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Wadeable Stream Habitat Monitoring at Congaree National Park

2018 Baseline Report

Natural Resource Report NPS/SECN/NRR—2021/2264



ON THE COVER
Photo looking upstream on transect 4 at the stream monitoring site on Cedar Creek (CONG002) at Congaree National Park. Photo by SECN Staff on June 14, 2018.

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Natural Resource Report NPS/SECN/NRR—2021/2264

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Summary and Key Findings

The Southeast Coast Network (SECN) Wadeable Stream Habitat Monitoring Protocol collects data to give park resource managers insight into the status of and trends in stream and near-channel habitat conditions (McDonald et al. 2018a). Wadeable stream monitoring is currently implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park (HOBE), Kennesaw Mountain National Battlefield Park (KEMO), Ocmulgee Mounds National Historical Park (OCMU), Chattahoochee River National Recreation Area (CHAT), and Congaree National Park (CONG). Streams at Congaree National Park chosen for monitoring were specifically targeted for management interest (e.g., upstream development and land use change, visitor use of streams as canoe trails, and potential social walking trail erosion) or to provide a context for similar-sized stream(s) within the park or network (McDonald and Starkey 2018a).

The objectives of the SECN wadeable stream habitat monitoring protocol are to:

- Determine status of upstream watershed characteristics (basin morphology) and trends in land cover that may affect stream habitat,
- Determine the status of and trends in benthic and near-channel habitat in selected wadeable stream reaches (e.g., bed sediment, geomorphic channel units, and large woody debris),
- Determine the status of and trends in cross-sectional morphology, longitudinal gradient, and sinuosity of selected wadeable stream reaches.

Between June 11 and 14, 2018, data were collected at Congaree National Park to characterize the in-stream and near-channel habitat within stream reaches on Cedar Creek (CONG001, CONG002, and CONG003) and McKenzie Creek (CONG004). These data, along with the analysis of remotely sensed geographic information system (GIS) data, are presented in this report to describe and compare the watershed-, reach-, and transect-scale characteristics of these four stream reaches to each other and to selected similar-sized stream reaches at Ocmulgee Mounds National Historical Park, Kennesaw Mountain National Battlefield Park, and Chattahoochee National Recreation Area. Surveyed stream reaches at Congaree NP were compared to those previously surveyed in other parks in order to provide regional context and aid in interpretation of results.

Cedar Creek's watershed (CONG001, CONG002, and CONG003) drains nearly 200 square kilometers (77.22 square miles [mi^2]) of the Congaree River Valley Terrace complex and upper Coastal Plain to the north of the park (Shelley 2007a, 2007b). Cedar Creek's watershed has low slope and is covered mainly by forests and grasslands. Cedar Creek is designated an "Outstanding Resource Water" by the state of South Carolina (S.C. Code Regs. 61–68 [2014] and S.C. Code Regs. 61–69 [2012]) from the boundary of the park downstream to Wise Lake. Cedar Creek 'upstream' (CONG001) is located just downstream (south) of the park's Bannister Bridge canoe landing, which is located off Old Bluff Road and south of the confluence with Meyers Creek. Cedar Creek 'middle' and Cedar Creek 'downstream' (CONG002 and CONG003, respectively) are located downstream of Cedar Creek 'upstream' where Cedar Creek flows into the relatively flat backswamp of the Congaree River flood plain. Based on the geomorphic and land cover characteristics of the watershed, monitored reaches on Cedar Creek are likely to flood often and drain slowly. Flooding is more likely at Cedar Creek 'middle' and Cedar Creek 'downstream' than at Cedar Creek 'upstream.' This is due to the higher (relative to CONG001) connectivity between the channels of the lower reaches and their out-of-channel areas. Based on bed sediment characteristics, the heterogeneity of geomorphic channel units (GCUs) within each reach, and the abundance of large woody debris (LWD), in-stream habitat within each of the surveyed reaches on Cedar Creek (CONG001–003) was classified as 'fair to good.' Although, there is extensive evidence of animal activity (pig rooting and trails) in the out-of-channel areas surrounding Cedar Creek 'middle' and Cedar Creek 'downstream.' This activity is having a significant impact on the out-of-channel areas along these reaches and represents an immediate management concern.

The McKenzie Creek watershed (CONG004) drains 26.62 square kilometers (10.28 mi^2) of the Congaree River Valley Terrace complex as it drains from north to south into the park (Shelley 2007a, 2007c). McKenzie Creek is a small (narrow and shallow), third order stream that flows under Griffins Creek Road, and a railroad, before joining Toms Creek downstream of the monitored reach. Approximately 4.1 kilometers (2.55 miles [mi]) downstream of where McKenzie Creek flows into Toms Creek, Toms Creek flows into Cedar Creek in the backswamp of the Congaree River flood plain. McKenzie Creek's watershed has low slope and relief and is covered mostly by cultivated land, wetlands, and forest. Based on the geomorphic and land cover characteristics of the watershed, the monitored reach on McKenzie Creek is likely to flood often and drain slowly. Any increase in stream power and resulting geomorphic change that could be expected due to the presence of an upstream road and railroad bridge are ameliorated by nearly stagnant multichannel wetland that McKenzie Creek flows through just upstream of the monitored reach. Unlike the channel conditions immediately upstream, the monitored reach on McKenzie Creek is single thread and relatively straight. The vastly different channel morphology can be attributed to the presence of a relic gravel roadbed approximately 15 meters (49.21 feet [ft]) upstream of the monitored reach, which has altered flow conditions, bed sediment composition, and channel morphology within the monitored reach. Like Cedar Creek 'middle' and Cedar Creek 'downstream,' flooding is likely at McKenzie Creek due to the high connectivity between its channel and its out-of-channel area (extensive flood plain and high occurrence of flood chutes). Based on the diversity of GCUs within the reach (especially the presence of riffle and step habitat) and the abundance of LWD, in-stream habitat within the surveyed reach of McKenzie Creek was classified as 'fair.' McKenzie Creek does not have any immediate management concerns.

The in-stream habitat classifications of the monitored reaches on Cedar and McKenzie creeks are generalized interpretations of in-stream habitat. These classifications are based on (1) watershed characteristics (i.e. land use land cover, slope, and relief); (2) in-stream habitat conditions (i.e. high versus low energy GCUs, bed material, prevalence of LWD); and (4) general channel condition (i.e. bank conditions, degree of entrenchment, presence of knickpoints, or planform changes). Additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Congaree National Park.

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List of Acronyms

ANOVA—Analysis of variance

B—Sand/gravel bar

Be—Bench

Bf—Bankfull

BM—Benchmark

BSi—Bank stability index

CHAT—Chattahoochee National Recreation Area

CONG—Congaree National Park

CV—Coefficient of variance

DEM—Digital elevation model

FP—Flood plain

FPM—Flood plain margin

GCU—Geomorphic channel unit

GIS—Geographic information system

Gl—Glide

HOBE—Horseshoe Bend National Military Park

KEMO—Kennesaw Mountain National Battlefield Park

LWD—Large woody debris

NED—National Elevation Dataset

NL—Natural levee

NLCD—National Land Cover Dataset

NPS—National Park Service

OCMU—Ocmulgee Mounds National Historical Park

P—Pool

R—Riffle

Ru—Run

SECN—Southeast Coast Network

SOP—Standard operating procedure

T#—Standard transect

Introduction

The Southeast Coast Network (SECN) Wadeable Stream Habitat Monitoring Protocol collects data to provide park resource managers insight into the status of and trends in stream and near-channel habitat conditions (McDonald et al. 2018a). The data collected through this monitoring effort provides park staff with information regarding the physical linkage between streams and park resources. Additionally, this monitoring program provides early warnings of changing conditions that may negatively affect visitor experience and or park infrastructure.

Wadeable stream monitoring is currently implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park (HOBE) in Alabama, Kennesaw Mountain National Battlefield Park (KEMO), Ocmulgee Mounds National Historical Park (OCMU), and Chattahoochee River National Recreation Area (CHAT) in Georgia, and Congaree National Park (CONG) in South Carolina. The streams at Horseshoe Bend NMP, Kennesaw Mountain NBP, and Chattahoochee River NRA, are typical Appalachian Piedmont streams that are beginning to re-equilibrate to their modern flow and sediment regimes following the poor land use practices of the late 19th and early 20th centuries (McDonald 2019; McDonald and Starkey 2018a; McDonald and Starkey 2018b). The streams at Congaree NP are typical low gradient, blackwater, Coastal Plain streams (McDonald and Starkey 2018c) while the streams at Ocmulgee Mounds NHP are a mixture of Appalachian Piedmont and Coastal Plain type streams (McDonald and Starkey 2019a). Streams chosen for monitoring were specifically targeted due to management interest (e.g., upstream development and land use change, visitor use of streams as canoe trails, and potential social trail erosion) or to provide a context for similar-sized streams in the park or network (see suitability reports for each park [cited in this paragraph] for more information).

The objectives of the SECN wadeable stream habitat monitoring protocol are to:

- Determine status of upstream watershed characteristics, including basin area, basin slope, and drainage density, and trends in land cover that may affect stream habitat,
- Determine the status of and trends in the geomorphic dimensions of selected wadeable stream reaches, including cross-sectional morphology, bank characteristics (e.g., heights, angles, and vegetative cover), and reach slope and sinuosity, and
- Determine the status of and trends in physical measures of benthic and riparian habitat features present in selected wadeable stream reaches, including the size, type, and distribution of bed sediment and large woody debris, the distribution of geomorphic channel units, and canopy cover.

For the purposes of this report, wadeable streams are narrowly defined as small- to medium-sized, perennially flowing waterbodies, with easily identifiable channel banks, that can be accessed and traversed without the use of a watercraft. The wadeable streams at Congaree NP are connected to the Congaree River via an assemblage of ephemeral channels, locally termed “guts,” that connect to the river during high (but sub-bank-full) flows on the Congaree River (Cely 2001). During major floods, water levels may be meters above the creek banks such that the entire flood plain is inundated with a continuous water surface. Wadeable streams herein do not include these ephemeral channel-like features (i.e., “guts” of the Congaree River flood plain).

The objectives of this report are to:

- Present the wadeable stream surveys completed at Congaree NP during June 2018.
- Describe the watershed characteristics (i.e., basin morphology and land use and land cover) and the reach-scale physical characteristics of the monitored reaches on Cedar Creek (CONG001, CONG002, and CONG003) and McKenzie Creek (CONG004), and
- Provide regional context for the survey results by comparing the surveyed reaches at Congaree NP to similar sized, previously surveyed stream reaches (see Figure A-1 in Appendix A) at Chattahoochee River NRA (CHAT013; McDonald et al. 2019), Kennesaw Mountain NBP (KEMO002; McDonald and Starkey 2019b), and Ocmulgee Mounds NHP (OCMU001; Cooper et al. 2019).

Study Area

The hydro-climatic conditions of the study area are characterized as humid subtropical with mean annual rainfall of 111.76 centimeters (44 inches [in]) per year (2008–2018; www.climateanalyzer.org/secn). During the decade between 2008 and 2018, mean monthly precipitation ranged from 7.9 centimeters (3.11 in) in November to 14.3 centimeters (5.63 in) in July (Western Regional Climate Center 2020; www.raws.dri.edu) During 2017, the Congaree Remote Automatic Weather Station (RAWS) recorded 130 centimeters (51.18 in) of precipitation over 117 rain days (Western Regional Climate Center 2020; www.raws.dri.edu), which is slightly greater than the 2008–2018 average (106.5 centimeters [41.93 in]). Winters are mild, with negligible snowfall and infrequent ice storms. Summers are hot and humid. During 2017, average monthly temperatures at the Congaree RAWS ranged from 8.7°C (47.7°F) in December, to 26.3°C (79.3°F) in July (Western Regional Climate Center 2020; www.raws.dri.edu). In 2017, the highest average monthly maximum temperature was 34.0°C (93.2°F) in July and the lowest average monthly minimum temperature was 2.9°C (37.2°F) in December (Western Regional Climate Center 2020; www.raws.dri.edu). Annual peak flows tend to occur during winter and spring with a secondary peak occurring in late summer and early fall (Lecce 2000). While monthly precipitation tends to be higher in the summer, the high levels of evapotranspiration attenuate streamflow during this part of the year (Lins 1997).

All three Cedar Creek sites (CONG001, CONG002, and CONG003; Figure 1) are on a fifth order segment (Strahler 1957) within their stream network. The Cedar Creek sites are underlain by a late Pleistocene to recent alluvial fan that is characterized by a sandy wedge up to 3.66 meters (12 ft) thick (Shelley 2007a, 2007b; Shelley et al. 2012). The Bannister Bridge canoe landing just upstream from Cedar Creek 'upstream' (CONG001) is also the site of an old earthen bridge abutment that constricts water flow during high (but still sub-bankfull) flows. The McKenzie Creek watershed (CONG004) drains approximately 26.62 square kilometers (10.28 mi^2) of the Congaree River Valley Terrace Complex as it drains from north to south into the park (Shelley 2007a, 2007c). The Congaree River Valley Terrace Complex is a series of estuarine to fluvial deposits that are Pliocene to recent in age (Shelley 2007c). Where complete, these deposits are graded sequences of massive, white to pink, poorly to moderately sorted medium to very coarse sand with varying thicknesses of interstitial clays grading upward into red clay and sandy clay. McKenzie Creek also receives sandy contributions from a historical alluvial fan which lies within the watershed (Shelley 2007c). The reach on McKenzie Creek (CONG004; Figure 1) is on a third order stream segment within its stream network (Strahler 1957). McKenzie Creek is located in or near a poorly characterized alluvial fan or terrace deposit above the bluff that defines the modern flood plain boundary (Shelley 2007a, 2007c). McKenzie Creek is a small (narrow and shallow) stream that flows under Griffins Creek Road, and a railroad, before joining Toms Creek approximately 450 meters (1,476.38 ft) downstream of the monitored reach on McKenzie Creek. Approximately 4.1 kilometers (2.55 mi) downstream of where McKenzie Creek flows into Toms Creek, Toms Creek flows into Cedar Creek in the backswamp of the Congaree River flood plain (approximately 19 kilometers (11.81 mi) downstream from Cedar Creek 'downstream' [CONG003]). Sediment sources for both Cedar Creek and McKenzie Creek include a wide range of recycled clastic fluvial deposits (Shelley 2007a, 2007b, 2007c). The recycled clastic fluvial deposits are typically composed of mature sediments dominated by quartz sand (with locally abundant mica on the upper end of the Cedar Creek alluvial fan) and clay. Additional clay and organic sediments are introduced to the channel within the flood plain (Shelley 2007a).

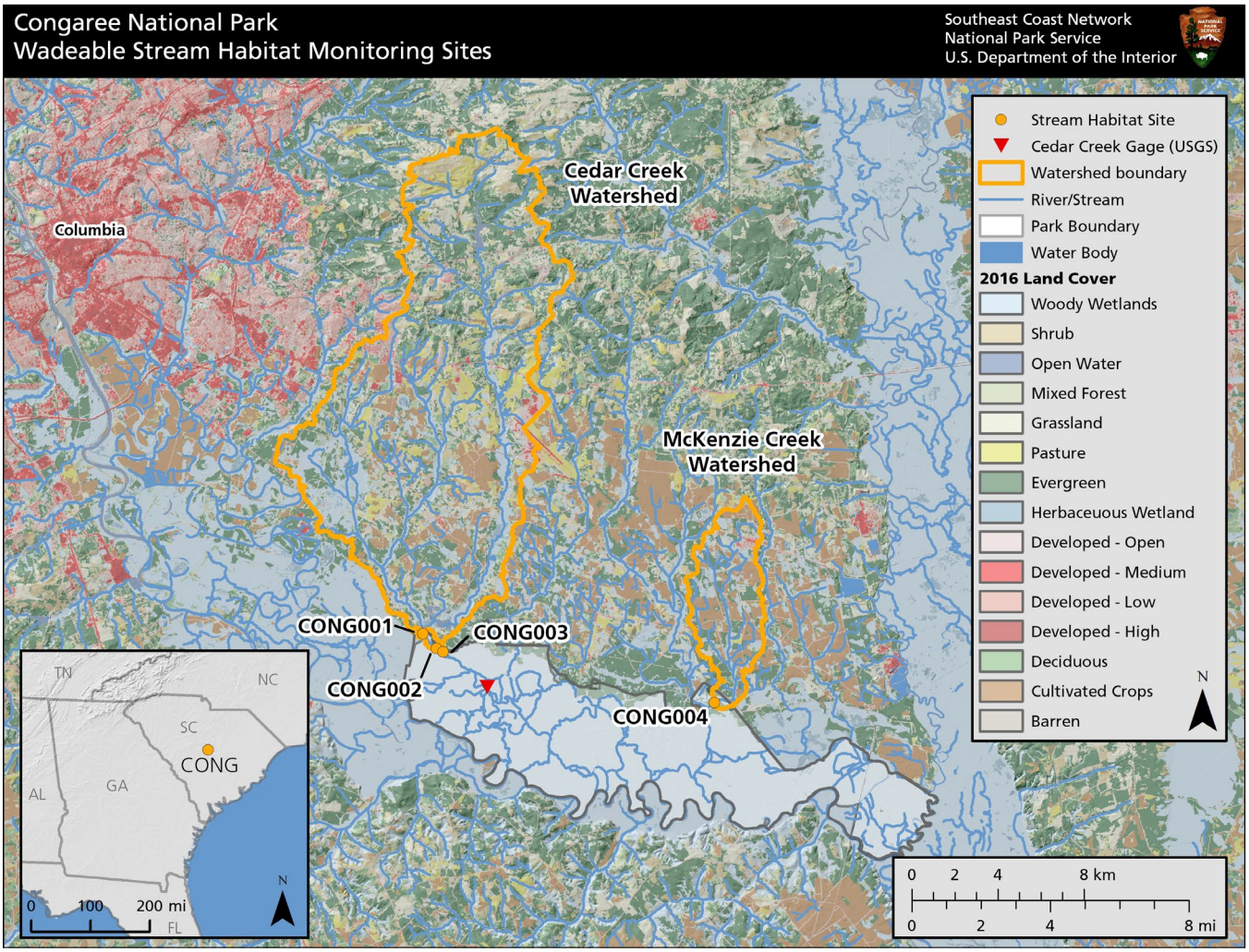


Figure 1. Map showing Congaree National Park and its wadeable stream sites (CONG001, CONG002, CONG003, and CONG004). The watersheds draining to the study reaches are shown to provide a context for the data presented in this report. The land use and land cover (NLCD 2016, Homer et al. 2020) and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

The natural condition of rivers and streams draining the southeastern U.S. are generally characterized by meandering channels with densely vegetated banks (Leigh 2008). Contemporary river systems in the southeastern U.S. are in variously altered states that reflect multiple legacies of anthropogenic disturbance (James 2018). Legacy effects of agriculture include massive topsoil erosion and channel incision in the Piedmont coupled with an immense downstream pulse of sediment (including the Coastal Plain; e.g., Jackson et al. 2005). Regional streams are further impacted by hydrologic alterations caused by urban and suburban development that increases the impervious surface area in their watersheds. These watershed changes increase the frequency and magnitude of peak discharges from rapid runoff (Paul and Meyer 2001) while reducing groundwater recharge and normal base flow during dry periods (Rose and Peters 2001). These flow alterations greatly influence available in- and near-stream habitats and can have a large negative impact on the biota found within a stream (Wenger et al. 2008). While streams at Congaree NP are not in a position to receive significant downstream pulses of Appalachian Piedmont legacy sediment, Hupp (2000) specifically notes that Coastal Plain streams near the Fall Line (transition zone between Coastal Plain and Appalachian Piedmont) are still in a state of change similar to morphologic changes on Appalachian Piedmont streams.

As each stream recovers from its unique history of land use and equilibrates to its current flow and sediment regime, it will pass through a series of semi-predictable stages of evolution (James 2018). These stages include aggradation

(receiving and storing more sediment than flow regime can transport), degradation and narrowing (channel bed erosion and incision from a reduction in sediment and/or increased discharge), further degradation and widening from unstable eroding banks, and finally stabilization and establishing a new equilibrium through the reworking of in-channel alluvium (Figure 2). The exact stage that a particular stream occupies, is dependent on the location of the stream within its network and the unique history and current land use and land cover conditions of the stream's watershed. In general, streams in the Appalachian Piedmont are at the third stage of channel development (further degradation and widening) and their banks are unstable and subject to undercutting and slumping (Ruhlman and Nutter 1999). The higher (third) order streams that were surveyed by the Southeast Coast Network at Chattahoochee River NRA and Kennesaw Mountain NBP are all at stage III and are beginning to develop meandering planforms within their entrenched channels (McDonald et al. 2019; McDonald and Starkey 2019b). However, these typical channel evolution models are not generally applicable to Coastal Plain streams (i.e. Congaree NP) because they usually have little energy available to do geomorphic work.

In general, low gradient, intra-Coastal Plain streams such as those found at Congaree NP have (1) low, often poorly-defined banks; (2) high flood plain connectivity; (3) low-energy flow regimes; (4) relatively high dissolved load; (5) relatively low suspended load (except during floods); and (6) relatively fine bed load (Dr. David Shelley, CONG Chief of Resource Stewardship and Science, personal communication). While such streams defy typical channel evolution models developed for more upland, higher energy systems, regional models are relevant for discussion.

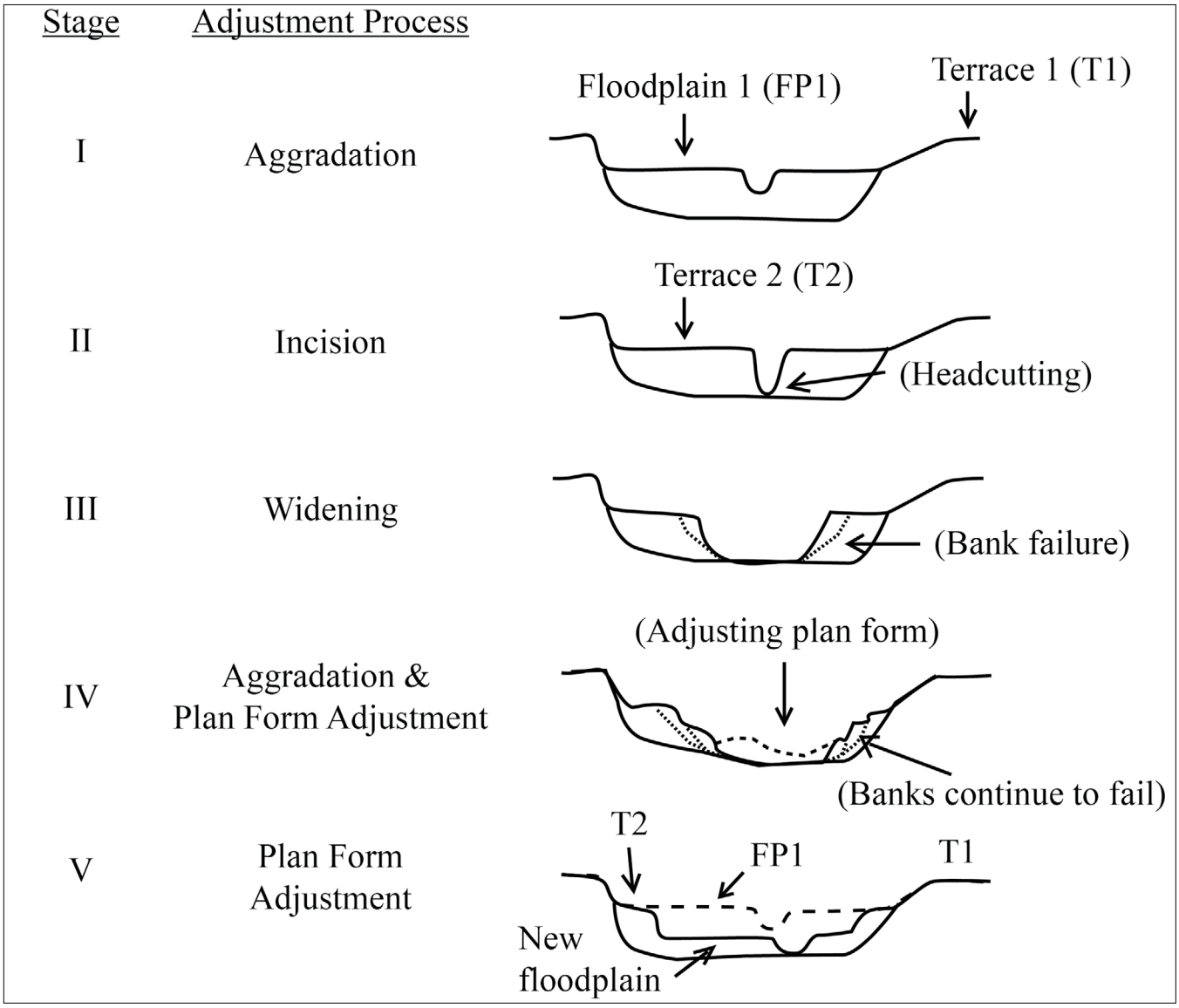


Figure 2. Generalized channel evolution model (modified from Schumm et al. 1984).

