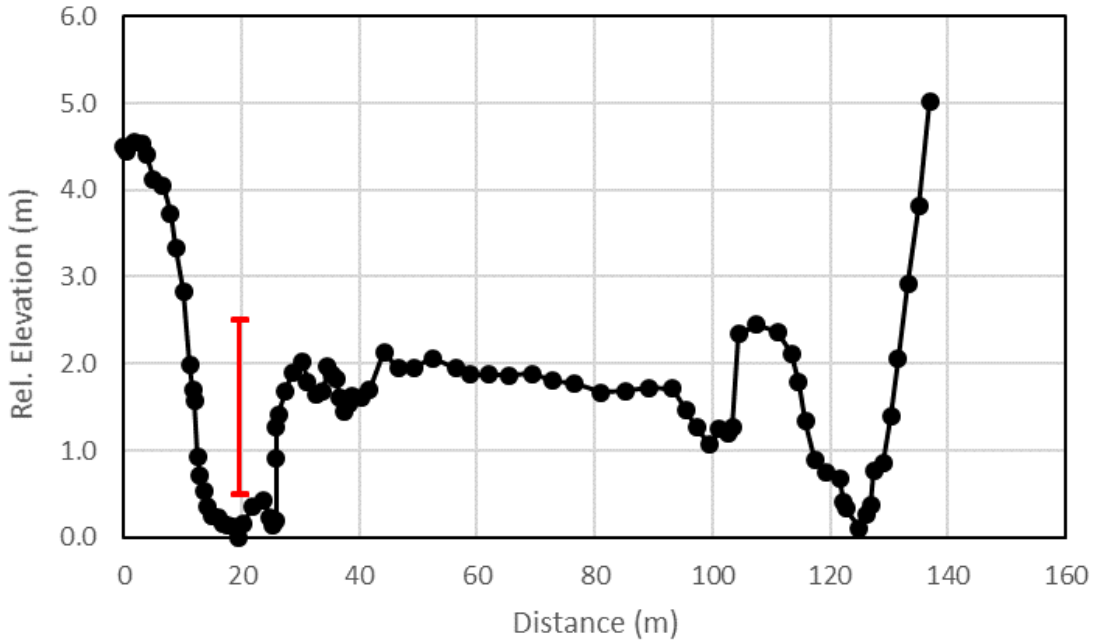

Figure 30. Cross-section for the Lower Natural Area.

Table 34. Rating table for the Lower Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
4.00	3.98	4.50	373.8	138.5	2.70	134	2.79	0.138	436.9	1.17
3.75	3.73	4.25	340.8	135.5	2.51	131	2.60	0.138	378.1	1.11
3.50	3.48	4.00	308.3	132.7	2.32	129	2.40	0.137	323.0	1.05
3.25	3.23	3.75	276.3	131.2	2.11	127	2.17	0.137	271.6	0.98
3.00	2.98	3.50	244.7	129.9	1.88	126	1.94	0.137	224.1	0.92
2.75	2.73	3.25	213.3	128.7	1.66	125	1.71	0.137	180.6	0.85
2.50	2.48	3.00	182.3	127.4	1.43	124	1.47	0.137	141.2	0.77
2.25	2.23	2.75	151.5	126.2	1.20	123	1.24	0.137	106.0	0.70
2.00	1.98	2.50	121.0	125.2	0.97	122	0.99	0.137	75.2	0.62
1.75	1.73	2.25	91.7	116.5	0.79	113	0.81	0.136	50.7	0.55
1.50	1.48	2.00	64.1	106.4	0.60	103	0.62	0.136	31.3	0.49
1.25	1.23	1.75	43.0	69.2	0.62	66.6	0.64	0.133	22.1	0.51
1.00	0.98	1.50	31.1	41.0	0.76	38.9	0.80	0.126	15.7	0.50
0.75	0.73	1.25	22.1	35.1	0.63	33.3	0.66	0.128	9.25	0.42
0.50	0.48	1.00	15.0	27.0	0.56	25.8	0.58	0.140	4.46	0.30
0.31	0.29								0.20	