Congaree National Park

Congaree National Park protects, studies, manages, and interprets the resources, history, stories, and wilderness character of the nation's largest remaining tract of southern old-growth bottomland forest and its associated ecosystems (NPS 2014). The park is located in central South Carolina, just to the northwest of the confluence of the Congaree and Wateree rivers (Figure 1). The park covers more than 26,000 acres (10,521 hectares [ha]) of biologically and geomorphically diverse flood plain forest, including 11,000 acres (4,452 ha) of true old growth (NPS 2014). Park lands also encompass a fringe of adjacent upland habitat. The park is fully contained within the Coastal Plain but only 24.1 kilometers (14.98 mi) southeast of the Fall Line, a regional geographic feature that separates the Piedmont from the Coastal Plain. The park has the largest concentration and highest diversity of fluvial features in the Southeast Coast Network. Examples include both wadeable and non-wadeable perennial streams as well as ephemeral channels (locally termed "guts," e.g. Cely 2001), meander channels (single abandoned meanders and complex avulsions), crevasse channels, meander-scroll swales, and chute channels that typically form on large alluvial flood plains (Meitzen 2009; Shelley et al. 2012). These channel-like features are not typically found in hillslope, upland areas and do not function as traditional hierarchal stream systems. During most of the year some of the channel-like features on the flood plain may be completely dry, while at other times they exhibit pooling and distributary flow patterns. Flow directions and pathways may change dramatically through the course of a rising and falling high flows from the main-stem river. Flow directions change from unidirectional upstream flow above the flood plain to bidirectional (and multi-directional) flow within the Congaree River flood plain, having significant implications for channel morphology. In this report, we refer to the confluence of these ephemeral flow paths with the perennial streams as 'side channels' (channelized ephemeral flow paths) and 'flood chutes' (unchannelized ephemeral flow paths). In addition to surface water influence, perennial intra-flood plain streams show seasonal patterns in gaining (in the winter) and losing (in the summer) behavior due to changes in the local groundwater table tied to precipitation and evapotranspiration (Patterson et al. 1985).

The flow of water through the Congaree River flood plain, with the exception of the perennial tributaries (Cedar Creek, McKenzie Creek, and Toms Creek), is largely controlled by flow on the Congaree and Wateree Rivers (e.g., Conrads et al. 2008). At a century time-scale, large floods were more frequent during the 19th and early 20th centuries, but have tapered off significantly since the 1930s. Conrads et al. (2008) showed this change is observed in other regional river systems without significant control structures and watershed development, suggesting that it is a regional land use signal rather than a result of the construction of the Saluda Dam at Lake Murray on the Saluda River upstream from Congaree NP. Since the construction of the Saluda Dam, the Congaree River's highest peak flow occurred in October of 2015 during flooding associated with the offshore passing of Hurricane Joaquin (Feaster et al. 2015).

Methods

The habitat characteristics and geomorphic parameters that were selected to monitor are based on those collected by other federal organizations (USFS, Harrelson et al. 1994; USGS, Fitzpatrick et al. 1998; and EPA, Hughes 2000). The physical structure of in- and near-stream habitat has a strong influence on the biological communities and overall ecological integrity of lotic ecosystems (Newson and Newson 2000). Monitoring stream habitat not only provides an understanding of the physical suitability for aquatic species but can also identify stressors that could degrade other park resources and negatively affect visitor experiences.

The data collected as part of the SECN wadeable stream monitoring protocol are divided into three scales of analysis (Figure 3): (1) basin-scale characteristics; (2) reach-scale measurements, along and between 11 standard transects per reach, and; (3) detailed cross-sectional measurements, at three of the 11 transects per reach. A table containing a list and definitions of all variables collected under the protocol can be found in Appendix B. While summarized in this document, a list of standard operating procedures and an overview of the methods used to collect the surveys and process the data are available in McDonald et al. (2018a).

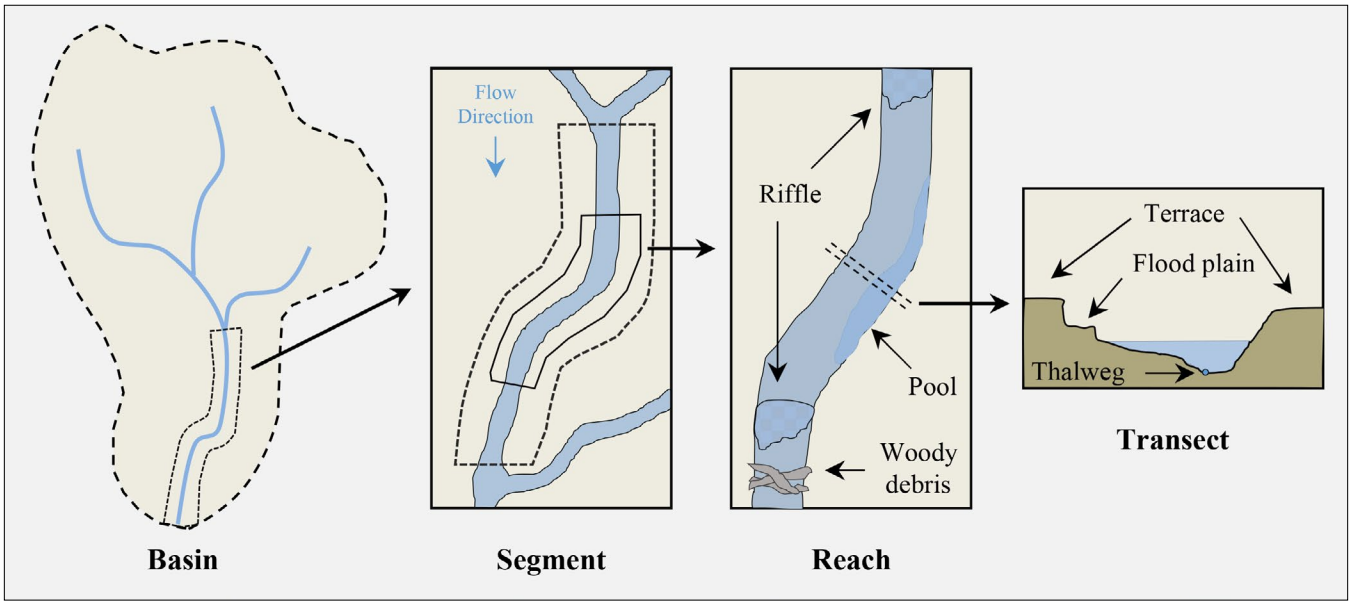


Figure 3. Spatial hierarchy of stream systems and scales of data collection (modified from Fitzpatrick et al. 1998). View in transect diagram is in the downstream direction.

Basin Characteristics

Understanding the physical characteristics of a drainage basin, as well as the land use and land cover upstream of a reach, is critical to understanding changes to and differences between streams. The parameters collected for this protocol describe how dissected the watershed is (drainage density; Knighton 1998), the magnitude and duration of floods (basin shape; Gregory and Walling 1973), the rainfall-runoff potential of a watershed (average watershed slope; Hewlett and Hibbert 1967), potential sediment yield (basin relief ratio; Strahler 1957), and the amount of energy available to move sediment through a stream network (entire stream gradient; Craig and Rankl 1978; Fitzpatrick et al. 1998). A description of these basin characteristics can be found in McDonald et al. (2018a).

Basin-scale measures are calculated after permanent sites have been determined. These measurements and analyses are conducted within a GIS using digital elevation models (DEMs) from the National Elevation Dataset (NED) and land cover data from the National Land Cover Database (NLCD). Procedures for the GIS basin analysis can be found in SECN SOP 1.2.15 *Stream Habitat Assessment Basin and Segment Scale Data Summary—Version 1.0* (McDonald et al. 2018b).

Reach-Scale Measurements

The reach-scale characteristics of each monitored reach are measured at and between 11 equidistant transects (distance between transects is two times average wetted width; Figure 4). Reach length is 20 times average wetted width (as determined during the initial survey of the reach).

Data collected at each of these transects include vegetative bank cover, presence of eroding banks, bed and bank material, channel widths (e.g., wetted, active, bankfull, and channel-full widths), water depth, and bank heights and angles. In addition to bankfull and channel-full bank heights, minimum bank height is also reported. Minimum bank height is the minimum bank height measured on each transect. A quantitative measure of bed sediment is obtained by conducting a Wolman pebble count on a representative riffle within the reach (Wolman 1954).

These data provide an understanding of the geomorphic and physical characteristics of the survey reach and are used to derive a bank stability score for the reach (Table 1). Many stream banks in the Appalachian Piedmont and in the upper portion of the Coastal Plain have bank stability scores of 'at-risk' or 'unstable.' This condition is consistent with expectations, given that many comparable streams in the region are currently reestablishing functional flood plains within their highly entrenched channel systems.

To understand in-stream and near-channel habitats, measurements are also taken between each transect. These between transect measurements include: canopy cover, the amount and type of in-stream habitat (e.g., high-energy riffles vs. low-energy pools), an inventory of large woody debris (LWD; defined as 1 meter [3.28 ft] in length and greater than 10 centimeters [3.94 in] in diameter as defined in McDonald et al. 2018a), and a description of in-channel features (e.g., sand or cobble bars). Using these measures of in-stream habitat, each stream's habitat is classified as 'poor,' 'poor-to-fair,' 'fair,' 'fair-to-good,' or 'good.' These classifications are based on (1) watershed characteristics (i.e. land use land cover, slope, and relief); (2) in-stream habitat conditions (i.e. high versus low energy GCUs, bed material, prevalence of LWD); and (4) general channel condition (i.e. bank conditions, degree of entrenchment, presence of knickpoints, or planform changes).These classifications are a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health on each reach.

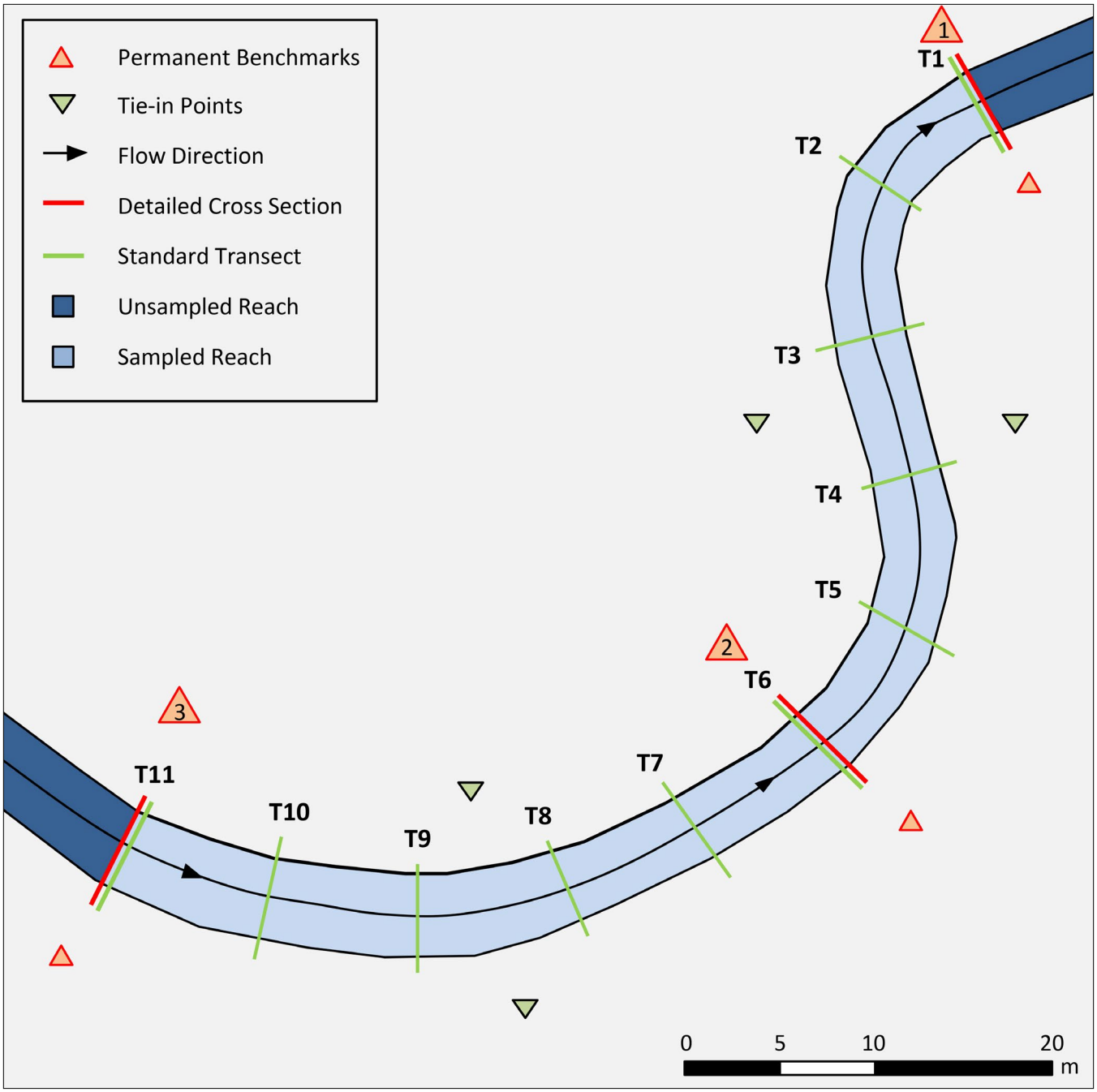


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.

Table 1. Bank Stability Index (BSi) from Fitzpatrick et al. (1998). A BSi score is determined by adding up the bank angle, vegetative cover, bank height, and bank sediment scores for each bank (separate score for left and right banks at each transect)[a].

Bank Stability Factor	Classification	Score
Angle (°)	0–30	1
	31–60	2
	> 60	3
Vegetative cover (%)	> 80	1
	50–80	2
	20–49	3
	< 20	4
Bank Height (meters)	< 1	1
	1–2	2
	2–3	3
	3–4	4
	> 4	5
Type of Bank Sediment	Bedrock, artificial	1
	Boulder, cobble	3
	Clay	4
	Silt	5
	Sand	8
	Gravel/Sand	10

[a] total score rankings: 4–7 stable; 8–10 at-risk; 11–15 unstable; and 16–22 very unstable.

Detailed Transect Cross-Sections

Three of the 11 standard transects (optimally T1, T6, and T11) are surveyed using a survey grade (sub-centimeter accuracy) total station. These surveys allow lateral variability along each transect to be quantified and in- and out-of-channel changes to be monitored through time (Figure 5). Additionally, repeated surveying of channel cross-sections allows changes in streambed elevation and bank profiles to be quantitatively assessed in relation to a known point (benchmark). These data are used to calculate bankfull and channel-full areas. They are also employed, along with the bank stability index values, to assess the condition and stability of the reach.

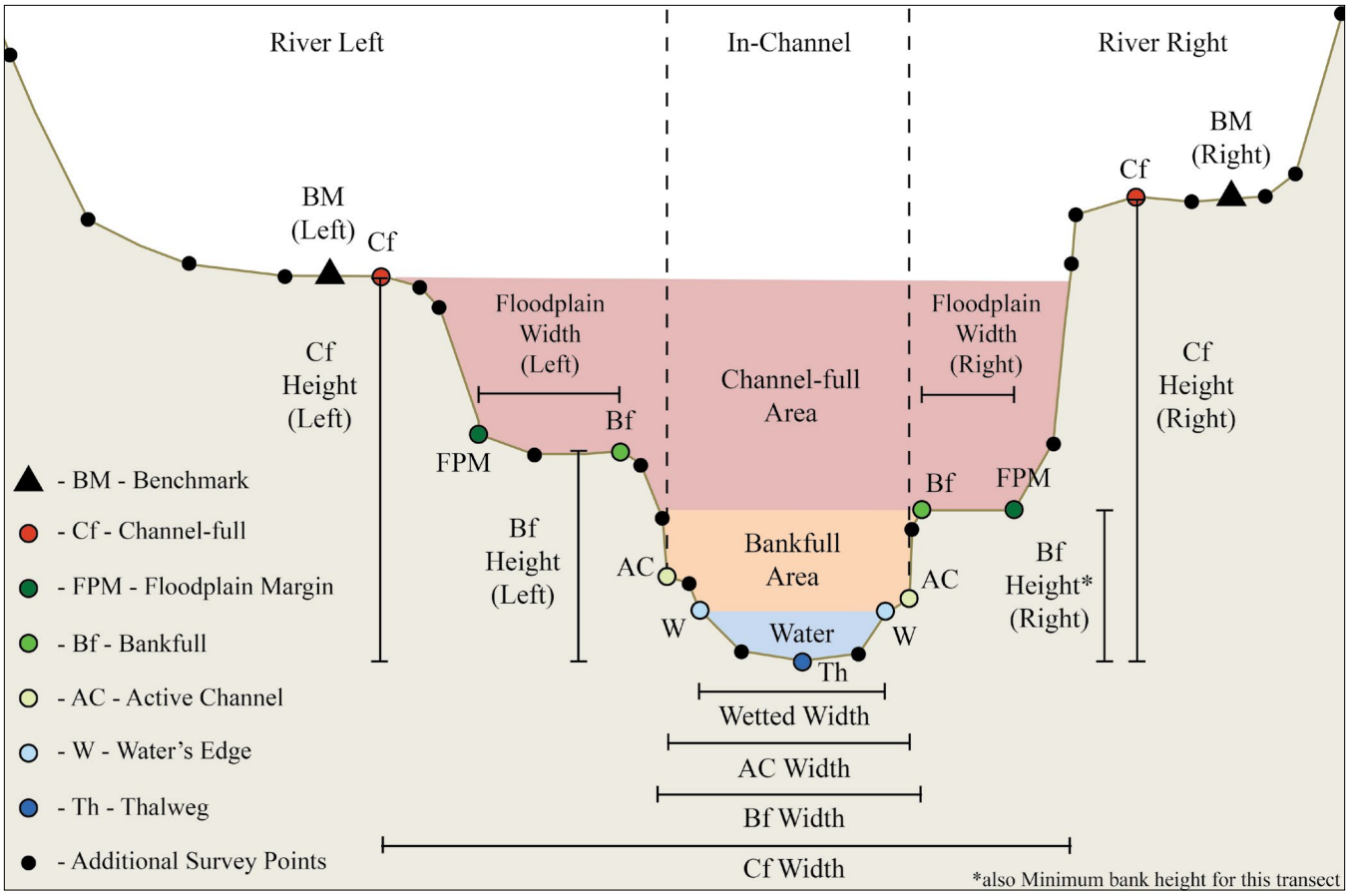


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes light blue (baseflow) and orange portions of the cross-section. Channel-full area includes baseflow, bankfull, and channel-full (red) areas.

Statistical Analysis

The surveyed reaches at Congaree NP are compared to third and fifth order streams at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA (Figure A-1). A one-way analysis of variance (ANOVA) test was conducted to determine if there were statistically significant differences in the reach-scale measures of: (1) pebble count data (millimeters); (2) thalweg depth (meters); (3) thalweg position (% distance from left bank); (4) wetted width (meters); (5) active channel width (meters); (6) channel-full width (meters); (7) channel-full height (meters); (8) bank angle (°); and (9) vegetative cover of the banks (%) among streams of similar order. Bankfull width and height are not included in the statistical analysis because bankfull was not measured on each transect (due to lack of flood plain) and the number of bankfull measurements at each reach was not equal. If the ANOVA showed a significant difference, a post hoc Tukey test was used to determine where the difference occurred (i.e. which site(s) differed significantly from the other site(s) of similar stream order).

Results

Between June 11 and 14, 2018, three stream reaches on Cedar Creek (CONG001, CONG002, and CONG003) and one stream reach on McKenzie Creek (CONG004) were surveyed following the methods outlined in SECN SOP 1.2.16 Wadeable Stream Reach-Scale Field Data Collection–Version 1.0 (McDonald et al. 2018c) and SECN SOP 1.2.18 Using a Total Station to Conduct a Stream Survey–Version 1.0 (McDonald et al. 2018d). The surveyed reaches on Cedar Creek are on a fifth order segment within their stream network, while the surveyed reach on McKenzie Creek is on a third order segment. Results and data summary tables for each reach are provided in Appendices C–F. Data summary tables for surveys conducted while training staff at McKenzie Creek (CONG004) on June 6 and 7, 2018 are available upon request. Survey results from two third order streams (Ward Creek [KEMO002] and Long Island Creek [CHAT013]) and one fifth order stream (Walnut Creek [OCMU001]) are included in this report to provide a context for the Congaree NP surveys.

The third order streams at Kennesaw Mountain NBP and Chattahoochee River NRA are typical Appalachian Piedmont streams that are beginning to develop a meandering planform inset within their higher historical terraces (McDonald and Starkey 2019b; McDonald et al. 2019). The fifth order stream surveyed at Ocmulgee Mounds NHP is located just below the Fall Line (the transitional zone between the Appalachian Piedmont and the Coastal Plain) and is representative of a stream located in this transitional area (Cooper et al. 2019). A map comparing the Cedar Creek (CONG001–003) and McKenzie Creek (CONG004) watersheds to the watersheds draining to monitored streams at Ocmulgee Mounds NHP, Chattahoochee River NRA, and Kennesaw Mountain NBP is provided in Appendix A. In the following sections, monitored stream reaches at Congaree NP will be referred to by their stream names and relative location (if multiple sites are on the same stream) (i.e. Cedar Creek 'upstream,' Cedar Creek 'middle,' Cedar Creek 'downstream,' and McKenzie Creek), while corresponding site codes (CONG001–003, CONG004, respectively) are used in data tables. The stream name and site code for the stream reaches at Ocmulgee Mounds NHP (OCMU001), Kennesaw Mountain NBP (KEMO002), and Chattahoochee River NRA (CHAT013) will be used to remind the reader where these stream reaches are located.

Precipitation and Flow Conditions

Wadeable stream surveys are done as close to baseflow conditions as possible given the time frame available to do the stream surveys each year (McDonald et al. 2018a). Less than 6 inches (15.24 centimeters [cm]) of precipitation fell at Congaree NP during the month prior to the 2018 wadeable stream surveys (Table 2). There were no precipitation events of greater than 1 inch (2.54 cm) during the week prior to the 2018 surveys. Light precipitation (0.38 inch [0.97 cm]) fell during the evening of the first survey day (Cedar Creek 'upstream'[CONG001]; June 11, 2018). More than 1 inch (2.54 cm) of precipitation fell in the afternoon and evening of the final survey day (Cedar Creek 'middle' [CONG002]; June 14, 2018), but surveys were completed before this precipitation began to fall.

Table 2. Amount of precipitation and number of precipitation events greater than 1 inch (2.5 cm) in the week and month(s) prior to and during the 2018 wadeable stream surveys at Congaree National Park. Data from Congaree, S.C. Remote Active Weather Station (National Weather Service ID: 382603), 33.81472° N, 80.78111° W.

Time Frame	Length of Period	Total Precipitation (Inches)	Number of Events > 1 Inch
6/14/2018	One Day	1.06	1
6/13/2018	One Day	0.00	0
6/12/2018	One Day	0.07	0
6/11/2018	One Day	0.38	0
6/03/2018–6/10/2018	One Week	0.37	0
5/10/2018–6/10/2018	One Month	5.32	1
3/10/2018–6/10/2018	Three Months	10.57	2

Daily mean gage height data from the nearest USGS gage (USGS 02169672 Cedar Creek at Congaree National Park near Gadsden, S.C.; https://waterdata.usgs.gov/nwis/uv?02169672) were analyzed for the period of January 1 through September 30, 2018 (Figure 6). The gage is approximately 3.3 kilometers (2.05 mi) downstream of and 1 meter (3.28 ft) lower in elevation than Cedar Creek 'downstream' (CONG003; Figure 1). The 10th percentile of mean daily gage height (0.81 meter [2.66 ft]) was used as an approximation of baseflow conditions on the Cedar Creek gage. Mean daily gage height was below baseflow for one of the four surveys (June 11; CONG001; 0.78 meter [2.56 ft]). The maximum mean gage height during the survey period was recorded on June 13 (CONG003; 0.94 meter [3.08 ft]; 30th percentile of flow). Future surveys should take into account differences in gage height conditions when comparing differences in thalweg depths, bank heights, and geomorphic channel unit distributions and percentages.

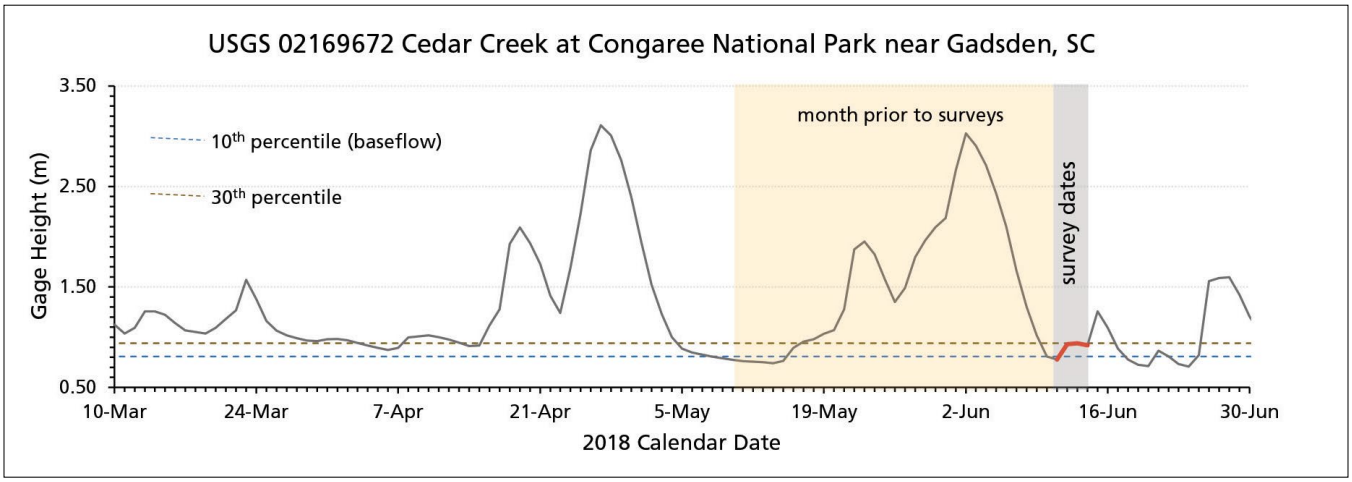


Figure 6. Daily mean gage height at USGS 02169672 Cedar Creek at Congaree National Park near Gadsden, SC gage (33.81627° N, 80.82731° W). 10th percentile (0.81 meters [2.7 ft]; blue dashed line) represents baseflow conditions at the gage location. Gage heights during survey days (June 11 through June 14, 2018) are shown in red).

Basin Characteristics

The monitored reaches on Cedar Creek (CONG001–003) and Walnut Creek (OCMU001) are fifth order streams while the monitored reach on McKenzie Creek (CONG004), Ward Creek (KEMO002), and Long Island Creek (CHAT013) are third order streams (Table 3). Watersheds draining to the monitored reaches at Congaree National Park range in size from 26.62 to 199.09 square kilometers (10.28 to 76.87 mi^2). It should be noted that measuring watershed areas of reaches that lie within the Congaree River flood plain (e.g., Cedar Creek 'middle' and 'downstream'), can be of limited value for predicting flood stage heights because the discharge during full flood stage originates from a much wider area (Conrads et al. 2008). The National Park Service manages 0.23% of the watershed draining to Cedar Creek 'downstream' and 1.53% of the watershed draining to McKenzie Creek. The CONG watersheds have similar drainage densities (Cedar Creek, 1.78; McKenzie Creek, 1.82). These drainage densities are greater than the drainage densities of the watersheds draining to Walnut Creek (OCMU001; 1.68) and Long Island Creek (CHAT001; 1.61). Cedar Creek's watershed had the highest bifurcation ratio (4.14) while McKenzie Creek's watershed had the second lowest bifurcation ratio (1.57). Entire stream gradients for the CONG watersheds (range of 0.0019 to 0.0025 m/m) and Walnut Creek's watershed (OCUM001; 0.0021 m/m) were at least three times lower than the entire stream gradients of the watersheds draining to Ward Creek (KEMO002; 0.0078 m/m) and Long Island Creek (CHAT013; 0.0065 m/m). Congaree NP's segment gradients were 0.0010 m/m and 0.0013 m/m (Cedar Creek and McKenzie Creek, respectively). Segment gradients at Walnut Creek (OCMU001; 0.0014 m/m) and Ward Creek (KEMO002, 0.0007 m/m) were comparable to those of the CONG sites and all were much gentler than the segment gradient at Long Island Creek (CHAT013; 0.0065 m/m; Table 3).

Table 3. Watershed characteristics for Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA calculated using the National Elevation Dataset (NED) 10-meter (32.8 ft) digital elevation model. The sites in bold are the focus of this report.

Basin Charactieristic	**CONG001**	**CONG002**	**CONG003**	OCMU001	**CONG004**	KEMO002	CHAT013
Strahler Order	5	5	5	5	3	3	3
Drainage Area (km^2)	198.32	198.95	199.09	239.35	26.62	12.66	16.88
NPS Managed Area (km^2)	0.04	0.39	0.46	0.65	0.42	1.00	0.29
NPS Managed Area (%)	0.02	0.20	0.23	0.27	1.58	7.87	1.72
Total Stream Length (km)	352.83	354.07	354.52	401.73	48.35	20.82	27.11
Drainage Density	1.78	1.78	1.78	1.68	1.82	1.94	1.61
Bifurcation Ratio	4.14	4.13	4.13	2.13	1.57	1.77	1.52
Entire Stream Gradient[a]	0.0020	0.0019	0.0019	0.0021	0.0025	0.0078	0.0065
Segment Gradient[b]	0.0010	0.0010	0.0010	0.0014	0.0013	0.0007	0.0065
Slope - Average	1.97	1.97	1.97	4.87	0.87	4.50	8.71
Slope - Std. Dev.	2.00	2.00	2.00	3.52	0.75	3.06	5.84
Slope - Coefficient of variation (CV)	1.01	1.01	1.01	0.72	0.86	0.68	0.67
Basin Length (km)	34.29	35.53	35.98	39.26	14.11	7.14	10.66
Basin Shape[c]	0.17	0.16	0.15	0.16	0.13	0.25	0.15
Basin Relief (m)	136	137	137	127	47	88	109
Basin Relief Ratio	0.004	0.004	0.004	0.003	0.003	0.012	0.010
Elevation - Std. Dev. (m)	32	32	32	21	8	15	23

[a] entire stream gradient is calculated by dividing the difference between the elevations at 10% and 85% stream length by the length of stream between.

[b] segment gradient is calculated by dividing the difference in elevations at the top of the stream segment and the bottom of the stream segment by the stream length between.

[c] basin shape is calculated by dividing drainage area by squared basin length.

The upper Coastal Plain watersheds draining to the monitored reaches at Congaree National Park have extremely gentle average watershed slopes (Cedar Creek, 1.97°; McKenzie Creek, 0.87°) compared to the watersheds that drain mostly (Walnut Creek [OCMU001]; 4.87°) or entirely from the Appalachian Piedmont (Ward Creek [KEMO002], 4.50°; Long Island Creek [CHAT013], 8.70°). McKenzie Creek's average watershed slope is an order of magnitude lower than Long Island Creek's average watershed slope. The Cedar and McKenzie Creek watersheds have similar basin relief ratios (Cedar Creek, 0.004; McKenzie Creek, 0.003) to that of Walnut Creek (0.003) but are an order of magnitude less than those of Ward Creek (0.012) and Long Island Creek (0.010; Table 3).

Land use and land cover (LULC) of the CONG watersheds is very different from the LULC of Walnut, Ward, and Long Island creeks (Table 4). The CONG watersheds have similar amounts of developed land cover (8% [McKenzie Creek] and 11% [Cedar Creek]). Walnut Creek's watershed also had a low amount of developed land cover (12%), while Ward Creek (68%) and Long Island Creek (60%) had far more developed land cover (Table 4). The major LULC difference between the CONG watersheds and Walnut Creek's watershed is that the CONG watersheds are covered by more wetlands (Cedar Creek, 18%; McKenzie Creek, 23%; Walnut Creek, 3%), grasslands (Cedar Creek, 21%; McKenzie Creek, 10%; Walnut Creek, 8%), and cultivated areas (Cedar Creek, 9%; McKenzie Creek, 30%; Walnut Creek, 0%). The watersheds of Walnut, Ward, and Long Island creeks all had 0% cultivated lands (Table 5).

Table 4. Land use and land cover characteristics in 2016 for Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The data included in this table are from the National Land Cover Dataset (Homer et al. 2020). The sites in bold are the focus of this report.

NLCD Classes	**CONGO001**	**CONG002**	**CONG003**	OCMU001	**CONG004**	KEMO002	CHAT013
Developed Open and Low (%)	10	10	10	11	8	58	47
Developed Medium and High (%)	1	1	1	1	0	10	13
Forested (%)	35	35	35	64	29	29	39
Grassland (%)	21	21	21	14	10	1	1
Wetland (%)	18	18	18	3	23	0	0
Cultivated (%)	9	9	9	0	30	0	0

Congaree National Park Monitored Reach Descriptions

CONG001—Cedar Creek 'Upstream'

Cedar Creek 'upstream' is located on Cedar Creek approximately 175 meters (574.15 ft; river distance) downstream from the canoe launch at Bannister Bridge. Cedar Creek 'upstream' is a sinuous, sandy bedded, black water stream. A well-used social walking trail (for fishing and canoe or kayak access) parallels the reach on river right. A side channel exits Cedar Creek 'upstream' on river left just downstream from the second benchmark (BM2, T6) and reenters the stream just downstream from transect 1 (Figure 7). The reach that was surveyed was 150 meters (492.13 ft) long with 15 meters (49.21 ft) between transects. The stream channel at Cedar Creek 'upstream' is relatively entrenched in comparison to the other monitored reaches on Cedar Creek. During the survey, a longitudinally continuous inset surface (on river left between T1 and T3) was interpreted as an incipient flood plain (Figure 7). Upon further review, this inset surface was reclassified as an 'elevated entrenched surface' as it may be a semi-stable rotational slump similar to the features observed on Ward (KEMO002) and Walnut (OCMU001) creeks (Bateman McDonald 2020a, 2020b). Future surveys will determine if the elevated entrenched surface is a flood plain (formed via depositional processes as the stream laterally migrates away from this bank) or if it was formed through erosional processes (i.e., bank slumping). Geomorphic channel units (GCU) within the reach consisted of mostly deep pools (n = 10) that were observed on the outside of meanders, with runs and glides (n = 9 and n = 6, respectively) separating the pools (Table 5). Sand bars were observed on the inside of meanders throughout the reach. Water surface slope (longitudinal profile) on Cedar Creek 'upstream' was 0.00032 m/m (Table 6; Figure 8). Although no riffles or steps were observed within the reach, the longitudinal profile shows a slight increase in slope downstream of T6. The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T10 (BM3). Sand bars were observed on detailed transects 1 (T1) and 2 (T6) and the elevated entrenched surface was observed on river left on detailed transect 1 (T1; Figure 9). Transect-scale survey results for Cedar Creek 'upstream' are in Appendix C.

Table 5. Comparison of geomorphic channel units (GCU) observed in the area between transects at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The data describe the percent coverage of each type of GCU. The sites in bold (beginning with CONG) are the focus of this report.

GCU Type	Site	Frequency	Maximum (%)	Mean (%)	Standard Deviation (%)
Riffle	**CONG001[a]**	0	0	0	0
	CONG002[a]	0	0	0	0
	CONG003[a]	0	0	0	0
	OCMU001[a]	0	0	0	0
	CONG004[b]	4	12	60	21
	KEMO002[b]	2	5	25	11
	CHAT013[b]	10	46	85	24
Run	**CONG001[a]**	9	25	50	15
	CONG002[a]	4	10	40	14
	CONG003[a]	7	34	70	29
	OCMU001[a]	9	61	90	30
	CONG004[b]	2	12	80	27
	KEMO002[b]	5	26	80	33
	CHAT013[b]	3	4	15	6
Glide	**CONG001[a]**	6	25	60	25
	CONG002[a]	10	38	100	29
	CONG003[a]	6	30	80	33
	OCMU001[b]	2	10	60	21
	CONG004[b]	0	0	0	0
	KEMO002[b]	1	2	20	6
	CHAT013[b]	1	39	60	27
Pool	**CONG001[a]**	10	50	90	29
	CONG002[a]	8	52	80	33
	CONG003[a]	8	36	80	28
	OCMU001[a]	10	28	50	14
	CONG004[b]	10	71	100	37
	KEMO002[b]	10	65	100	32
	CHAT013[b]	10	39	95	27
Step	**CONG001[a]**	0	0	0	0
	CONG002[a]	0	0	0	0
	CONG003[a]	0	0	0	0
	OCMU001[a]	1	2	20	6
	CONG004[b]	1	6	60	19
	KEMO002[b]	1	3	25	8
	CHAT013[b]	1	6	60	19

[a] fifth order stream.

[b] third order stream.

Table 6. Comparison of average detailed transect characteristics at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [m—meters].

Site	n[a]	Slope	Sinuosity	n[b]	Bankfull Area (m^2)	Bankfull Width (m)	Bankfull Height (m)	Channel-full Area (m^2)	Channel-full Width (m)	Channel-full Height (m)
CONG001[c]	11	-0.00032	1.74	3	10.68	9.78	1.58	12.88	12.59	1.78
CONG002[c]	11	-0.00025	1.04	3	5.62	11.69	0.83	8.81	13.60	1.09
CONG003[c]	11	-0.00040	1.11	3	4.59	8.77	0.96	8.66	26.41	1.19
OCMU001[c]	12	-0.00182	1.15	3	4.56	8.29	0.70	16.03	18.11	1.43
CONG004[d]	11	-0.00400	1.03	3	0.97	3.28	0.36	3.01	16.53	0.61
KEMO002[d]	11	-0.00197	1.09	3	3.15	6.68	0.70	7.53	8.67	1.28
CHAT013[d]	17	-0.00447	1.14	3	5.08	11.39	0.63	26.27	16.72	2.09

[a] number of slope measurements taken.

[b] number of detailed transects.

[c] fifth order stream.

[d] third order stream.

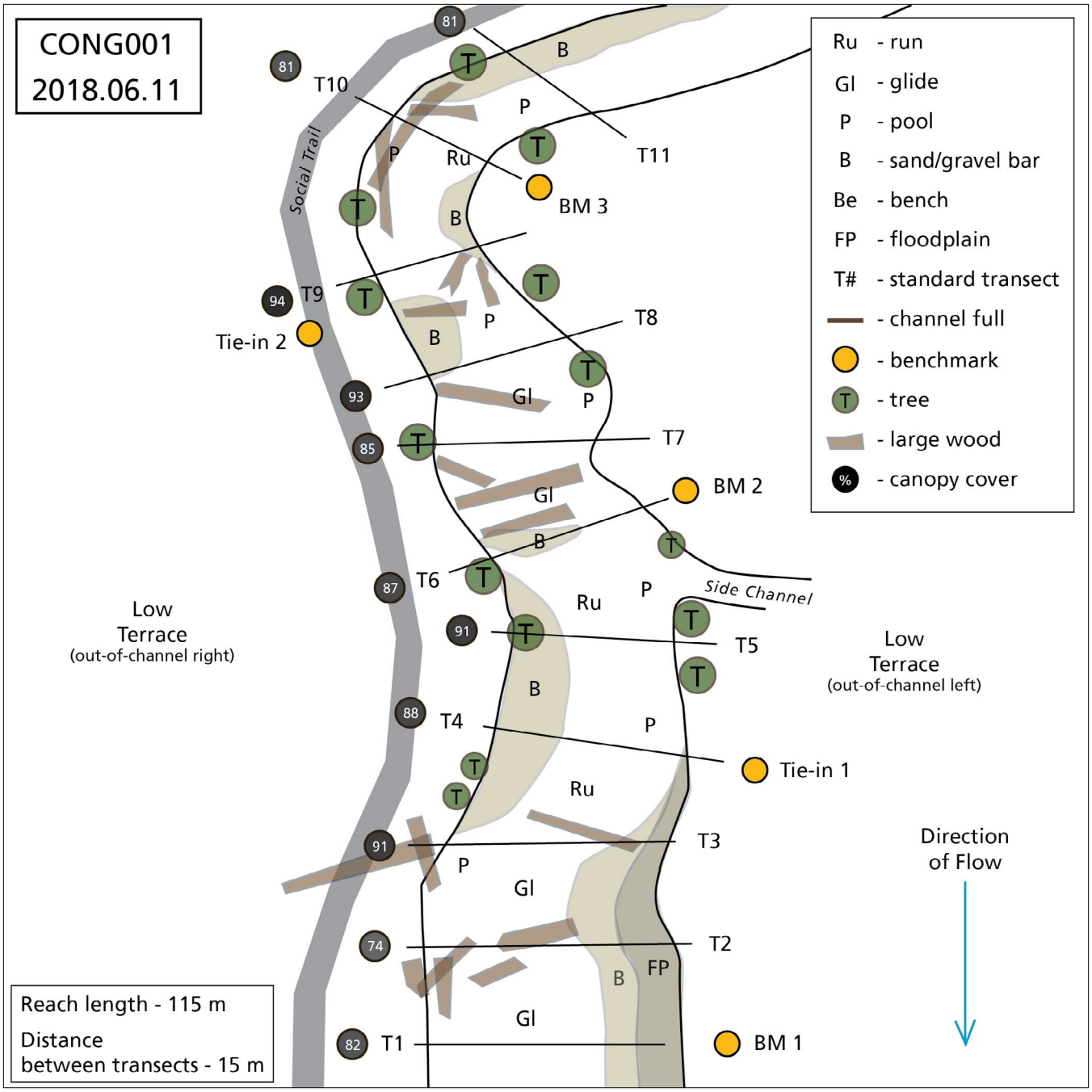


Figure 7. Reach-scale map of Cedar Creek upstream (CONG001). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Map is not drawn to scale.

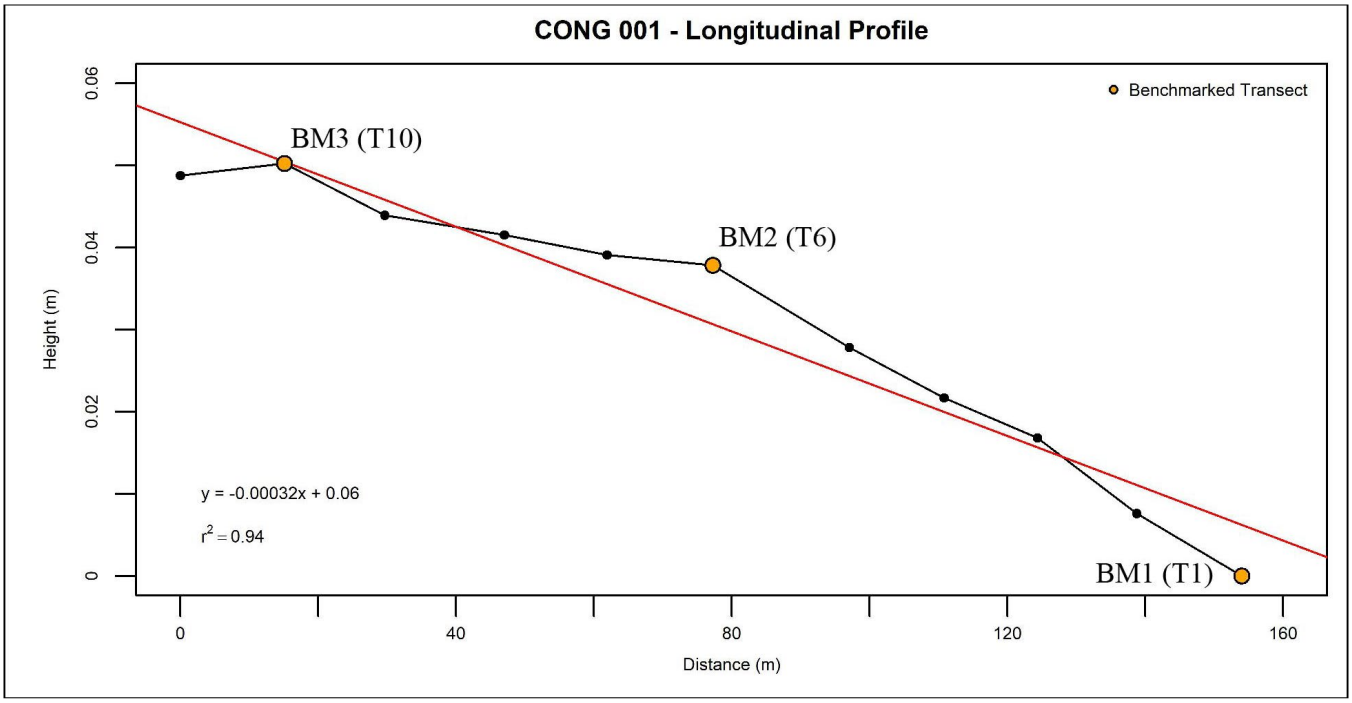


Figure 8. Longitudinal profile for Cedar Creek 'upstream' (CONG001). The red line on the graph corresponds to the interpreted slope of the reach. The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

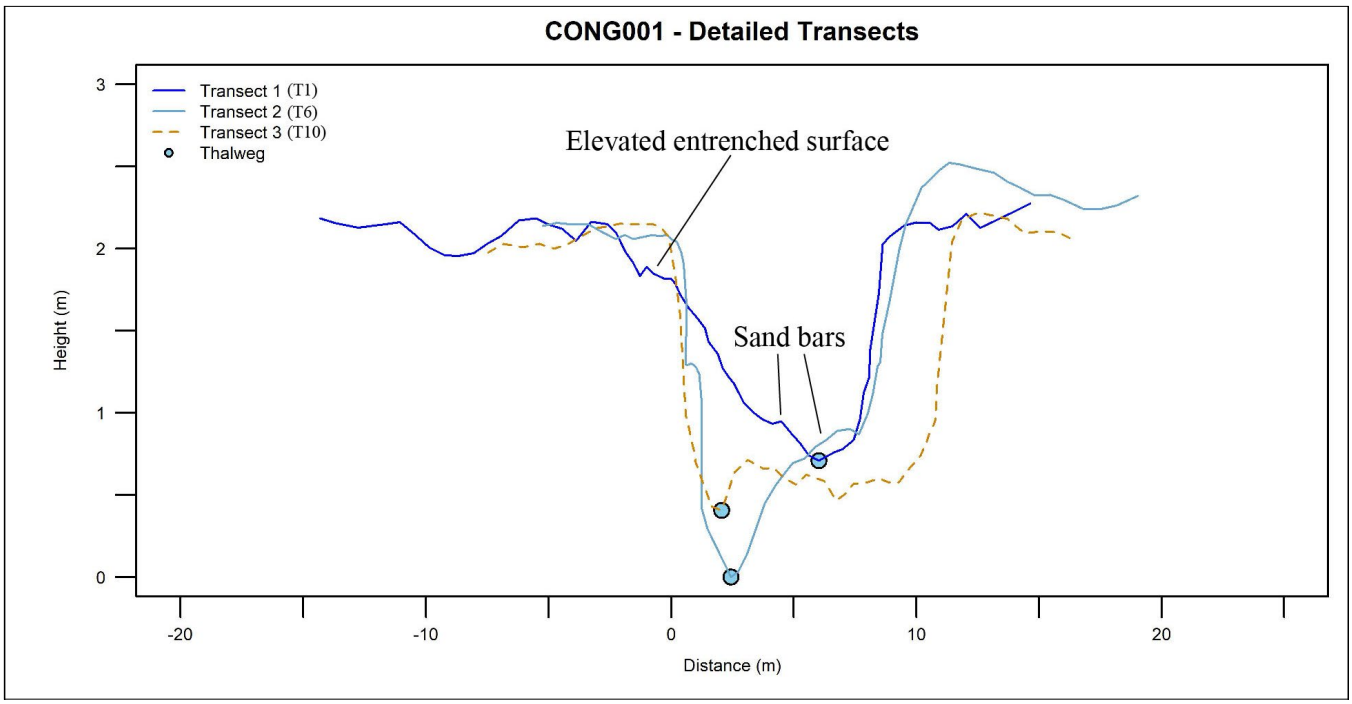


Figure 9. Comparison of the detailed transects at Cedar Creek 'upstream' (CONG001). The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed. View is in the downstream direction (river left is on the left side of the diagram).