WP = wetted perimeter
R = hydraulic radius
Q = discharge

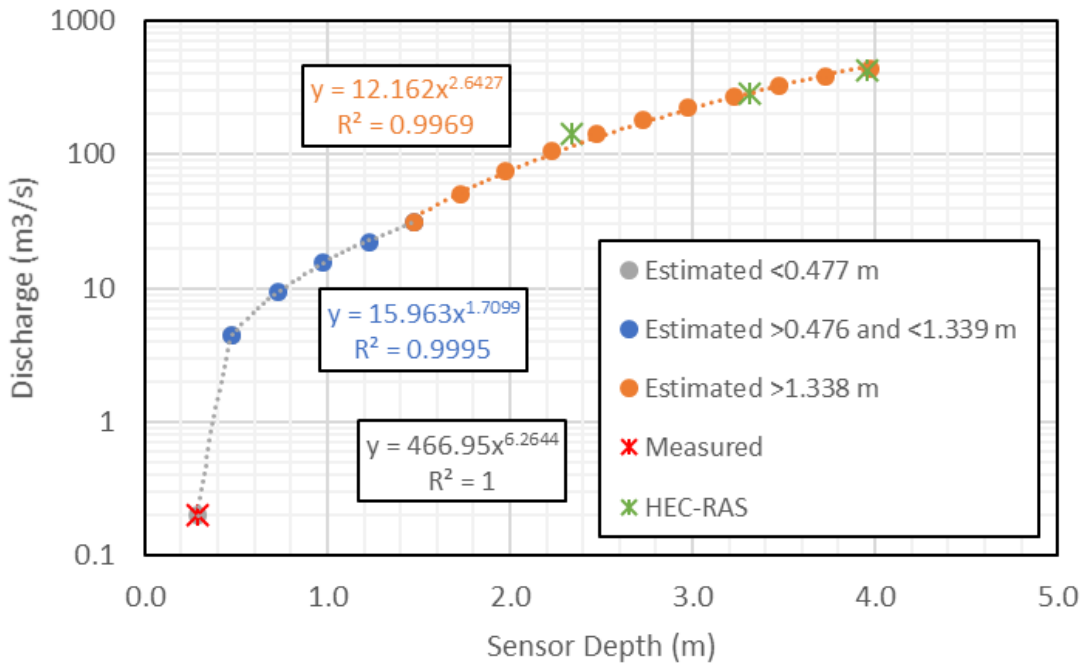

Figure 31. Rating curves for the Lower Natural Area.

Table 35. Rating equations for Lower Natural Area.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<0.477	Power[1]	466.952447	6.264411
0.477-<1.339	Power[1]	15.963446	1.709869
>1.338	Power[1]	12.162300	2.642723

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m

Lower Big Barren (186.1 km^2)

Site Name:	Lower Big Barren Creek
Site ID:	LBB
Location Description:	Gage is located 20 m downstream of the low water crossing at Ripley County C-10, approximately 240 m upstream of the confluence with Racetrack Hollow.
Northing (m) UTM Zone 15N	4,074,388.720
Easting (m)	681,374.962
Elevation (m)	121.83
Stream Name:	Big Barren Creek (main stem)
Type:	Ephemeral
River KM:	4.5
Drainage Area (km2):	186.1
Date Installed:	9/8/2016
Burn History:	Mixed

Photo 20. Gage at LBB looking downstream of low water crossing at Ripley County C-10 (Oct 22, 2019).

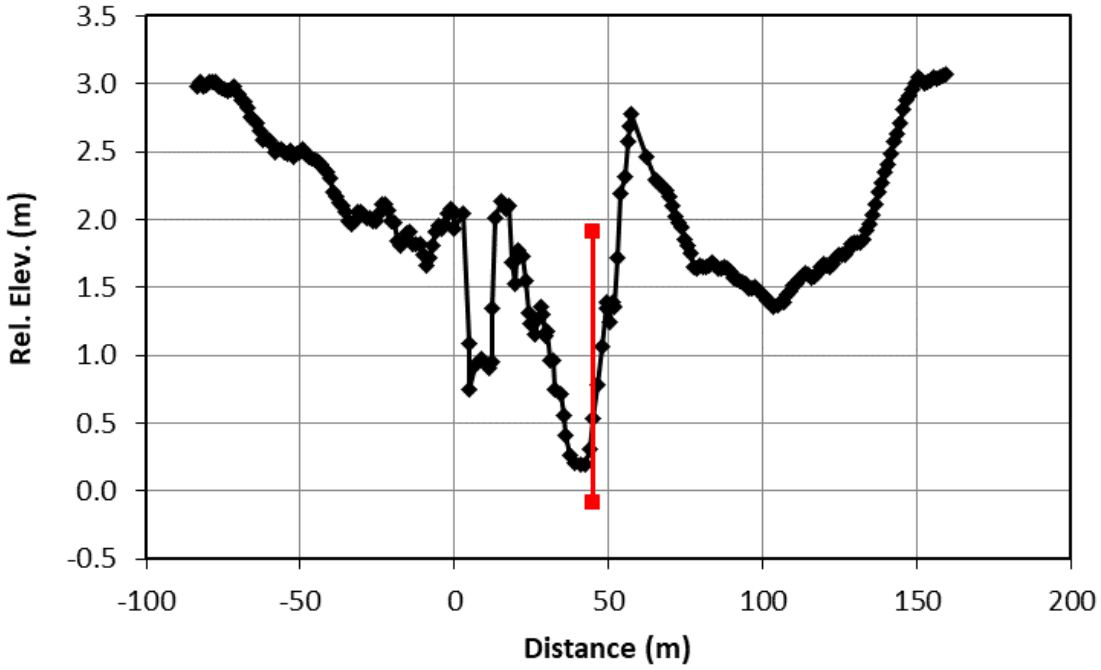

Figure 32. Rating curves for the Lower Big Barren.