CONG002—Cedar Creek 'Middle'

Cedar Creek ‘middle’ is located approximately 1.1 kilometer (0.68 mi; river distance) downstream of Cedar Creek ‘upstream.’ Cedar Creek ‘middle’ is a relatively straight, deep, sandy-bedded, blackwater stream. The reach that was surveyed was 170 meters (557.74 ft) long with 17 meters (55.77 ft) between transects. Many flood chutes and side channels enter Cedar Creek ‘middle’ on both sides of the stream (Figure 10). An animal trail (travelled by wild pigs and or deer) was observed on river right just downstream of T9. The stream channel at Cedar Creek ‘middle’ is not entrenched and there is an extensive flood plain in the out-of-channel area on both sides of the stream (Figure 10). Sand bars were observed on river right on T6 and T10. Within the reach, GCUs consisted of mostly glides (n = 10) with some deep pools (n = 8) and relatively few runs (n = 4; Table 5). Water surface slope (longitudinal profile) along Cedar Creek ‘middle’ was 0.00025 m/m (Table 6; Figure 11). The longitudinal profile is relatively consistent, and no riffles or steps were observed within the reach. The detailed transects were surveyed on T4 (BM1), T6 (BM2), and T9 (BM3). The streambed was relatively irregular along detailed transects 1 (T4) and 2 (T6; Figure 12) due to the presence of buried LWD. A sand bar was observed on river right along detailed transect 2 (T6). A side channel was observed on river left on detailed transect 1 (T4) and a flood chute was observed behind BM3 on river left on detailed transect 3 (T9). An animal trail passed in front of the secondary benchmark on river right on detailed transect 3 (T9). Transect-scale survey results for Cedar Creek ‘middle’ can be found in Appendix D.

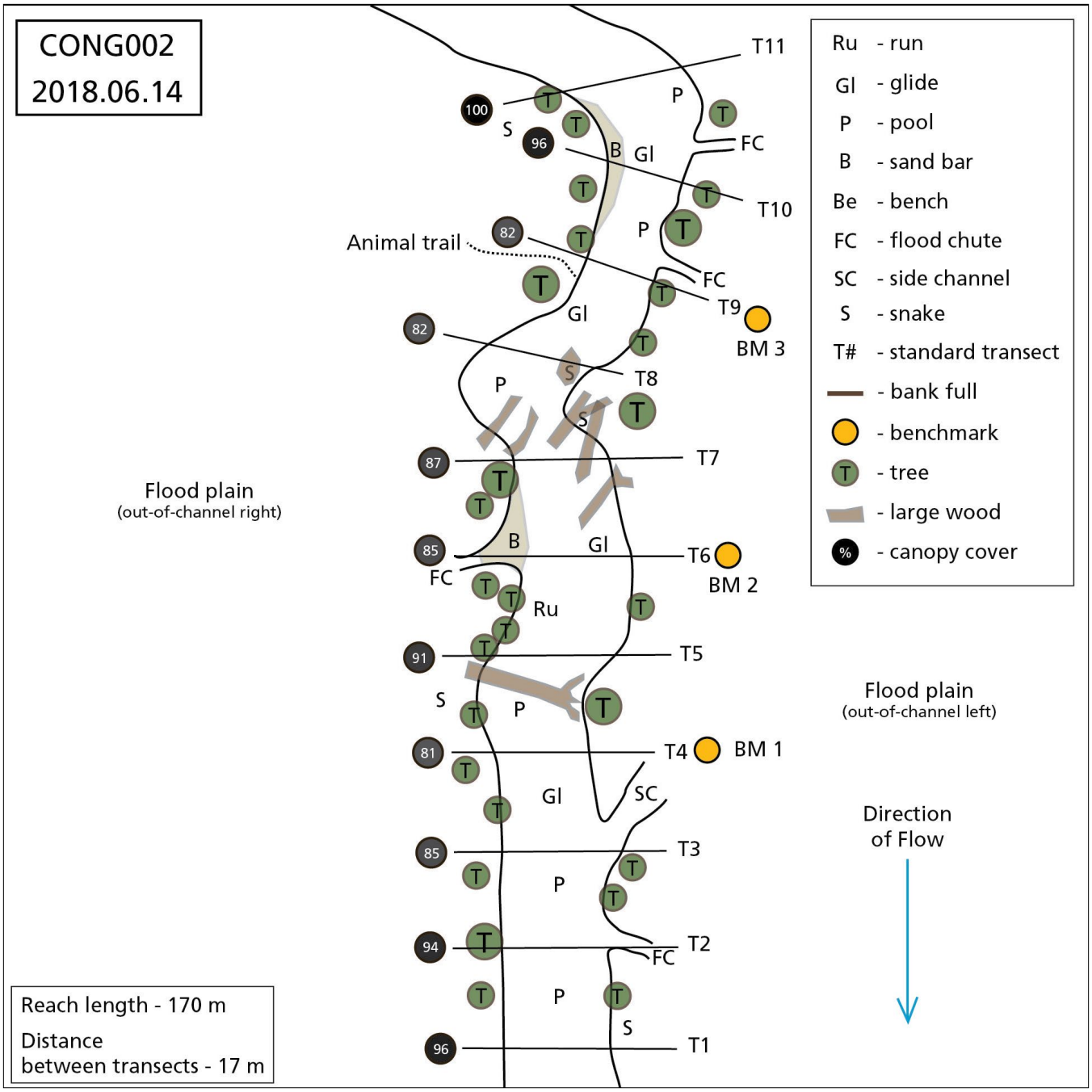


Figure 10. Reach-scale map of Cedar Creek middle (CONG002). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Map is not drawn to scale.

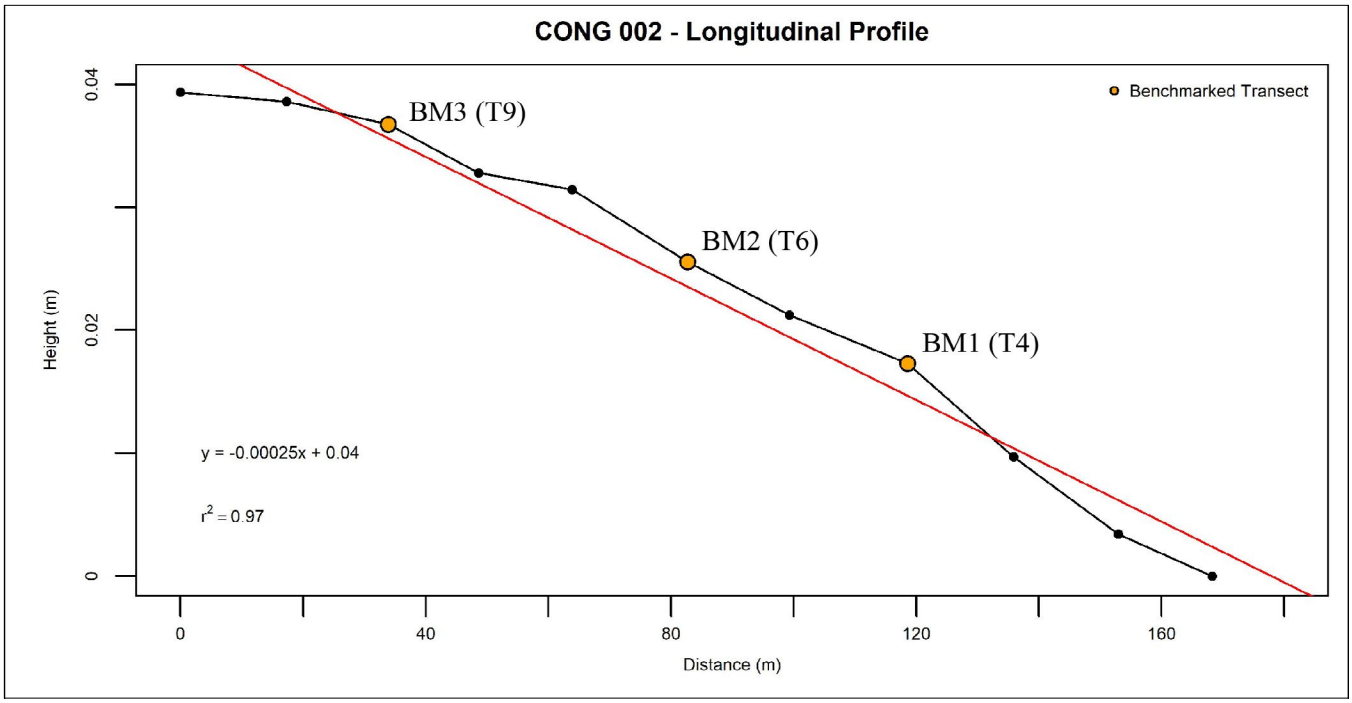


Figure 11. Longitudinal profile for Cedar Creek 'middle' (CONG002). The red line on the graph corresponds to the interpreted slope of the reach. The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

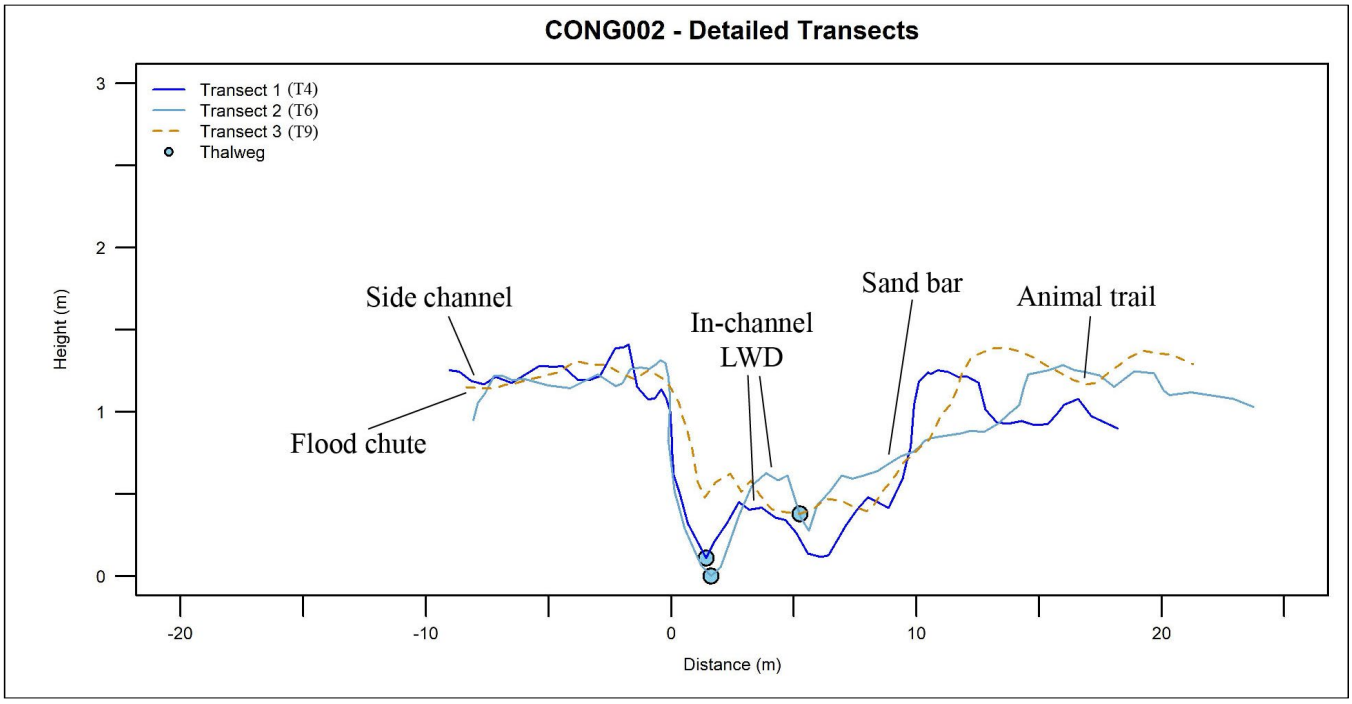


Figure 12. Comparison of the detailed transects at Cedar Creek 'middle' (CONG002). The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed. View is in the downstream direction (river left is on the left side of the diagram).

CONG003—Cedar Creek 'Downstream'

Cedar Creek ‘downstream’ is located approximately 400 meters (1,312.34 ft, river distance) downstream of Cedar Creek ‘middle’ and is the farthest downstream reach monitored on Cedar Creek (approximately 1.9 kilometers [1.18 mi] downstream distance from Bannister Bridge). Similar to the upstream Cedar Creek reaches, Cedar Creek ‘downstream’ is a sandy bedded, blackwater stream. The reach that was surveyed was 150 meters (492.13 ft) long with 15 meters (49.21 ft) between transects. Cedar Creek ‘downstream’ is more sinuous than Cedar Creek ‘middle’ but much straighter than Cedar Creek ‘upstream.’ The stream channel at Cedar Creek ‘downstream’ is not entrenched and extensive flood plain, higher hummocks (small rounded or conical mounds and other small changes in elevation), and many ephemeral channels are present in the out-of-channel areas along the reach (Figure 13). A flood chute enters the reach on river left, just downstream of T11. Patches of submerged aquatic vegetation were observed in the streambed between T3 and T4, and along T9. Cedar Creek ‘downstream’ is farther into the Congaree River flood plain than the other monitored reaches and many cypress trees and associated roots or knees are present in the flood plain areas and alongside the stream. GCUs at Cedar Creek ‘downstream’ consisted of deep pools (n = 8), with some runs (n = 7) and glides (n = 6; Table 5). Water surface slope (longitudinal profile) along Cedar Creek downstream was 0.00040 m/m (Table 6; Figure 14). The longitudinal profile is consistent, and no riffles or steps were observed within the reach. The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T9 (BM3). Higher hummocks separate the stream channel from the surrounding backswamp area along each detailed transect (T1, T6, T9). Lower flood plain areas lie between the higher hummocks and the backswamp area on river left of detailed transect 1 (T2) and on river right of detailed transect 3 (T9; Figure 15). A wild pig wallow was observed in front of BM3 on river left on detailed transect 3 (T9). Large woody debris was observed in the channel along detailed transects 2 (T6) and 3 (T9), forming pools on the river right side of both transects. Transect-scale survey results for Cedar Creek downstream can be found in Appendix E.

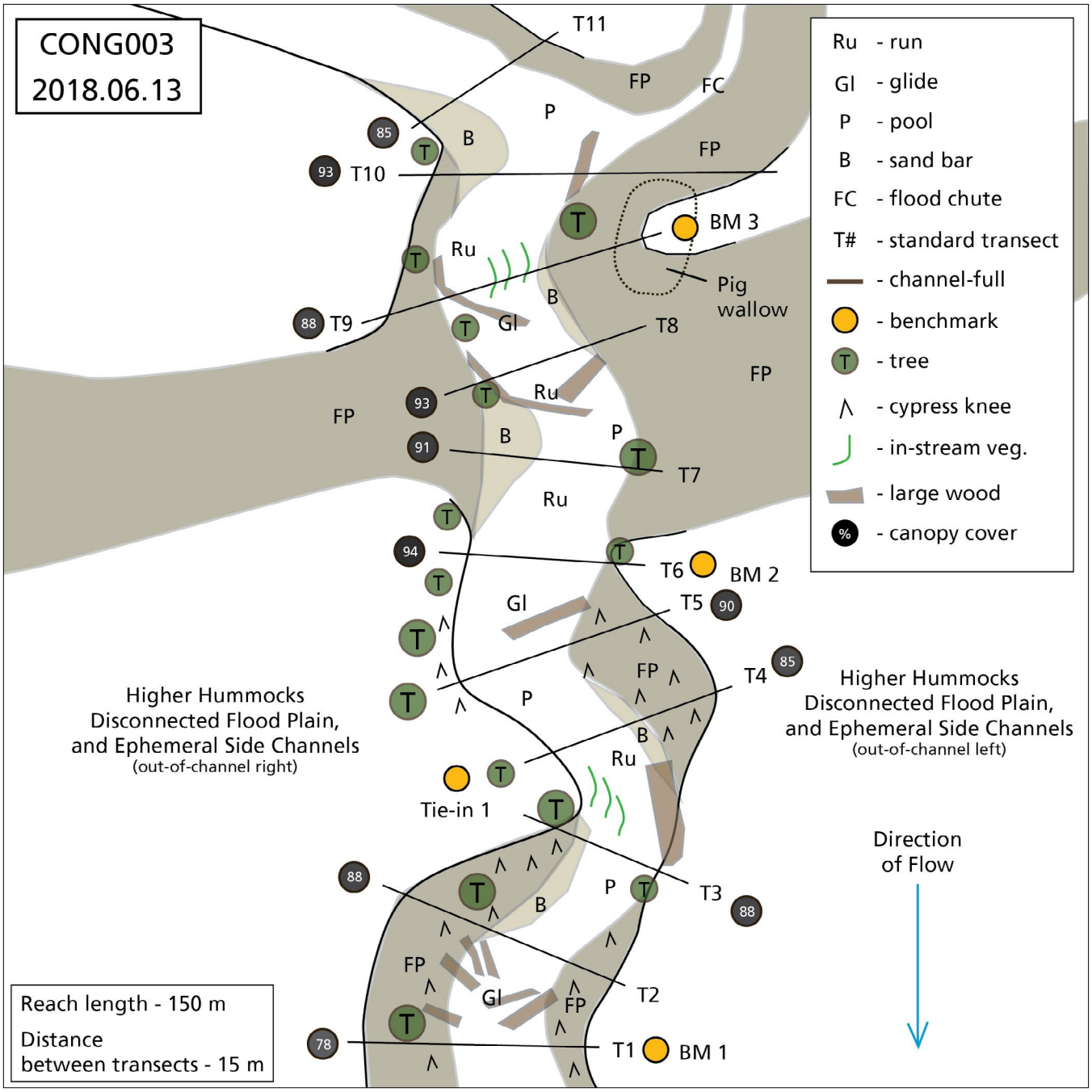


Figure 13. Reach-scale map of Cedar Creek downstream (CONG003). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Map is not drawn to scale.

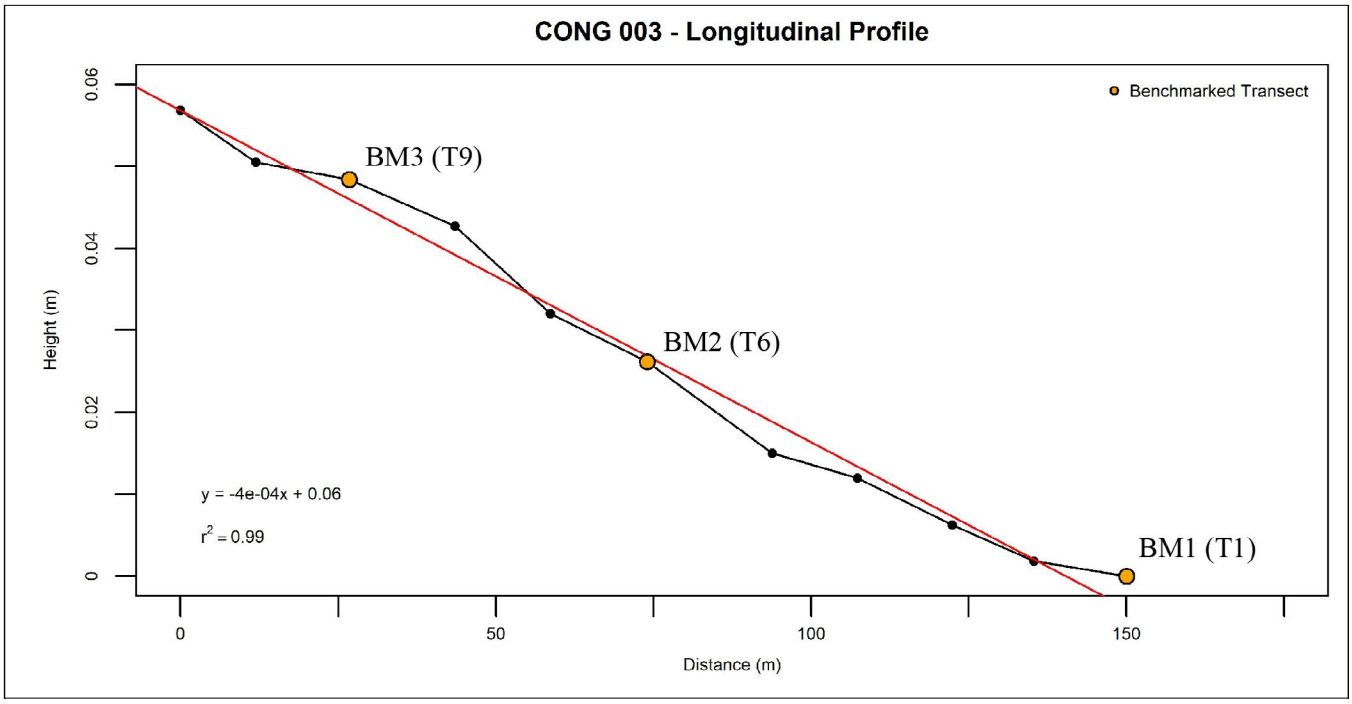


Figure 14. Longitudinal profile for Cedar Creek 'downstream' (CONG003). The red line on the graph corresponds to the interpreted slope of the reach. The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

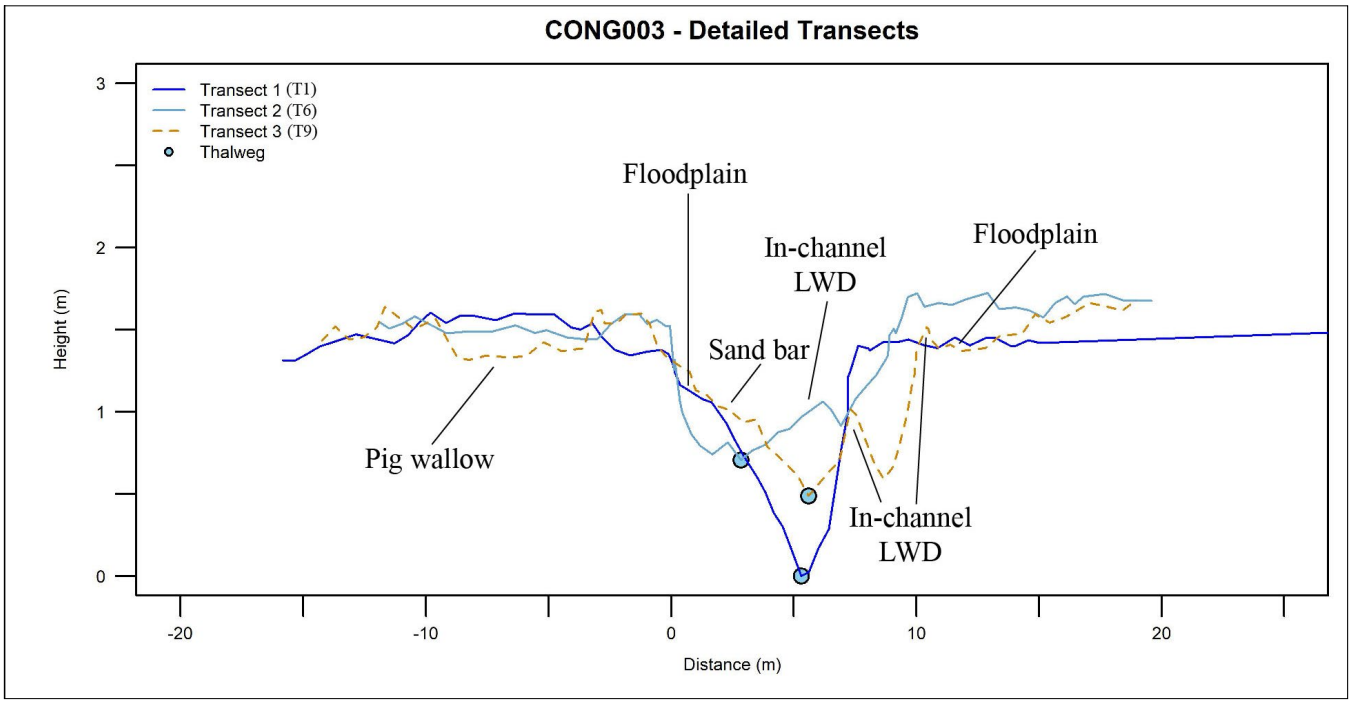


Figure 15. Comparison of the detailed transects at Cedar Creek 'downstream' (CONG003). The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed. View is in the downstream direction (river left is on the left side of the diagram).

CONG004—McKenzie Creek

McKenzie Creek is located in the northeastern portion of Congaree National Park. The reach that was surveyed is approximately 700 meters (2,296.59 ft) downstream of both a road and railroad bridge. Immediately downstream of the railroad bridge, McKenzie Creek flows through a multichannel, anastomosing section and is nearly stagnant upstream of the monitored reach. A relic gravel roadbed lies approximately 15 meters (49.21 ft) upstream of the monitored reach. McKenzie Creek is a straight, shallow, fine-bedded (silt-sand-organic) stream. Multiple flood chutes enter McKenzie Creek on river right (upstream of T3, T7, T9, and T10) and ephemeral side channels were observed in the out-of-channel areas on both sides of the stream (Figure 16). McKenzie Creek's channel is not entrenched, and flood plains were observed on both sides of the stream throughout the reach. In addition to the ephemeral side channels, higher hummocks were observed in the out-of-channel areas on both sides of the reach. The reach that was surveyed was 60 meters (196.85 ft) long, with 6 meters (19.69 ft) between transects. Within the reach, GCUs consisted mostly of runs and pools (Table 5). Water surface slope (longitudinal profile) for this section of McKenzie Creek was 0.004 m/m (Table 6; Figure 17). Reach slope was an order of magnitude higher at McKenzie Creek than the monitored reaches on Cedar Creek (range of 0.00025 m/m to 0.004 m/m; Table 6). The longitudinal profile shows that the reach has relatively a relatively large increase in slope between T6 and T8 (Figure 17). The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3). Bars were observed on each detailed transect (Figure 18). A relatively small sand bar was observed on river left along detailed transect 1 (T1), a larger sand bar was observed at mid-channel along detailed transect 2 (T6), and along detailed transect 3 (T11), a gravel bar was observed on river right. Flood chutes were observed in the out-of-channel areas along both sides of the stream at detailed transect 3 (T11). A flood chute was also observed in the out-of-channel area on river left on detailed transect 2 (T6). The majority of the LWD observed within the reach was in a jam at the step between T6 and T7. Though, not every piece of LWD in this jam could be measured because at least five venomous snakes were observed within the LWD jam during the survey. Transect-scale survey results for McKenzie Creek can be found in Appendix F.

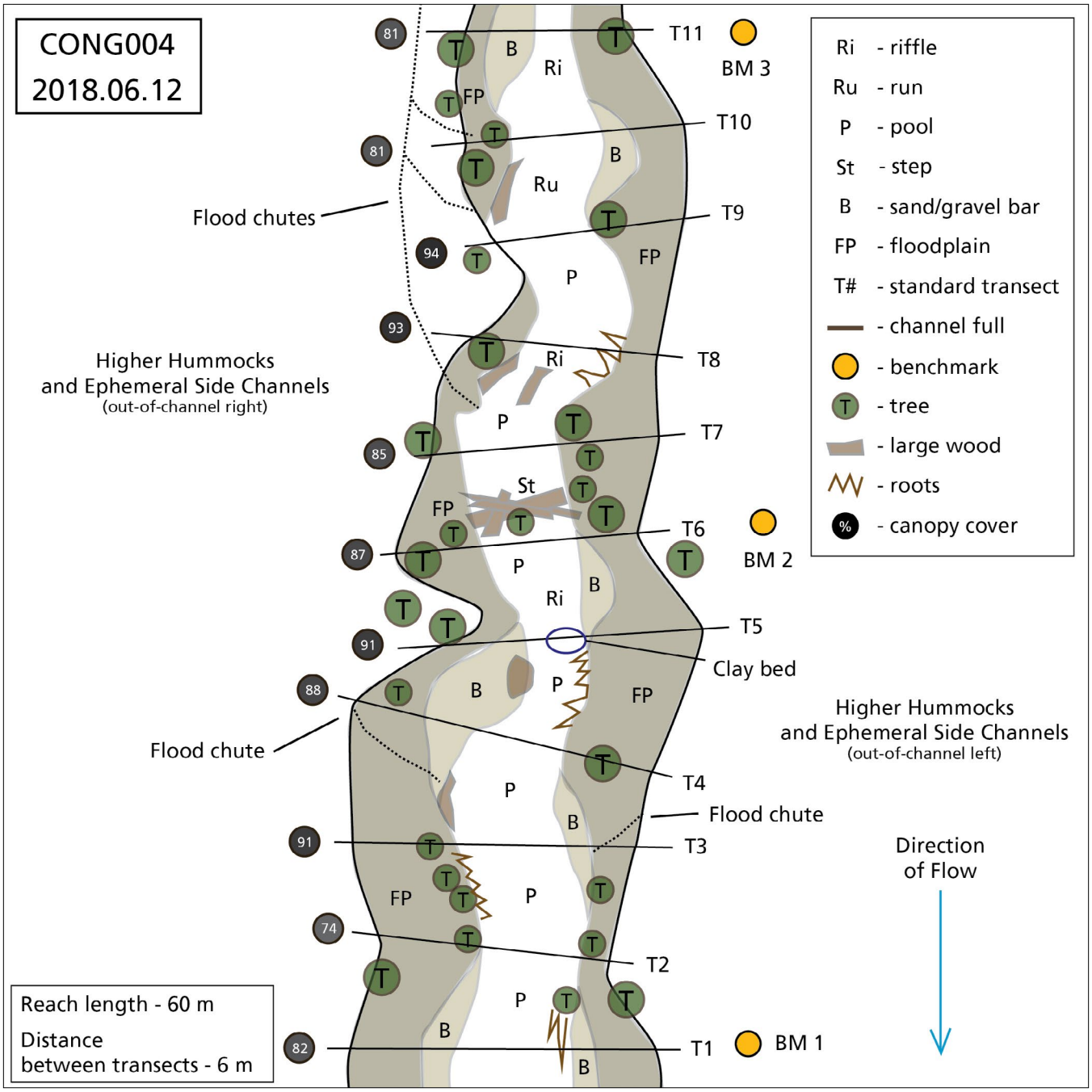


Figure 16. Reach-scale map of McKenzie Creek (CONG004). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Map is not drawn to scale.

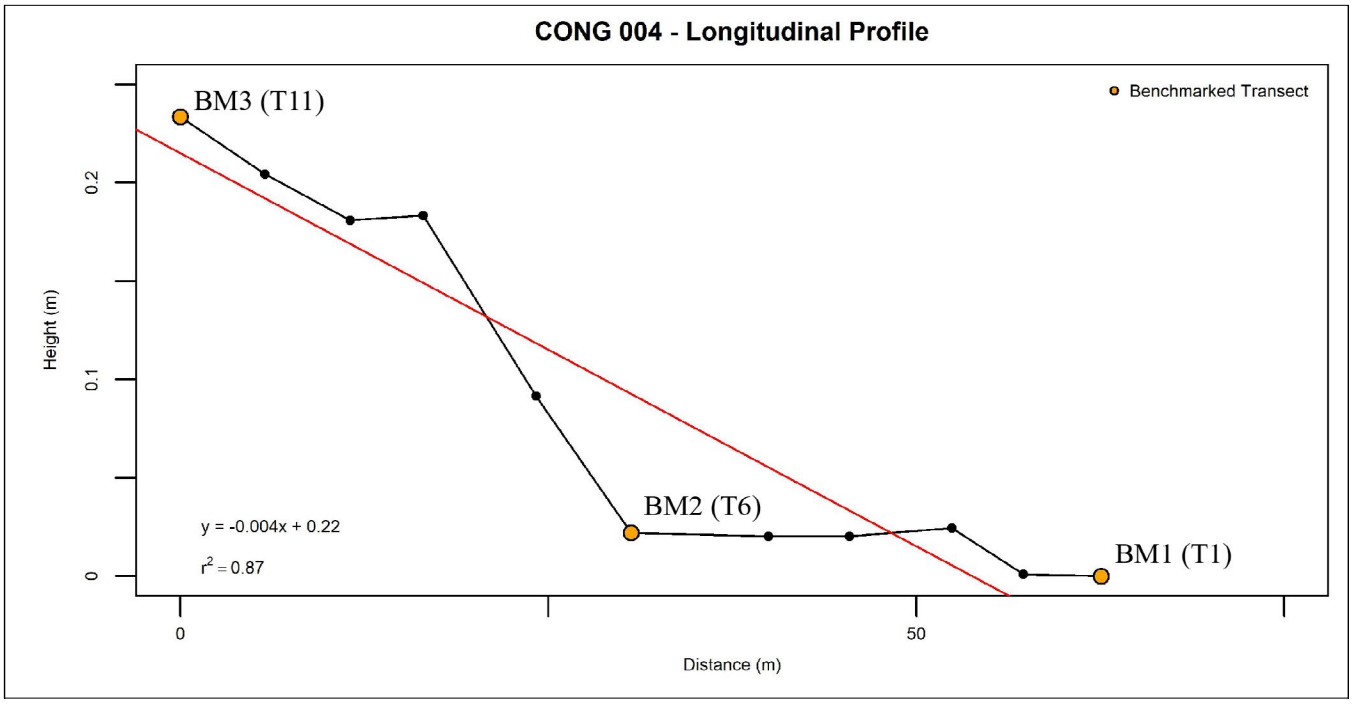


Figure 17. Longitudinal profile for McKenzie Creek (CONG004). The red line on the graph corresponds to the interpreted slope of the reach. The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

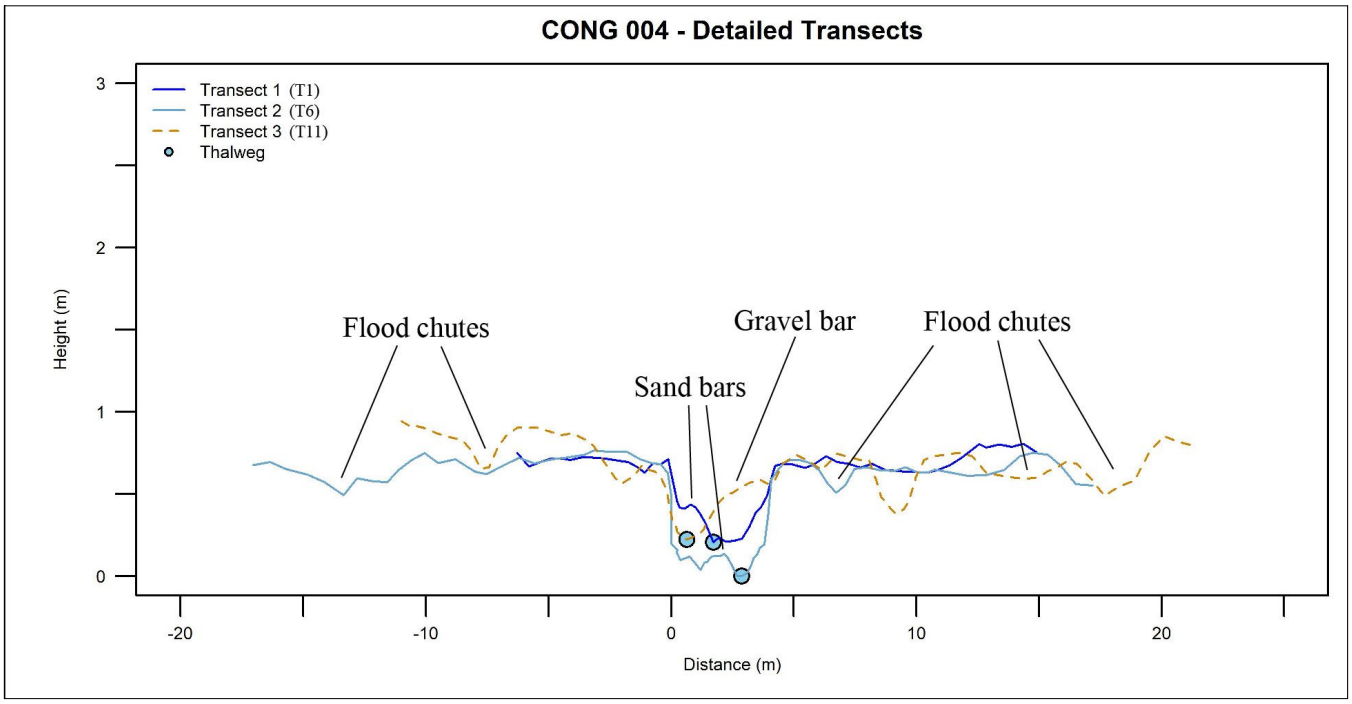


Figure 18. Comparison of the detailed transects at McKenzie Creek (CONG004). The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed. View is in the downstream direction (river left is on the left side of the diagram).

Habitat Characteristics

The geomorphic channel units (GCU) observed on the Cedar Creek reaches (CONG001–003) consisted of pools, runs and glides (Table 5; Figures 7, 10, and 13). Though the sites differed in the amount of the other GCUs, all three monitored reaches on Cedar Creek were pool dominant (range of 36% [CONG003] to 52% [CONG002]). Cedar Creek 'upstream' had equal percentages of run and glide (25%), while Cedar Creek 'middle' had more glide (38%) than run (10%). Cedar Creek 'downstream' had a more even GCU breakdown than the upstream sites with 36% pool, 34% run, and 30% glide. The GCU distributions on the Cedar Creek reaches were similar to the GCUs observed at Walnut Creek (OCMU001). The main difference between the Cedar Creek reaches and Walnut Creek was that Cedar Creek had more glide habitat (range of 25–38% compared to 10%) and Walnut Creek had more run habitat (61% compared to a range of 10–34%). Another difference between the Cedar Creek reaches and Walnut Creek is that no riffle habitat was observed at or near any of the Cedar Creek monitored reaches (so a pebble count could not be conducted on any of those reaches).

The GCUs at McKenzie Creek consisted of pools (71%), riffles (12%), runs (12%), and a step (6%; Table 5 and Figure 16). The step was created by a LWD jam between transects 6 and 7. As mentioned in the reach description, at least five venomous snakes were observed living in and around this LWD jam. Compared to Ward Creek (KEMO002) and Long Island Creek (CHAT014), McKenzie Creek was more similar to Ward Creek than Long Island Creek. The main difference between McKenzie Creek and Long Island Creek was the relatively high concentration of riffle habitat at Long Island Creek (46%) compared to McKenzie Creek (12%). No glide habitat was observed on McKenzie Creek.

Bed sediment was sandy throughout the surveyed reaches on Cedar Creek. Particle size distributions could not be quantified for the Cedar Creek reaches because none of the monitored reaches had a representative riffle on which to conduct a pebble count. McKenzie Creek contained mostly sandy sediments as well, though some gravel was observed within the reach. This coarser sediment appears to have been eroded from the relic roadbed located approximately 15 meters (49.21 ft) upstream of the reach. McKenzie Creek contained riffle habitat so a pebble count could be conducted (Table 7). The mean bed sediment particle size at McKenzie Creek (8.35 mm) was significantly coarser than the bed sediment on Walnut Creek (4.54 mm; p-value = 0.025; Tables 7 and 8). While the mean bed sediment particle size at McKenzie Creek was significantly finer than the bed sediment from the representative riffles on Ward Creek (12.56 mm; p-value = 0.015) and Long Island Creek (24.76 mm; p-value < 0.001; Tables 7 and 8).

Table 7. Comparison of the particle size distributions of bed sediment (in millimeters [mm]) from the pebble count pebble surveys conducted at McKenzie Creek (CONG004) and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The subscripts indicate the percent of the sample that is smaller than the reported diameter. No representative riffles were observed at Cedar Creek (CONG001–003).

Statistic	CONG004 (n=100)	OCMU001 (n=100)	KEMO002 (n=100)	CHAT013 (n=100)
Min	0.06	0.06	0.06	0.06
D_5	2.05	1.00	1.00	2.00
D_{16}	4.00	1.00	1.00	9.00
D_{50}	8.00	4.00	12.00	25.00
Mean	8.35	4.54	12.56	24.76
D_{84}	12.84	8.00	20.84	41.16
D_{95}	16.90	11.95	29.95	50.00
Max	21.00	21.00	57.00	65.00

Table 8. Significance of the differences in the pebble counts, thalweg depths, and thalweg positions based on a post-hoc Tukey analysis. The significance of the differences is indicated by: "–" not significant; "*" p-value < 0.05, "**" p-value < 0.01, and "***" p-value < 0.001. F-value and p-value of ANOVA results are reported as footnotes [mm—millimeters; m—meters].

Pairs	n[a]	Pebble Count (mm)[b]	P-value	Sig.	n[c]	Thalweg Depth (m)[d]	P-value	Sig.	n[e]	Thalweg Position (m)[f]	P-value	Sig.
CONG001 - CONG002	–	–	–	–	11	0.07	0.985	–	11	-0.15	0.888	–
CONG001 - CONG003	–	–	–	–	11	0.02	1.000	–	11	-0.29	0.254	–
CONG001 - CONG004	–	–	–	–	11	0.81	< 0.001	***	11	-0.21	0.603	–
CONG001 - OCMU001	–	–	–	–	11	0.58	< 0.001	***	11	-0.29	0.237	–
CONG001 - KEMO002	–	–	–	–	11	0.66	< 0.001	***	11	-0.16	0.840	–
CONG001 - CHAT013	–	–	–	–	11	0.71	< 0.001	***	11	-0.50	0.002	**
CONG002 - CONG003	–	–	–	–	11	-0.05	0.997	–	11	-0.14	0.926	–
CONG002 - CONG004	–	–	–	–	11	0.74	< 0.001	***	11	-0.06	0.999	–
CONG002 - OCMU001	–	–	–	–	11	0.51	< 0.001	***	11	-0.14	0.914	–
CONG002 - KEMO002	–	–	–	–	11	0.59	< 0.001	***	11	-0.01	1.000	–
CONG002 - CHAT013	–	–	–	–	11	0.64	< 0.001	***	11	-0.35	0.078	–
CONG003 - CONG004	–	–	–	–	11	0.79	< 0.001	***	11	0.07	0.997	–
CONG003 - OCMU001	–	–	–	–	11	0.56	< 0.001	***	11	0.00	1.000	–
CONG003 - KEMO002	–	–	–	–	11	0.64	< 0.001	***	11	0.12	0.955	–
CONG003 - CHAT013	–	–	–	–	11	0.69	< 0.001	***	11	-0.22	0.579	-
CONG004 - OCMU001	100	3.81	0.025	*	11	-0.23	0.144	–	11	-0.08	0.996	–
CONG004 - KEMO002	100	-4.04	0.015	*	11	-0.15	0.646	–	11	0.05	1.000	–
CONG004 - CHAT013	100	-16.41	< 0.001	***	11	-0.10	0.915	–	11	-0.29	0.237	–

[a] Number of measurements taken for pebble count.

[b] $F(5,100) = 84.73$, $p < 0.001$.

[c] number of measurements taken for thalweg depth.

[d] $F(8,11) = 31.88$, $p = < 0.001$.

[e] number of measurements taken for thalweg position.

[f] $F(8,11) = 3.17$, $p = 0.008$.

Many pieces of large woody debris (LWD) were recorded at the reaches on Cedar Creek (range of n = 26 to 41; Table 9). Cedar Creek 'middle' contained the most pieces of LWD (n = 41) and more were likely present in the reach but were hidden beneath the relatively deep black water. Nearly all measured LWD in the Cedar Creek reaches was buried in the sandy bed. Large woody debris per channel area decreased from Cedar Creek 'upstream' (0.0039 m^3/m^2) to 'middle' (0.0033 m^3/m^2) to 'downstream' (0.0023 m^3/m^2). Overall, the fifth order reaches (Cedar Creek 'upstream,' 'middle,' 'downstream,' and Walnut Creek) had similar LWD volume per channel area (OCMU001 = 0.0023 m^3/m^2; Table 9). McKenzie Creek had the fewest pieces of LWD (n = 9) and the lowest volume of LWD per channel area (0.0010 m^3/m^2). However, these numbers should be considered minimum values because the presence of venomous snakes limited the LWD data collection in the LWD jam where the majority of the LWD was found within the reach.