Table 36. Rating table for the Lower Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Area (m2)	WP (m)	R (m)	Width (m)	Avg. Depth (m)	*"n"*	Q (m3/s)	Velocity (m/s)
2.91	2.93	3.00	257.5	230.7	1.12	229	1.13	0.122	199.6	0.78
2.66	2.68	2.75	203.4	212.2	0.96	210	0.97	0.125	149.4	0.73
2.41	2.43	2.50	152.9	191.5	0.80	190	0.81	0.126	107.5	0.70
2.16	2.18	2.25	109.2	167.4	0.65	166	0.66	0.129	74.5	0.68
1.91	1.93	2.00	70.9	133.6	0.53	132	0.54	0.133	49.1	0.69
1.66	1.68	1.75	42.9	96.5	0.44	95.0	0.45	0.134	31.1	0.73
1.41	1.43	1.50	25.0	52.0	0.48	50.8	0.49	0.110	18.3	0.73
1.16	1.18	1.25	15.5	30.1	0.52	29.2	0.53	0.066	9.70	0.62
0.91	0.93	1.00	9.14	24.0	0.38	23.6	0.39	0.055	4.60	0.50
0.66	0.68	0.75	4.80	13.9	0.35	13.8	0.35	0.073	1.50	0.31
0.41	0.43	0.50	2.10	9.25	0.23	9.22	0.23	0.119	0.30	0.15
0.16	0.18	0.25	0.20	5.19	0.04	5.19	0.04	0.043	0.02	0.12
0.11	0.13	0.20	0.0	0.0	0.00	0.0	0.00	0.119	0.01	0.00

WP = wetted perimeter
R = hydraulic radius
Q = discharge

Table 37. Rating table from HEC-RAS for the Lower Big Barren.

Sensor Depth (m)	Staff Gage (m)	Depth (m)	Q (m3/s)
2.74	2.72	2.81	142
3.55	3.53	3.62	283
4.42	4.40	4.49	425
5.21	5.19	5.28	566

Q = discharge

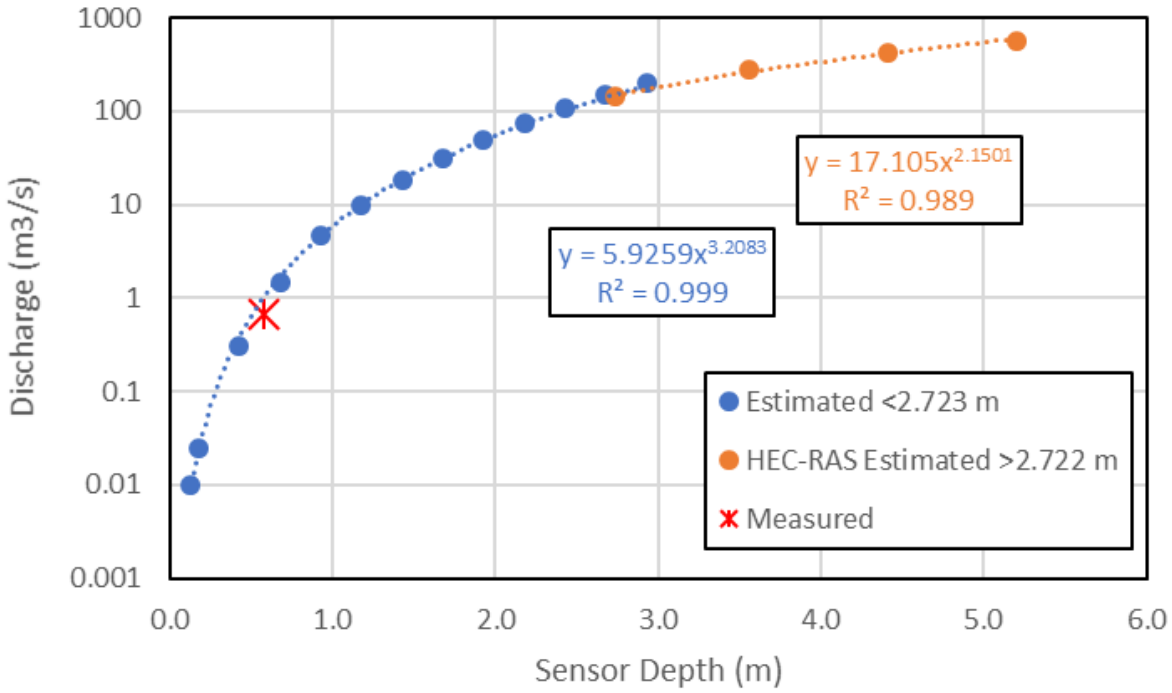

Figure 33. Rating curves for the Lower Big Barren.

Table 38. Rating equations for Lower Big Barren.

Stage Range (m)	Equation Type	Y intercept (b)	Slope (m)
<2.723	Power[1]	5.925869	3.208302
>2.722	Power[1]	17.10521	2.150077

y = discharge (m^3/s)

x = sensor depth (m)

1. Power function: y = b*x^m