Table 9. Comparison of summary statistics for the large woody debris measured at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [m—meters].

Statistic	Site	n	Length (m)	Diameter (m)	Volume (m^3)
Mean	**CONG001[a]**	26	3.24	0.30	0.28
	CONG002[a]	41	3.51	0.21	0.18
	CONG003[a]	26	3.52	0.26	0.27
	OCMU001[a]	24	2.48	0.21	0.09
	CONG004[b]	9	1.93	0.23	0.11
	KEMO002[b]	25	3.89	0.19	0.13
	CHAT013[b]	30	2.94	0.21	0.15
Max	**CONG001[a]**	26	8.86	0.51	0.96
	CONG002[a]	41	13.68	0.49	2.03
	CONG003[a]	26	7.33	0.63	2.28
	OCMU001[a]	24	7.50	0.37	0.24
	CONG004[b]	9	4.43	0.63	0.45
	KEMO002[b]	25	9.59	0.47	0.48
	CHAT013[b]	30	7.17	0.46	0.82
Sum	**CONG001[a]**	26	–	–	7.18
	CONG002[a]	41	–	–	7.35
	CONG003[a]	26	–	–	6.94
	OCMU001[a]	24	–	–	2.10
	CONG004[b]	9	–	–	0.96
	KEMO002[b]	25	–	–	3.31
	CHAT013[b]	30	–	–	4.51
Per Channel Area (m^3/m^2)	**CONG001[a]**	–	–	–	0.0039
	CONG002[a]	–	–	–	0.0033
	CONG003[a]	–	–	–	0.0023
	OCMU001[a]	–	–	–	0.0023
	CONG004[b]	–	–	–	0.0010
	KEMO002[b]	–	–	–	0.0054
	CHAT013[b]	–	–	–	0.0019

[a] fifth order stream.

[b] third order stream.

Average canopy cover values were high at all monitored reaches (range of 85% at Ward Creek [KEMO002] to 93% at McKenzie Creek; Table 10), except for Walnut Creek (OCMU001; 58%). Cedar Creek 'upstream' had the lowest average canopy cover of any monitored reach at Congaree National Park (86%), while Cedar Creek 'middle' and 'downstream' had only slightly greater canopy cover (89% at both reaches). Again, except for Walnut Creek (CV = 0.44), canopy cover had little variance at all monitored reaches (CV range of 0.05 to 0.07).

Table 10. Descriptive statistics for reach-scale canopy cover at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [SD—standard deviation; CV—coefficient of variance].

Site	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
CONG001[a]	11	74	86	94	6	0.07
CONG002[a]	11	81	89	100	7	0.07
CONG003[a]	11	78	89	94	5	0.05
OCMU001[a]	11	16	58	85	25	0.44
CONG004[b]	11	82	93	100	5	0.06
KEMO002[b]	11	76	89	96	6	0.07
CHAT013[b]	11	75	85	93	6	0.07

[a] fifth order stream.

[b] third order stream.

Average thalweg depths at the Cedar Creek reaches ranged from 0.91 meters (2.99 ft) at Cedar Creek 'middle' to 0.98 meters (3.22 ft) at Cedar Creek 'upstream' (Table 11). The differences in average thalweg depth between the Cedar Creek reaches were not statistically significant. Variability in thalweg depth at Cedar Creek 'middle' (CV = 0.23; Table 11) was less than at both Cedar Creek 'upstream' (CV = 0.32) and 'downstream' (CV = 0.31). The monitored reaches on Cedar Creek were all significantly deeper than the other monitored reaches (p-values < 0.001; Table 8). McKenzie Creek had the shallowest average thalweg depth (0.17 meters [0.56 ft]; Table 11). The difference in thalweg depth between McKenzie Creek and the other monitored reaches was only statistically significant when compared to the Cedar Creek reaches (p-values < 0.001; Table 8). Variance in thalweg position on Cedar Creek was greatest at Cedar Creek 'upstream' (CV = 0.94) and decreased downstream (CV = 0.82 at Cedar Creek 'middle' and CV = 0.55 at Cedar Creek 'downstream'; Table 11). Thalweg position at Cedar Creek 'upstream' was more variable than at any other monitored reach. Variance in thalweg position at McKenzie Creek (CV = 0.37) was less than that of the Cedar Creek reaches, and only Long Island Creek (CHAT013; CV = 0.26) had less variability in thalweg position.

Table 11. Reach-scale averaged thalweg conditions at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [SD—standard deviation; CV—coefficient of variance].

Thalweg	Site	n	Min	Mean	Max	SD	CV
Depth (m)	CONG001[a]	11	0.50	0.98	1.40	0.31	0.32
	CONG002[a]	11	0.52	0.91	1.25	0.21	0.23
	CONG003[a]	11	0.53	0.96	1.41	0.30	0.31
	OCMU001[a]	11	0.21	0.40	0.66	0.14	0.35
	CONG004[b]	11	0.05	0.17	0.38	0.09	0.56
	KEMO002[b]	11	0.09	0.32	0.49	0.13	0.42
	CHAT013[b]	11	0.14	0.27	0.77	0.19	0.70
Position[c] (%)	CONG001[a]	11	10	26	95	29	0.94
	CONG002[a]	11	5	41	95	34	0.82
	CONG003[a]	11	15	55	95	31	0.55
	OCMU001[a]	11	5	55	95	35	0.63
	CONG004[b]	11	20	48	75	18	0.37
	KEMO002[b]	11	5	43	90	36	0.84
	CHAT013[b]	11	30	77	95	20	0.26

[a] fifth order stream.

[b] third order stream.

[c] position is percent distance from left active channel bank.

Channel Morphology

Average wetted widths of the Cedar Creek reaches ranged from 7.30 meters (23.95 ft) at Cedar Creek 'upstream' to 8.97 meters (29.43 ft) at Cedar Creek 'middle' (Table 12). The differences between the average wetted widths at the Cedar Creek reaches were not statistically significant (Table 13). Average wetted widths at the Cedar Creek reaches were significantly wider than McKenzie Creek (1.91 meters [6.27 ft]; p-values < 0.001) and Ward Creek (KEMO002; 4.37 meters [14.34 ft]; p-value < 0.001; Tables 12 and 13). Cedar Creek 'middle' also had an average wetted width (8.97 meters [29.43 ft]) that was significantly wider than at Long Island Creek (CHAT013; 6.68 meters [21.92 ft]; p-value = 0.008). Differences in the average wetted widths of the Cedar Creek sites and those of Walnut Creek (OCMU001; 7.20 meters [23.62 ft]) were not statistically significant. In addition to the Cedar Creek reaches, McKenzie Creek's average wetted width was significantly narrower than Walnut Creek (p-value < 0.001), Ward Creek (p-value = 0.003), and Long Island Creek (p-value < 0.001; Table 13).

Table 12. Reach-scale averaged width characteristics of Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [m—meters; SD—standard deviation; CV—coefficient of variance].

Width	Site	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Wetted	CONG001[a]	11	5.47	7.30	11.39	1.89	0.26
	CONG002[a]	11	7.31	8.97	10.30	1.20	0.13
	CONG003[a]	11	5.86	8.02	10.94	1.49	0.19
	OCMU001[a]	11	5.82	7.20	8.67	0.98	0.14
	CONG004[b]	11	1.08	1.91	2.47	0.41	0.21
	KEMO002[b]	11	2.48	4.37	6.11	1.20	0.27
	CHAT013[b]	11	3.27	6.68	9.30	2.27	0.34
Active Channel	CONG001[a]	11	6.71	8.64	12.11	1.74	0.20
	CONG002[a]	11	7.77	10.97	20.25	3.66	0.33
	CONG003[a]	11	7.09	9.26	12.24	1.69	0.18
	OCMU001[a]	11	5.82	8.41	11.16	1.37	0.16
	CONG004[b]	11	2.18	3.34	4.12	0.68	0.21
	KEMO002[b]	11	3.33	5.40	7.36	1.52	0.28
	CHAT013[b]	11	6.35	8.95	14.00	2.27	0.25
Bankfull	CONG001[a]	6	7.26	8.85	10.14	0.98	0.11
	CONG002[a]	11	9.70	12.89	21.33	3.61	0.28
	CONG003[a]	11	8.04	13.13	24.63	5.39	0.41
	OCMU001[a]	9	7.21	10.98	13.25	1.84	0.17
	CONG004[b]	11	3.78	5.02	7.82	1.12	0.22
	KEMO002[b]	7	4.86	6.00	7.49	0.97	0.16
	CHAT013[b]	3	10.55	11.09	11.75	0.61	0.05
Channel-Full	CONG001[a]	11	8.74	12.25	14.55	1.96	0.16
	CONG002[a,c]	1	–	24.42	–	–	–
	CONG003[a,c]	9	10.78	19.75	27.50	6.39	0.32
	OCMU001[a]	11	10.45	18.27	23.01	4.62	0.25
	CONG004[b]	11	5.64	16.24	21.55	4.31	0.27
	KEMO002[b]	11	7.36	8.75	9.55	0.81	0.09
	CHAT013[b]	11	10.46	14.77	26.65	4.44	0.30

[a] fifth order stream.

[b] third order stream.

[c] all other transects had an estimated channel-full width greater than 30 meters (98.4 ft).

Table 13. Significance of the differences in the wetted widths, active channel widths, and channel-full widths based on a post-hoc Tukey analysis. The significance of the differences is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001. F-value and p-value of ANOVA results are reported as footnotes.

Pairs	n[a]	Wetted Width (m)[b]	P-value	Sig.	n[c]	Active Channel Width (m)[d]	P-value	Sig.	n[e]	Channel-full Width (m)[f]	P-value	Sig.
CONG001 - CONG002	11	-1.67	0.117	–	11	-2.34	0.117	–	11	-0.92	0.998	–
CONG001 - CONG003	11	-0.71	0.911	–	11	-0.62	0.992	–	11	-8.09	< 0.001	***
CONG001 - CONG004	11	5.39	< 0.001	***	11	5.30	< 0.001	***	11	-3.99	0.269	–
CONG001 - OCMU001	11	0.10	1.000	–	11	0.23	1.000	–	11	-6.02	0.017	*
CONG001 - KEMO002	11	2.93	< 0.001	***	11	3.24	0.007	**	11	3.51	0.423	–
CONG001 - CHAT013	11	0.62	0.953	–	11	-0.31	1.000	–	11	2.52	0.780	–
CONG002 - CONG003	11	0.96	0.721	–	11	1.72	0.438	–	11	-7.17	0.002	**
CONG002 - CONG004	11	7.06	< 0.001	***	11	7.64	< 0.001	***	11	-3.07	0.584	–
CONG002 - OCMU001	11	1.78	0.079	–	11	2.57	0.062	–	11	-5.10	0.069	–
CONG002 - KEMO002	11	4.60	< 0.001	***	11	5.57	< 0.001	***	11	4.43	0.165	–
CONG002 - CHAT013	11	2.29	0.008	**	11	2.02	0.247	–	11	1.59	0.970	–
CONG003 - CONG004	11	6.10	< 0.001	***	11	5.92	< 0.001	***	11	4.10	0.241	–
CONG003 - OCMU001	11	0.82	0.843	–	11	0.85	0.958	–	11	2.07	0.898	–
CONG003 - KEMO002	11	3.64	< 0.001	***	11	3.85	< 0.001	***	11	11.60	< 0.001	***
CONG003 - CHAT013	11	1.34	0.340	–	11	0.30	1.000	–	11	5.57	0.034	*
CONG004 - OCMU001	11	-5.29	< 0.001	***	11	-5.07	< 0.001	***	11	-2.03	0.908	–
CONG004 - KEMO002	11	-2.46	0.003	**	11	-2.07	0.224	–	11	7.50	0.001	***
CONG004 - CHAT013	11	-4.77	< 0.001	***	11	-5.62	< 0.001	***	11	1.48	0.979	–

[a] number of wetted width measurements taken.

[b] $F(5,100) = 84.73$, $p < 0.001$.

[c] number of active channel width measurements taken.

[d] $F(8,11) = 31.88$, $p = < 0.001$.

[e] number of channel-ful width measurements taken.

[f] $F(8,11) = 3.17$, $p = 0.008$.

Average active channel widths of the monitored reaches at Congaree National Park ranged from 3.34 meters (10.96 ft) at McKenzie Creek to 10.97 meters (35.99 ft) at Cedar Creek 'middle' (Table 12). Of the reaches on Cedar Creek, Cedar Creek 'upstream' had the narrowest average active channel width (8.64 meters [28.35 ft]), Cedar Creek 'middle' had the widest (10.97 meters [35.99 ft]), and Cedar Creek 'downstream' fell in between (9.26 meters [30.38 ft]). The differences between the average active channel widths of the Cedar Creek reaches were not statistically significant (Table 13). However, average active channel widths of the Cedar Creek reaches were significantly wider than McKenzie Creek (p-values <0.001) and Ward Creek (KEMO002; 5.40 meters [17.72 ft]; p-values < 0.001). The average active channel width of McKenzie Creek was also significantly narrower than Walnut Creek (OCUM001; 8.41 meters [27.59 ft]; p-value < 0.001) and Long Island Creek (CHAT013; 8.95 meters [29.36 ft]; p-value < 0.001). Active channel widths were most variable at Cedar Creek 'middle' (CV = 0.33) and least variable at Cedar Creek 'downstream' (CV = 0.18; Table 12). Only the active channel width of Walnut Creek was less variable (CV = 0.16) that at Cedar Creek 'downstream.'

Average bankfull width was widest at Cedar Creek 'downstream' (13.13 meters [43.08 ft]; Table 12) and narrowest at McKenzie Creek (5.02 meters [16.47 ft]). Flood plain surfaces were observed on each transect at all the CONG monitored reaches (n = 11 for each) except for Cedar Creek 'upstream' (n = 6). Average bankfull width at the Cedar Creek reaches increased downstream from 8.85 meters (29.04 ft; 'upstream'), to 12.89 meters (42.29 ft; 'middle'), to 13.13 meters (43.08 ft; 'downstream'). Cedar Creek 'downstream' had the widest average bankfull width of any monitored reach and its bankfull widths were also most the variable (CV = 0.41 compare to a range of CV = 0.05 [CHAT013] to 0.28 [Cedar Creek 'middle']). Average bankfull widths of the monitored reaches on Cedar Creek were similar to the average bankfull widths of both Walnut Creek (OCMU001; 10.98 meters [36.02 ft]) and Long Island Creek (CHAT013; 11.09 meters [36.38 ft]). McKenzie Creek had the narrowest average bankfull width (5.02 meters [16.47 ft]) and only Ward Creek (KEMO002) had a similarly narrow average bankfull width (6.00 meters [19.69 ft]; Table 12).

Average channel-full width at the Cedar Creek reaches that lie within the Congaree River flood plain (Cedar Creek 'middle' and 'downstream'; 12.89 meters [42.29 ft] and 13.13 meters [43.08 ft], respectively) were far wider that of Cedar Creek 'upstream' (12.12 meters [39.76 ft]; Table 12). In fact, the actual channel-full widths of the Congaree River flood plain reaches were much wider. Ten transects on Cedar Creek 'middle' and two transects on Cedar Creek 'downstream' had channel-full widths that were too wide to be measured in the field (> 30 meters [98.42 ft]). In order to conduct statistical comparisons of average channel-full widths, bankfull width measurements were substituted in for channel-full widths when needed. Using the augmented data set, average channel-full width at Cedar Creek 'upstream' was significantly narrower than both Cedar Creek 'downstream' (19.75 meters [64.80 ft]; p-value < 0.001) and Walnut Creek (18.27 meters [59.94 ft]; p-value = 0.017; Table 13). The difference in average channel-full widths at Cedar Creek 'upstream' (12.25 meters [40.19 ft]) and Cedar Creek 'middle' (12.89 meters [42.29 ft]) was not significant (p-value = 0.117; Tables 12 and 13). The augmented average channel-full width at Cedar Creek 'middle' was significantly narrower than the augmented average channel-full width at Cedar Creek 'downstream' (p-value = 0.002; Table 13). Average channel-full width at Cedar Creek 'downstream' was significantly wider than all other sites (p-values range from < 0.001 to 0.034), except McKenzie Creek (p-value = 0.241) and Walnut Creek (OCMU001; p-value = 0.898; Table 13). Average channel-full width at McKenzie Creek was significantly wider than Ward Creek (KEMO002; p-value = 0.001).

Average minimum bank heights at Congaree National Park ranged from 0.65 meters (2.13 ft) at McKenzie Creek to 2.02 meters (6.63 ft) at Cedar Creek 'upstream' (Table 14). Only Long Island Creek (CHAT013) had a higher average minimum bank height (2.15 meters [7.05 ft]) than Cedar Creek 'upstream.' Average minimum bank height at the Cedar Creek reaches decreased downstream, measuring 2.02 meters (6.63 ft) at Cedar Creek 'upstream', 1.43 meters (4.69 ft) at Cedar Creek 'middle,' and 1.32 meters (4.33 ft) at Cedar Creek 'downstream.' Variability in average minimum bank heights was low at Cedar Creek 'middle' (CV = 0.16) relative to the other CONG reaches (CV range: 0.22 to 0.25; Table 14). Average bankfull heights at Congaree National Park ranged from 0.64 meters (2.10 ft) at McKenzie Creek to 1.60 meters (5.25 ft) at Cedar Creek 'upstream.' Average bankfull height at the Cedar Creek reaches also decreased downstream, measuring 1.60 meters (5.25 ft) at Cedar Creek 'upstream,' 1.39 meters (4.56 ft) at Cedar Creek 'middle,' and 1.31 meters (4.30 ft) at Cedar Creek 'downstream.' Variability in bankfull heights was again low at Cedar Creek 'middle' (CV = 0.16) when compared to the other CONG reaches (CV range: 0.21 to 0.25; Table 14). Average channel-full height ranged from 0.74 meters (2.43 ft) at McKenzie Creek to 2.10 meters (6.89 ft) at Cedar Creek 'upstream.' Similar to the other bank heights, average channel-full height at the Cedar

Creek reaches decreased downstream, measuring 2.10 meters (6.89 ft) at Cedar Creek 'upstream,' 1.63 meters (5.35 ft) at Cedar Creek 'middle,' and 1.31 meters (4.30 ft) at Cedar Creek 'downstream.' Average channel-full height at Cedar Creek 'upstream' was significantly higher than all of the other CONG reaches (p-values < 0.001), Walnut Creek (OCMU001; p-value <0.001), and Long Island Creek (CHAT014; p-value = 0.024; Table 15). Average channel-full height at Cedar Creek 'middle' and 'downstream' were significantly higher than McKenzie Creek (p-value < 0.001) and significantly lower than Ward Creek (KEMO002; p-values < 0.001). Average channel-full height at Cedar Creek 'downstream' was also significantly lower than at Long Island Creek (CHAT013; p-value = 0.038). Average channel-full height at McKenzie Creek was significantly lower than all other reaches (p-values < 0.001 for all Cedar Creek reaches, Ward Creek, and Long Island Creek; p-value = 0.006 for Walnut Creek). Variability in channel-full heights was lowest at Cedar Creek 'middle' (CV = 0.09) and Walnut Creek (CV = 0.09), and highest at Cedar Creek 'downstream' (CV = 0.23; Table 14).

Table 14. Comparisons of average reach-scale bank characteristics at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [m—meters; SD—standard deviation; CV—coefficient of variance].

Bank	Site	n	Min	Mean	Max	SD	CV
Minimum Bank Height[a,b] (m)	**CONG001[d]**	22	1.10	2.02	3.23	0.51	0.25
	CONG002[d]	22	0.88	1.43	1.85	0.24	0.16
	CONG003[d]	22	0.78	1.32	1.80	0.32	0.24
	OCMU001[d]	22	0.77	1.28	1.88	0.31	0.25
	CONG004[e]	22	0.32	0.65	1.00	0.14	0.22
	KEMO002[e]	22	0.34	1.44	2.20	0.57	0.40
	CHAT013[e]	22	0.47	2.15	2.99	0.65	0.30
Bankfull Height[a,c] (m)	**CONG001[d]**	6	1.10	1.60	2.16	0.40	0.25
	CONG002[d]	18	0.88	1.39	1.78	0.22	0.16
	CONG003[d]	17	0.78	1.31	1.80	0.33	0.25
	OCMU001[d]	12	0.77	1.04	1.32	0.14	0.17
	CONG004[e]	21	0.32	0.64	1.00	0.14	0.21
	KEMO002[e]	7	0.34	0.75	1.02	0.23	0.31
	CHAT013[e]	3	0.47	0.74	1.19	0.39	0.54
Channel-full Height[a] (m)	**CONG001[d]**	22	1.39	2.10	3.23	0.46	0.22
	CONG002[d]	6	1.38	1.63	1.85	0.15	0.09
	CONG003[d]	18	0.88	1.31	1.75	0.31	0.23
	OCMU001[d]	22	1.28	1.56	1.88	0.14	0.09
	CONG004[e]	22	0.39	0.74	1.11	0.15	0.20
	KEMO002[e]	22	0.96	1.72	2.20	0.36	0.21
	CHAT013[e]	22	1.96	2.37	2.99	0.29	0.12

[a] above thalweg.

[b] this height refers to the lowest bank height on either side (bankfull or channel-full).

[c] statistics are based on the transects where feature is present (# in parentheses).

[d] fifth order stream.

[e] third order stream.

Table 15. Significance of the differences of the channel-full heights, bank angles, and vegetative cover based on a post-hoc Tukey analysis. The significance of the differences is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001. F-value and p-value of ANOVA results are reported as footnotes.

Pairs	n[a]	Channel-full Height (m)[b]	P-value	Sig.	n[c]	Bank Angle (°)[d]	P-value	Sig.	n[e]	Vegetative Cover (%)[f]	P-value	Sig.
CONG001 - CONG002	22	0.65	< 0.001	***	22	6.43	0.979	–	22	-0.23	1.000	–
CONG001 - CONG003	22	0.73	< 0.001	***	22	9.90	0.845	–	22	-0.23	1.000	–
CONG001 - CONG004	22	1.36	< 0.001	***	22	7.28	0.961	–	22	7.73	0.968	–
CONG001 - OCMU001	22	0.94	< 0.001	***	22	6.30	0.981	–	22	-3.64	0.999	–
CONG001 - KEMO002	22	-0.27	0.263	–	22	-0.91	1.000	–	22	35.91	< 0.001	***
CONG001 - CHAT013	22	0.38	0.024	*	22	-4.45	0.997	–	22	19.77	0.218	–
CONG002 - CONG003	22	0.08	0.998	–	22	3.46	0.999	–	22	0.00	1.000	–
CONG002 - CONG004	22	0.71	< 0.001	***	22	0.85	1.000	–	22	7.95	0.963	–
CONG002 - OCMU001	22	0.29	0.202	–	22	-0.13	1.000	–	22	-3.41	1.000	–
CONG002 - KEMO002	22	-0.92	< 0.001	***	22	-7.35	0.959	–	22	36.14	< 0.001	***
CONG002 - CHAT013	22	-0.27	0.251	–	22	-10.89	0.777	–	22	20.00	0.206	–
CONG003 - CONG004	22	0.62	< 0.001	***	22	-2.61	1.000	–	22	7.95	0.963	–
CONG003 - OCMU001	22	0.20	0.666	–	22	-3.60	0.999	–	22	-3.41	1.000	–
CONG003 - KEMO002	22	-1.01	< 0.001	***	22	-10.81	0.783	–	22	36.14	< 0.001	***
CONG003 - CHAT013	22	-0.36	0.038	*	22	-14.35	0.482	–	22	20.00	0.206	–
CONG004 - OCMU001	22	-0.42	0.006	**	22	-0.98	1.000	–	22	-11.36	0.820	–
CONG004 - KEMO002	22	-1.63	< 0.001	***	22	-8.20	0.931	–	22	28.18	0.016	*
CONG004 - CHAT013	22	-0.98	< 0.001	***	22	-11.74	0.710	–	22	12.05	0.776	–

[a] number of channel-full height measurements taken.

[b] $F(8,22) = 75.35$, $p < 0.001$.

[c] number of bank angle measurements taken.

[d] $F(8,22) = 0.98$, $p = 0.44$.

[e] number of vegetative cover measurements taken.

[f] $F(8,22) = 6.01$, $p < 0.001$.

All of the monitored reaches at Congaree National Park had at least one undercut bank. Cedar Creek 'upstream' had the most undercut banks (n = 3), Cedar Creek 'middle' had two, and one undercut was measured at Cedar Creek 'downstream' (Table 16). Two undercuts were observed on McKenzie Creek. The number of undercut banks observed at each CONG site was close to Walnut Creek (OCMU001; n = 2) and Ward Creek (KEMO002; n = 2) but less than at Long Island Creek (CHAT013; n = 7). The average depth of the undercuts measured on the CONG reaches ranged from 0.13 meters (0.43 ft) at McKenzie Creek to 0.74 meters (2.43 ft) at Cedar Creek 'middle' (Table 16). On average, Cedar Creek 'upstream' also had relatively deep undercuts (0.52 meters [1.71 ft]). Only Walnut Creek had a shallower average undercut depth (0.10 meters [0.33 ft]) than McKenzie Creek. Average bank angles of the monitored reaches on Cedar Creek were all within 10° of each other and decreased downstream measuring 55°, 49°, and 45°, respectively (Table 16). Differences between average bank angles on all reaches were not statistically significant (Table 15). Variability in bank angles increased from Cedar Creek 'upstream' (CV = 0.42) to Cedar Creek 'middle' (CV = 0.50) to Cedar Creek 'downstream' (CV = 0.64). Average bank vegetation cover of the monitored reaches at Congaree National Park ranged from 46% at McKenzie Creek to 54% at both Cedar Creek 'upstream' and 'middle.' Walnut Creek (OCMU001) had more average bank vegetation cover (58%) than the CONG reaches and both Ward Creek (KEMO002) and Long Island Creek (CHAT013) had less (18% and 34%, respectively; Table 16). Average bank vegetation cover at Ward Creek was significantly lower than all of the Cedar Creek reaches (p-values > 0.001) as well as McKenzie Creek (p-value = 0.016; Table 15).

Table 16. Continuation of comparisons of average reach-scale bank characteristics at Cedar Creek (CONG001–003), McKenzie Creek (CONG004), and fifth and third order sites at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA. The sites in bold are the focus of this report [m—meters; SD—standard deviation; CV—coefficient of variance].

Bank Characteristics	Site	n	Min	Mean	Max	SD	CV
Bank Undercut[a] (m)	**CONG001[c]**	3	0.41	0.52	0.59	0.09	0.18
	CONG002[c]	2	0.30	0.74	1.17	0.62	0.84
	CONG003[c]	1	–	0.17	–	–	–
	OCMU001[c]	2	0.05	0.10	0.14	0.06	0.67
	CONG004[d]	2	0.11	0.13	0.14	0.02	0.17
	KEMO002[d]	2	0.37	0.44	0.51	0.10	0.22
	CHAT013[d]	7	0.09	0.21	0.54	0.15	0.71
Bank Angle (°)	**CONG001[c]**	22	13	55	90	23	0.42
	CONG002[c]	22	21	49	90	24	0.50
	CONG003[c]	22	3	45	90	29	0.64
	OCMU001[c]	22	23	49	85	20	0.41
	CONG004[d]	22	3	48	82	23	0.47
	KEMO002[d]	22	9	56	90	27	0.48
	CHAT013[d]	22	6	60	88	27	0.46
Vegetation Cover (%)	**CONG001[c]**	22	5	54	100	31	0.57
	CONG002[c]	22	5	54	100	33	0.61
	CONG003[c]	22	5	51	90	29	0.54
	OCMU001[c]	22	10	58	100	30	0.51
	CONG004[d]	22	5	46	90	30	0.65
	KEMO002[d]	22	0	18	50	18	0.99
	CHAT013[d]	22	0	34	60	19	0.54
Bank Stability[b]	**CONG001[c]**	22	13	15	17	1	0.09
	CONG002[a,c]	22	11	13	15	1	0.10
	CONG003[a,c]	22	6	11	15	2	0.22
	OCMU001[c]	22	9	12	15	2	0.15
	CONG004[d]	22	11	12	16	1	0.11
	KEMO002[d]	22	12	14	16	1	0.09
	CHAT013[d]	22	9	14	18	3	0.18

[a] statistics are based on the transects where feature is present (# in parentheses).

[b] bank stability score rankings: 4–7 stable; 8–10 at-risk; 11–15 unstable; and 16–22 very unstable.

[c] fifth order stream.

[d] third order stream.

The minimum bank stability score (most stable; see Table 1 for an explanation of the scores) at Cedar Creek 'downstream' was 'stable' while all the other CONG reaches had a minimum score of 'unstable' (Table 16). The maximum bank stability score (most unstable) on both Cedar Creek 'upstream' and McKenzie Creek was 'very unstable.' The maximum bank stability score (most unstable) at Cedar Creek 'middle' and 'downstream' was 'unstable.' On average, the banks at all of the monitored reaches compared in this report were rated as 'unstable'; though, average bank stability scores for the monitored reaches on Cedar Creek decrease (banks become more stable) downstream. Average bank stability score at Cedar Creek 'upstream' was 15, which is only one point less than a 'very-unstable' rating. Cedar Creek 'middle' had an average bank stability score of 13, which ranks as 'unstable,' while Cedar Creek 'downstream' had an average bank stability score of 11, which is only one point more than an 'at-risk' rating. Bank stability scores were most variable at Cedar Creek 'downstream' (CV = 0.22), while bank stability scores at Cedar Creek 'upstream' were least variable (CV = 0.09).

Channel slopes of the Cedar Creek reaches were the gentlest of the monitored reaches and ranged from 0.00025 m/m at Cedar Creek 'middle' to 0.00040 m/m at Cedar Creek 'downstream' (Table 6). McKenzie Creek had the steepest channel slope (0.004 m/m) of the CONG reaches and was similar to the slope measured at Long Island Creek (CHAT013; 0.00447 m/m). Channel slope at Walnut Creek (OCMU001; 0.00182 m/m) and Ward Creek (KEMO002; 0.00197) was steeper than at Cedar Creek but gentler than McKenzie and Long Island Creeks. Reach sinuosity was greatest at Cedar Creek 'upstream' (1.74) and least at McKenzie Creek (1.03; Table 6). Bankfull area ranged from 0.97 square meters (10.44 square feet [ft^2] at McKenzie Creek to 10.68 square meters (114.96 ft^2) at Cedar Creek 'upstream.' Bankfull area on the Cedar Creek reaches decreased downstream. Bankfull heights of the Cedar Creek reaches were higher than of any other reaches compared in this report, with Cedar Creek 'upstream' having the highest bankfull height (1.58 meters [5.18 ft]). Bankfull height at McKenzie Creek was the lowest of all reaches compared in this report (0.36 meters [1.18 ft]). Channel-full area ranged from 3.01 square meters (32.40 ft^2) at McKenzie Creek to 12.88 square meters (138.64 ft^2) at Cedar Creek 'upstream.' Similar to bankfull area, channel-full area on the Cedar Creek reaches decreased downstream. Channel-full area at McKenzie Creek was at least 4 square meters (43.05 ft^2) smaller than at any other reach included in this report.

Implications and Synthesis of Results

This section describes the processes that were observed on each reach and the potential changes that may occur between surveys (next field surveys are tentatively scheduled for spring or summer 2022). The described processes are explained within the context of the objectives of the protocol (i.e., basin characteristics that affect channel morphology and habitat, and the status of channel morphology and habitat characteristics at each reach). The descriptors of watershed-scale variables (e.g., low, average, high) are in comparison to the other watersheds in the report (i.e., Cedar Creek 'upstream' is compared to the other fifth order streams).

Cedar Creek Watershed

All three Cedar Creek reaches (CONG001, CONG002, CONG003) are relatively close in proximity and share a common watershed. A primary concern for the Cedar Creek watershed is local development pressure, including plans for a major sewer utility extension that will facilitate more suburban land use in the future (D. Shelley, personal communication, July 29, 2019). As of 2016, approximately 11% of Cedar Creek's watershed is developed, with 1% covered by medium- and/or high-intensity development (Table 4). Forested land covers 35% of the Cedar Creek watershed and most of these forested areas lie in the northernmost portion of the watershed (Figures C-1, D-1, and E-1). Though the Cedar Creek watershed currently does not have a high amount of urban and suburban land cover (and associated impervious surfaces), the relatively high density of pastured and cultivated lands (30% of the watershed) along the stream network could contribute to flashier stormflows (Price et al. 2011). Conversely, the presence of woody wetlands (18%) in the low-lying areas surrounding most of the perennial streams within the southern portion of the watershed attenuates flashy flows and or floods (Acreman and Holden 2013). The watershed draining to the Cedar Creek reaches has a low entire stream gradient, low segment gradients, and low reach gradients (Tables 3 and 6). The watershed has low average slope, average drainage density, low basin shape, and a low basin relief ratio. In the northern portions of the watershed, slope and stream gradients are higher and relatively flashier flow regimes are expected (compared to the lower portions of the watershed). As the upper portions of the watershed drain into the Congaree River flood plain, watershed, segment, and channel slope all decrease. This lowering of slope also decreases stream power, creating conditions that increase flood retention times and potentially causes greater flood stage heights because the water is not quickly routed through the system; though, additional gage data are needed to confirm these interpretations.

CONG001—Cedar Creek 'Upstream'

A social walking trail, from the Bannister Bridge canoe put-in, follows along the river-right side of Cedar Creek 'upstream.' Visitors are expected to interact with the stream (e.g., fishing and canoeing) along the surveyed reach. In-stream habitat was mostly pool, run, and glide habitats (Table 5). Habitat was evenly distributed throughout the reach with runs and glides separating the pools (Figure 7). Average thalweg depth was greater than that of all of the other stream reaches that were compared in this report (Table 11). Bed material was sandy, and no representative riffles were present within the reach. The lack of a representative riffle prevented a pebble count from being completed on this reach. Cedar Creek upstream had the highest volume of large woody debris (LWD) per channel area of all of Cedar Creek reaches and one of the highest volumes of LWD per channel area of all of the reaches compared in this report. The abundance of LWD is a positive benthic macroinvertebrate habitat attribute (Benke et al. 1985; Smock et al. 1985) and, in many cases, promotes biodiversity (Wondzell and Bisson 2003). Fine bed material (sand and silt) may negatively influence benthic organisms (Allan and Castillo 2007), but the addition of fine particulate organic matter to these fine sediments (from decomposing LWD) may be positive for macroinvertebrate production in the benthos (Smock et al. 1985). Additionally, Cedar Creek 'upstream' displayed habitat heterogeneity thought to promote biodiversity (Allan and Castillo 2007; Palmer et al. 2010). Based on the diversity of low-energy GCUs, the presence of sandy bed sediment, and abundance of LWD within the reach, in-stream habitat at Cedar Creek 'upstream' was classified as 'fair to good.'

The major defining characteristics of the reach were its high bank heights, presence of a side channel, and the presence of an elevated entrenched surface. Cedar Creek 'upstream' had the highest average bank heights of all the fifth order reaches compared in this report. The high banks at Cedar Creek 'upstream' are likely a result of the reach's close proximity to the historical alluvial fan (Shelley 2007a, 2007b) as sand deposition is more likely to occur closer to the alluvial fan than sites further downstream. Cedar Creek 'upstream' is the only monitored reach on Cedar Creek that does not lie within the Congaree River flood

plain, and for that reason is more representative of other upper Coastal Plain streams than the monitored reaches downstream. The high channel-full bank heights at Cedar Creek 'upstream' decrease the likelihood of flooding, relative to monitored reaches within the Congaree River flood plain. The presence of the side channel just downstream of T6 is affecting channel morphology throughout the lower portion of the reach. During floods, flow is diverted into the side channel, reducing discharge on the mainstem in the lower portions of the reach, before re-joining the mainstem downstream (Figure 19). This reduction in discharge reduces the mainstem's ability to erode the banks and shape the channel and is responsible for the lower bankfull and channel-full area at detailed transect 1 (T1). The entrenched elevated surface observed on river left between T1 and T4, is a particularly defining characteristic of this reach, as no such surfaces were observed on the other monitored reaches at Congaree National Park. Future surveys will help to determine if this surface, which was identified as a flood plain surface during the baseline survey, is indeed a flood plain (created through lateral migration) or if it is a semi-stable slump surface formed through erosive forces. The reason why this surface has been reclassified as an elevated entrenched surface is that it has similar morphology to landforms identified at Kennesaw Mountain National Battlefield Park and Ocmulgee Mounds National Historical Park during the resurveys of the monitored reaches at these parks (Bateman McDonald 2020a, 2020b). If this elevated entrenched surface was correctly identified as an inset flood plain, then it is expected to continue to develop and expand laterally as the opposite bank erodes through lateral migration. Alternatively, if this surface was formed by rotational slumping of the bank material, then this surface is expected to lose height and or area as the toe of the slump block erodes and the block continues to slump. The defining morphological characteristics appear to be representative of an upper Coastal Plain stream and no immediate management concerns were identified at Cedar Creek 'upstream.'

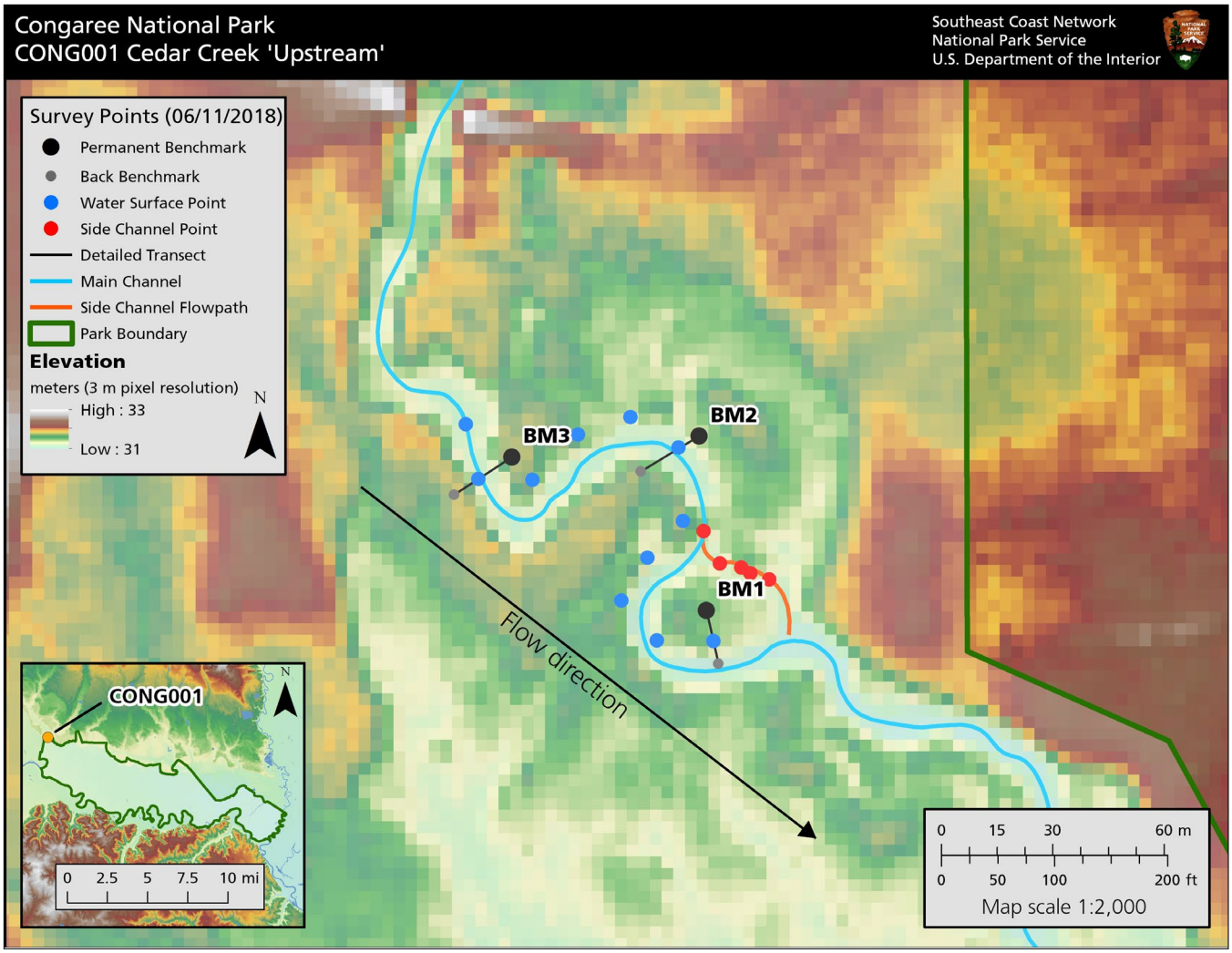


Figure 19. Map of the Wadeable Stream Habitat Monitoring site at CONG001 highlighting the side channel present downstream of transect 6. During high-flows, flow is diverted from the main channel (blue) into an ephemeral side channel (red) and re-joins the stream below the monitored reach.

CONG002—Cedar Creek 'Middle'

Cedar Creek 'middle' lies approximately 1 kilometer (0.62 mi) downstream of Cedar Creek 'upstream,' and well within the Congaree River active flood plain. The Congaree River flood plain in this area is very flat, quick to flood from the south and west, and slow to drain. Since Cedar Creek 'middle' and Cedar Creek 'upstream' are so close to each other, watershed characteristics are nearly identical. The main difference between Cedar Creek 'middle' and Cedar Creek 'upstream' is that Cedar Creek 'middle' lies within the Congaree River flood plain and receives both surface discharge and groundwater contributions from many areas outside of its GIS defined watershed when the Congaree River is at or above flood stage (Conrads et al. 2008). One additional factor affecting Cedar Creek 'middle' is that this reach is further removed from the influences of higher river terraces (e.g. higher slopes and gradients) and though the results of the GIS analysis do not show it, the area immediately surrounding Cedar Creek 'middle' have much lower slope than the area around Cedar Creek 'upstream.' The low reach slope of Cedar Creek 'middle' lowers stream power and, in combination with the reach's high connectivity to the surrounding Congaree River flood plain, creates conditions that increase flood retention times because the water is not quickly routed through the system.

There are no social walking trails in the vicinity of Cedar Creek 'middle' and visitor interaction with the stream along the reach is expected to be primarily through the canoe trail. Cedar Creek 'middle' was relatively straight and featured one small meander and few bars. There were several flood chutes and side channels coming into and flowing out of the channel (on T2, T3, T6, between T9–T10, and between T10–T11; Figure 10). In-stream habitat was mostly pool, glide, and run habitats (Table 5). These different habitat types were distributed throughout the reach with glides and

runs separating the pools. While average thalweg depth was relatively deep, Cedar Creek 'middle' was the shallowest reach surveyed on Cedar Creek (Table 11). Similar to Cedar Creek 'upstream,' the bed material at Cedar Creek 'middle' was sandy, and the lack of a representative riffle prevented a pebble count from being conducted. The irregularities in the streambed, which are visible on detailed transects 1 and 2 (Figure 12), were caused by buried pieces of LWD along the transects. Cedar Creek 'middle' had the second highest volume of LWD per channel area on Cedar Creek (Cedar Creek 'upstream' had the highest volume). Cedar Creek 'middle' also had the highest number of pieces of LWD of any reach compared in this report. Similar to Cedar Creek 'upstream,' based on the diversity of low-energy GCUs (Allan and Castillo 2007; Palmer et al. 2010), the presence of sandy bed sediment (Smock et al. 1985), and abundance of LWD within the reach (Benke et al. 1985; Smock et al. 1985), in-stream habitat at Cedar Creek 'middle' was classified as 'fair to good.'

The major defining characteristics of the reach were that the out-of-channel areas on both sides of the reach are flood plain of the Congaree River, the abundance of side channels and flood chutes within the reach, prevalence of LWD throughout the reach, and evidence of animal activity in the out-of-channel areas. Cedar Creek 'middle' lies well within the Congaree River flood plain and is a low energy, depositional environment which will continue to be subject to regular flooding and slow post-flood draining. Unlike Cedar Creek 'upstream,' a semi-continuous flood plain surface occupies the out-of-channel areas surrounding Cedar Creek 'middle.' The area of the Congaree River flood plain surrounding the monitored reach at Cedar Creek 'middle' is extremely flat, therefore channel-full width at Cedar Creek 'middle' was far wider than all other fifth order streams compared in this report. Ten out of eleven channel-full width measurements were greater than 30 meters (98.43 ft) and could not be measured in the field. Only six channel-full heights were able to be measured at Cedar Creek 'middle' because dense vegetation obstructed identification of the distant channel-full bank locations. The numerous side channels and flood chutes present in the out-of-channel areas on both sides of Cedar Creek 'middle' are evidence that this reach is not a standard meandering system and should not be interpreted in the same fashion. Unlike Cedar Creek 'upstream,' the side channel that is influencing Cedar Creek 'middle' does not affect the morphology of the detailed transects because it enters the stream downstream of detailed transect 1 (between T3 and T4; Figure 10). Conversely, the abundance of LWD within the channel at Cedar Creek 'middle' is affecting channel morphology. In general, sandy bed sediments such as those observed within the reach are expected to be quite mobile. At Cedar Creek 'middle,' the abundance of buried LWD is creating semi-permanent structure to the bed of the channel and is contributing to the development of relatively deep pools in their vicinity. In the out-of-channel areas, there was extensive evidence of wild pig rooting and wallowing surrounding Cedar Creek 'middle.' Disturbance of flood plain sediments by wild pigs can remove vegetation and leaf litter cover, exposing and loosening soils that may become susceptible to erosion, and may contribute to turbidity and potential downstream sedimentation, especially during flood periods following extensive rooting (Zengel and Conner 2008). It is also possible that the activity of these wild pig populations could affect the integrity of the permanent benchmarks placed along Cedar Creek 'middle,' which would hinder accurate resurveys of this reach. This wild pig activity represents an immediate management concern.

CONG003—Cedar Creek 'Downstream'

Cedar Creek 'downstream' lies on the Congaree River flood plain and is the farthest downstream reach that was surveyed on Cedar Creek (Figure D-1). Since Cedar Creek 'downstream' is located approximately 400 meters (1,312.34 ft) downstream of Cedar Creek 'middle,' its watershed characteristics are nearly identical to the other Cedar Creek reaches (Table 3). The same influences on flood flow and geomorphic characteristics described for Cedar Creek 'middle' are at work within the Cedar Creek 'downstream' reach (e.g., surface and groundwater contributions from the Congaree River flood plain, low reach slope, and high connectivity to the surrounding flood plain). Flood flows are furthered slowed at Cedar Creek 'downstream' by the wide and flat Congaree River flood plain. Similar to Cedar Creek 'middle,' the lowering of stream power creates conditions that increase flood retention times because the water is not quickly routed through the system.

There are no social walking trails in the vicinity of Cedar Creek 'downstream,' and visitor interaction with the stream along the reach is expected to be primarily through the canoe trail. Cedar Creek 'downstream' was slightly more sinuous than Cedar Creek 'middle' and featured many bars and vast flood plains on both sides of the stream. Unlike the out-of-channel area along Cedar Creek 'middle,' the out-of-channel area along Cedar Creek 'downstream' is characterized by a complex assortment of higher hummocks, disconnected flood plain, and many ephemeral side channels (Figure 13). Similar

to the upstream reaches of Cedar Creek, GCUs at Cedar Creek 'downstream' consisted of pool, run, and glide habitats (Table 5). Habitat was evenly distributed throughout the reach with runs and glides separating the pools (Figure 13). Cedar Creek 'downstream' was the only monitored reach at Congaree National Park that contained patches of aquatic vegetation on the streambed (between T3–T4, and T9). Average thalweg depth was greater than that of all of the other stream reaches compared in this report, excluding Cedar Creek 'upstream' (Table 11). Though, Cedar Creek 'downstream' did have the deepest maximum thalweg depth of any monitored reach (1.41 meters [4.63 ft], Table 11). Like the upstream reaches on Cedar Creek, bed material at Cedar Creek 'downstream' was sandy and no representative riffles were observed within the reach. The depositional environment of Cedar Creek 'downstream' has facilitated the development of multiple bars surfaces on the inside of the meander bends (and upstream of some LWD near T4; Figure 13). Cypress knees were prevalent in the low flood plain areas between T1 and T5. Cedar Creek 'downstream' contained a fair amount of LWD; which is a positive benthic macroinvertebrate habitat attribute (Benke et al. 1985; Smock et al. 1985) and, in many cases, promotes biodiversity (Wondzell and Bisson 2003). Additionally, the presence of in-stream vegetation promotes a more stable macroinvertebrate community structure, as it provides shelter during adverse flow conditions (Huttunen et al. 2017). Cedar Creek 'downstream' also displayed habitat heterogeneity thought to promote biodiversity (Allan and Castillo 2007; Palmer et al. 2010). Based on the diversity of low-energy GCUs, the presence of sandy bed sediment, the presence of in-stream vegetation, and abundance of LWD within the reach, in-stream habitat at Cedar Creek 'downstream' was classified as 'fair to good.'

The major defining characteristics of the reach were the presence of extensive flood plain on the surrounding out of channel areas, the prevalence of LWD throughout the reach, the presence of in-channel vegetation, and evidence of animal activity. Like Cedar Creek 'middle,' Cedar Creek 'downstream' lies well within the Congaree River flood plain and is a low energy, depositional environment which will continue to be subject to regular flooding and slow post-flood draining. The Congaree River flood plain surrounding Cedar Creek 'downstream' is characterized by many ephemeral channels, disconnected flood plain, and slightly higher hummocks. While not as flat as the areas around Cedar Creek 'middle,' the flood plain surrounding Cedar Creek 'downstream' is still quite flat. For that reason, like Cedar Creek 'middle,' there were transects on which channel-full width was greater than 30 meters (98.43 ft; two of eleven transects) and could not be measured. Only six channel-full heights were able to be measured at Cedar Creek 'middle' because dense vegetation obstructed identification of the distant channel-full bank locations. Another defining characteristic of Cedar Creek 'downstream' was the abundance of LWD within the channel. Like Cedar Creek 'middle,' the majority of LWD was buried in the sandy substrate and is providing semi-permanent structure to the sandy streambed. The buried LWD observed at Cedar Creek 'downstream' is also contributing to the creation of deep pools within the reach. Similar to Cedar Creek 'middle,' there was extensive evidence of wild pig rooting and wallowing in the out-of-channel area surrounding Cedar Creek 'downstream.' Again, it is also possible that the wild pig rooting could affect the integrity of the permanent benchmarks which were placed along Cedar Creek 'downstream,' which would hinder accurate resurveys of this reach. This wild pig activity represents an immediate management concern.

CONG004—McKenzie Creek

McKenzie Creek is a third order stream and its watershed had the smallest drainage area of all the CONG reaches (26.62 square kilometers [10.28 mi^2]; Table 3). Only 8% of McKenzie Creek's watershed is developed, none of which is covered by medium- and/or high-intensity development (Table 4). Forest cover (29%) is well distributed throughout the watershed and is primarily made up of evergreen (pine) forest. Though the McKenzie Creek watershed has very little urban and suburban land cover (and associated impervious surfaces), the high density of pastured and cultivated lands (40%) along the stream network in the northern areas of the watershed could contribute to flashier stormflows (Price et al. 2011). Similar to the Cedar Creek watershed, these potentially flashy flows in the McKenzie Creek watershed are slowed by the presence of woody wetlands (23%) that have developed in the low-lying areas surrounding perennial streams within the southern portion of the watershed (Acreman and Holden 2013). The McKenzie Creek watershed has a slightly higher entire stream gradient than Cedar Creek's watershed and a slightly higher segment gradient than the Cedar Creek reaches' segments (Table 3). McKenzie Creek's reach gradient was an order of magnitude higher than any surveyed reach on Cedar Creek (Table 6). Overall, McKenzie Creek's watershed has very low slope, average drainage density, low basin shape, and a low basin relief ratio. Based on the geomorphic characteristics of McKenzie Creek's watershed, the reach does not have a flashy flow regime, though gage data are needed to confirm this interpretation.

The surveyed reach on McKenzie Creek is located approximately 15 meters (49.21 ft) downstream of a relic roadbed and 450 meters (1,476.38 ft) upstream of McKenzie Creek's confluence with Toms Creek. Visitors are not expected to interact with the stream along the surveyed reach, as there are no social walking trails or canoe trails in the vicinity of the reach. McKenzie Creek was relatively straight and had a similar sinuosity to Cedar Creek 'middle' (Table 6). Bars were present throughout the reach, mostly on the insides of the small meanders found within the reach (Figure 16). In-stream habitat consisted of pools, riffles, runs, and a step (Table 5). Habitat was evenly distributed in the upstream portion of the reach but transitioned to relatively homogeneous pool habitat below the step between T6 and T7. Average thalweg depth was less than that of all other stream reaches that were compared in this report (Table 11). The presence of riffle habitat within the reach allowed for a pebble count to be conducted. The bed sediment at McKenzie Creek was significantly finer than all of the monitored reaches included in this report, except Walnut Creek (OCMU001; Table 7). McKenzie Creek had the lowest average widths (excluding channel-full width; Table 12) and lowest average bank heights (Table 14) of all the streams compared in this report. McKenzie Creek had the lowest volume of LWD per channel area (Table 9). The low amount of LWD is interpreted as a negative attribute for benthic macroinvertebrate habitat, but due to the presence of venomous snakes present within a LWD jam, not all LWD at McKenzie Creek could be measured. Because not all pieces of LWD could be measured, the LWD characteristics of McKenzie Creek should be interpreted as minimum values. McKenzie Creek contained habitat heterogeneity thought to promote biodiversity (Allan and Castillo 2007; Palmer et al. 2010) and included riffle and step habitats. Fine bed material (sand and silt) may negatively influence benthic organisms (Allan and Castillo 2007), but the addition of fine particulate organic matter (from decomposing LWD) to these fine sediments may be positive for macroinvertebrate production in the benthos (Smock et al. 1985). Based on the diversity of GCUs (especially the presence of step and riffle habitat), the presence of sandy bed sediment, and the relative lack of LWD within the reach, McKenzie Creek's in-stream habitat was classified as 'fair.'

The major defining characteristics of McKenzie Creek were its fine bed sediment (with introduced coarse material), channel morphology, and the abundance of flood chutes in the flood plain. Bed sediment at McKenzie Creek was expected to be more like the other low-lying streams at Congaree National Park due to similarities in their watershed gradient and land use. The presence of a relic roadbed just upstream of McKenzie Creek (Figure 20) is causing the size of bed sediment to be artificially inflated due to an influx of gravels eroded from the road. Additionally, the relic road has also influenced channel morphology at McKenzie Creek. Upstream of the roadbed, McKenzie Creek is a multi-thread anastomosing wetland with no clear main channel (Figure 20). The presence of this near stagnant wetland upstream of McKenzie Creek ameliorates any geomorphic influences the upstream railroad bridge and road crossing have on the reach. However, the higher energy flows caused by the concentration of McKenzie Creek as it flows over the relic roadbed have caused McKenzie Creek to incise into the flat surrounding area, carving the small narrow channel. The abundance of flood chutes in the out-of-channel flood plain areas on both sides of the stream provide evidence of McKenzie Creek's former anastomosing planform in the area of the reach. These flood chutes also contribute to the relatively small size of the channel at McKenzie Creek, because during flood flows these chutes and side channels serve to divert flow out of the main channel. A similar hypothesized flood flow diversion was observed at Walnut Creek (OCUM001), where the stream channel was smaller than expected relative to its drainage area (Cooper et al. 2019). Though the presence of a relic roadbed approximately 15 meters (49.21 ft) upstream of the monitored reach at McKenzie Creek is affecting bed sediment characteristics and channel morphology within the reach, there are no immediate management concerns at McKenzie Creek.

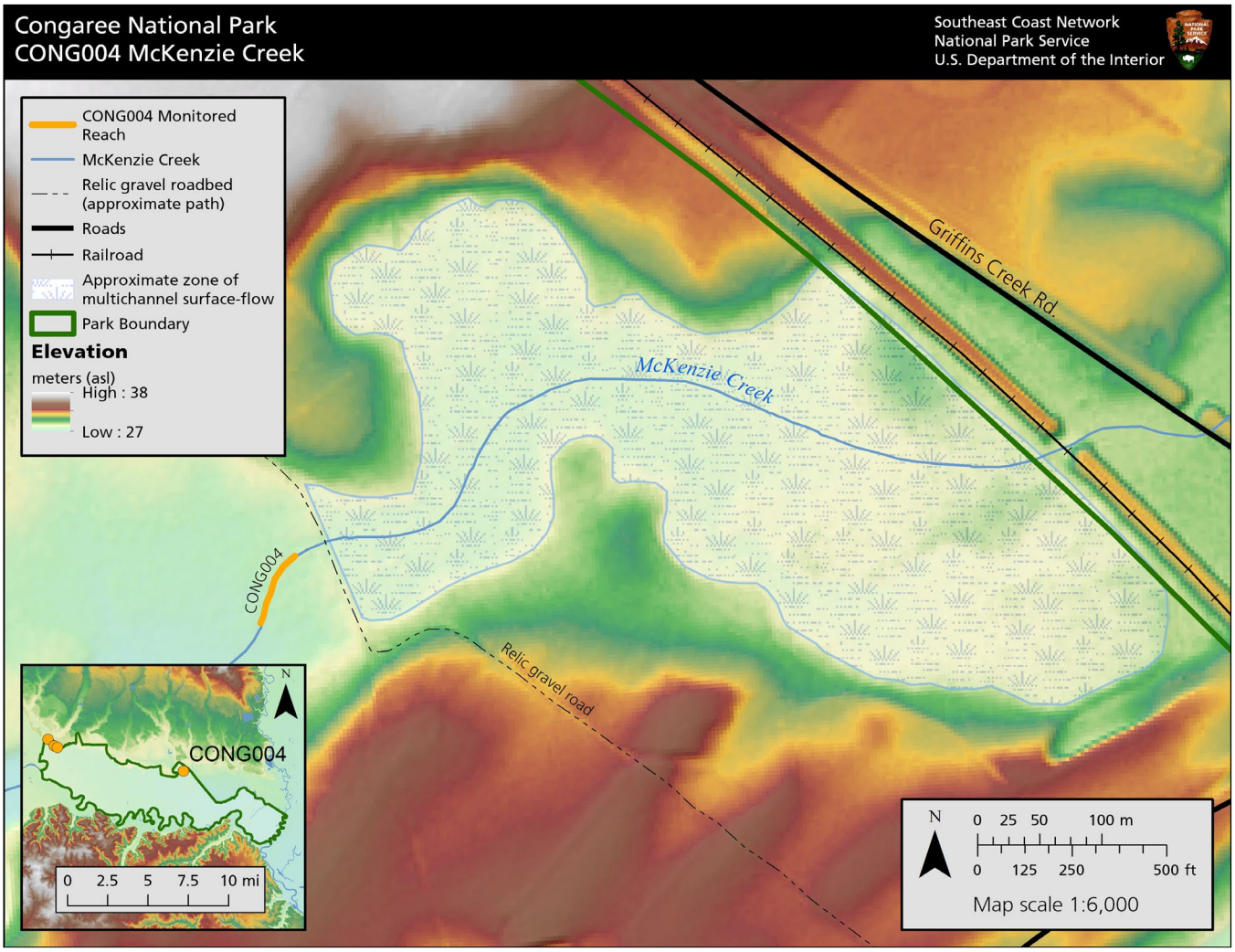


Figure 20. Small scale map of McKenzie Creek showing the proximity of the monitored reach (CONG004) to the Griffins Creek Road Bridge, the railroad bridge, the anastomosing surface-flow zone, and the relic roadbed just upstream of the monitored reach.

Conclusion

The Cedar Creek watershed drains the Congaree River Valley Terrace Complex and upper Coastal Plain. Downstream of Cedar Creek 'upstream,' Cedar Creek flows through the relatively flat swamps of the Congaree River flood plain. Based on the geomorphic and land cover characteristics of Cedar Creek's watershed, the monitored reaches on Cedar Creek are likely to flood often and drain slowly. Flooding is more likely at Cedar Creek 'middle' and Cedar Creek 'downstream,' because of their relatively low bank heights, their lack of channel entrenchment, and their locations within the relatively flat Congaree flood plain. Based on bed sediment, the type and distribution of GCUs (and relatively deep pool habitats) within the reaches, and the abundance of LWD, in-stream habitat on each of the Cedar Creek reaches was classified as 'fair to good.' These classifications are generalized interpretations of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Congaree National Park. There is extensive evidence of animal activity (e.g., pig rooting and wallowing, trails) in the out-of-channel areas surrounding the channel at Cedar Creek 'middle' and 'downstream.' The wild pig rooting is having a large impact on the morphology and stability of the out-of-channel areas along these reaches. This altering of the landscape by an invasive species represents an immediate management concern and could affect the integrity of the installed permanent benchmarks along these reaches, potentially preventing accurate resurveys of the detailed transect surveys along these reaches.

The McKenzie Creek watershed drains a portion of the Congaree River Valley Terrace complex north of the park. McKenzie Creek is a small, third order stream that drains into Toms Creek before entering the Congaree River flood plain. Based on the geomorphic and land cover characteristics of the watershed, the monitored reach on McKenzie Creek is likely to flood often and drain slowly. On the monitored portion of McKenzie Creek, flood flows are diverted through many flood chutes and side channels, reducing stream power within the main channel. This flow diversion causes the main channel of McKenzie Creek to be smaller than expected given its stream order and the size of its watershed (similar to the conditions seen at OCMU001, Cooper et al. 2019). A relic roadbed upstream of the monitored reach has also altered natural flow conditions within the reach. Upstream of the relic roadbed and monitored reach, McKenzie Creek is nearly stagnant and flows through a multichannel anastomosing swamp. Below the relic roadbed, McKenzie Creek has incised into a small single-thread stream at the monitored reach before reaching its confluence with Toms Creek. Based on the diversity of GCUs within the reach (and presence of riffle and step habitat) and the presence of LWD, in-stream habitat within the surveyed reach on McKenzie Creek was classified as 'fair.' These classifications are generalized interpretations of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at McKenzie Creek. McKenzie Creek does not have immediate management concerns.

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Appendix A. Watershed Comparison of Wadeable Stream Habitat Monitoring Sites

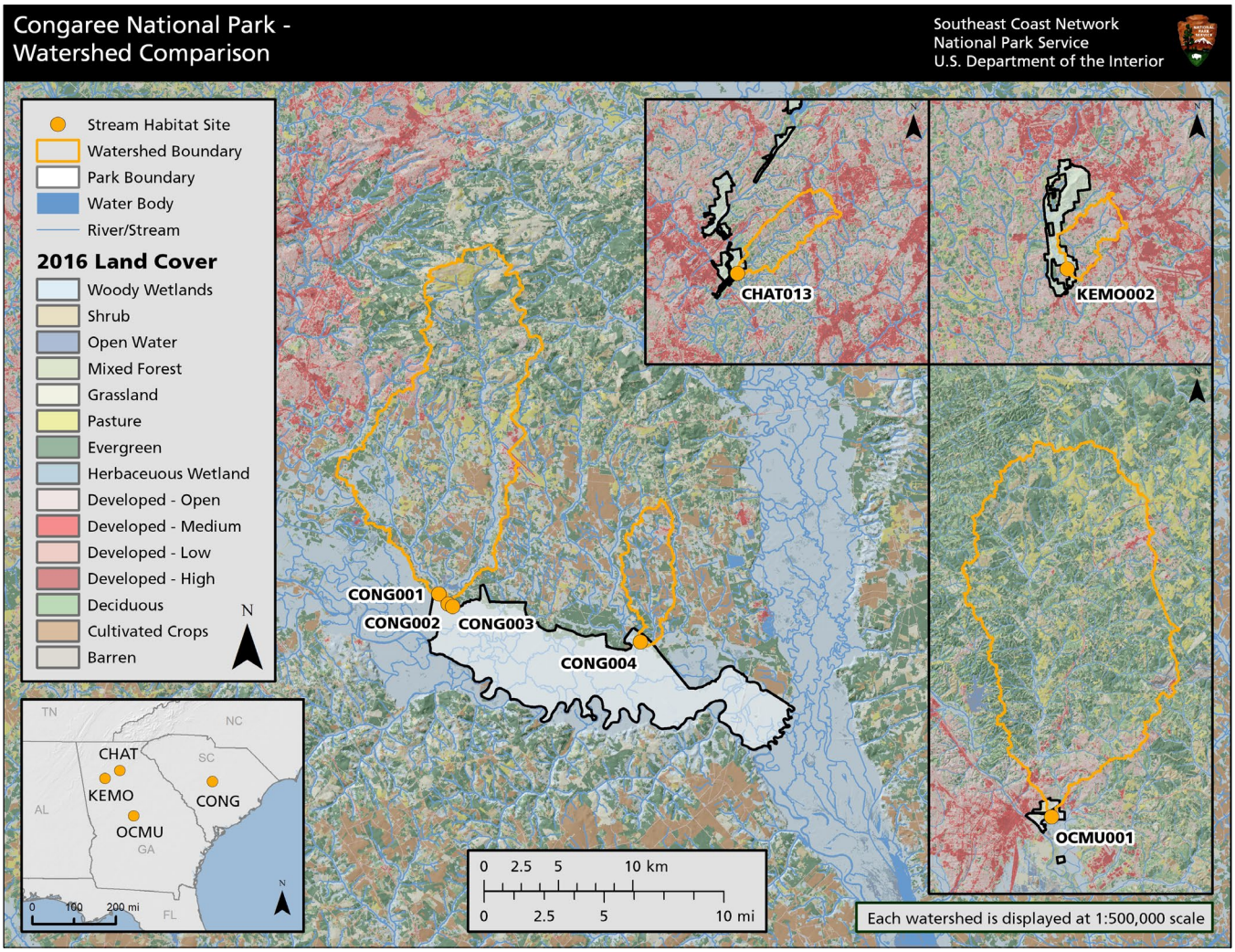


Figure A-1. Map showing the Cedar Creek (CONG001-003) and McKenzie Creek (CONG004) watersheds draining to Congaree National Park and watersheds draining to Ocmulgee Mounds NHP, Chattahoochee River NRA, and Kennesaw Mountain NBP. Map scale is equal across all locations allowing for size comparison between watersheds. The land use and land cover (NLCD 2016, Homer et al. 2020) and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

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Appendix B. Explanation of Variables

Table B-1. Explanation of variables collected by the Wadeable Stream Habitat Monitoring Protocol including the scale at which each is collected.

Variable	Variable Scale	Description
Drainage Area	Basin	The topographical area to which precipitation, sediment, and dissolved constituents are funneled to a common outlet point along a given stream channel (Dunne and Leopold 1978).
Total Stream Length	Basin	The sum of the length of perennial streams within a watershed.
Drainage Density	Basin	The ratio of total stream length to drainage area.
Basin Length	Basin	The length of the line that bisects a watershed running from outlet to drainage divide.
Basin Shape	Basin	Drainage area divided by basin length squared (Horton 1932)
Average Watershed Slope	Basin	Within watershed, average of the slope values of each pixel of a digital elevation model.
Standard Deviation of Slope	Basin	Within watershed, standard deviation of the slope values of each pixel of a digital elevation model.
Basin Relief	Basin	Within watershed, maximum elevation minus minimum elevation
Standard Deviation of Elevation	Basin	The standard deviation of elevation within a watershed.
Basin Relief Ratio	Basin	A ratio calculated by dividing basin relief by basin length.
Entire Stream Gradient	Basin	The difference in elevation at 85% and 10% of the main stem stream length divided by the stream length between the two points (Fitzpatrick et al. 1998).
Segment Gradient	Basin	The difference in elevation between the upstream extent of the stream segment and the downstream extent of the stream segment, divided by the length of the stream segment.
Strahler Stream Order	Basin	A stream ordering system where order increases when two orders of the same magnitude join.
Bifurcation Ratio	Basin	The ratio of streams in a given Strahler order to streams in the next highest order (e.g., number of first order streams/number of second order streams).
Land Use/Land Cover	Basin	Land use/land cover is derived from the NLCD dataset.
Geomorphic Channel Units	Reach	Geomorphic channel units are a way to classify in-channel habitat (e.g., riffles and pools)
Large Woody Debris	Reach	Pieces of woody material that have a diameter greater than 0.1 meters (0.3 ft) and are 1 meter (3.3 ft) or longer.
Pebble Count	Reach	The size and distribution of 100 particles (pebble count) from a representative riffle (Wolman 1954).
Canopy Closure	Reach[a]	The average of four measurements (looking upstream, downstream, and at each bank) taken using a spherical densiometer.
Reach Sinuosity	Reach	Sinuosity is calculated by dividing reach length by valley length.
Longitudinal Profile	Reach	The gradient of the line that connects the tops of the steps and riffles within a reach (channel slope)
Wetted Width	Transect[a]	Wetted channel width is measured where water is flowing (including undercuts)
Active Channel Width	Transect[a]	Active channel width is measured to the beginning of vegetation within the stream channel
Bankfull Width	Transect[a,b]	Bankfull widths should only be measured if there is a flood plain (or incipient flood plain) present
Bankfull Height	Transect[a,b]	The height of the channel bank where a flood plain is present

Variable	Variable Scale	Description
Bankfull Area	Transect[b]	The cross-sectional area of a stream channel at bankfull stage (height) measured perpendicular to flow
Bankfull Perimeter	Transect[b]	The length of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at bankfull discharge
Bankfull Hydraulic Radius	Transect[b]	A measure of hydraulic efficiency defined by the ratio between bankfull area and bankfull perimeter
Channel-full Width	Transect[a,b]	Channel full widths are measured from the top of the lowest bank that is not a flood plain.
Channel-full Height	Transect[a,b]	The height of the channel bank where a flood plain is not present (channel-full height is also measured where a flood plain is inset within an entrenched channel)
Channel-full Area	Transect[b]	The cross-sectional area of a stream channel at bankfull stage measured perpendicular to flow
Channel-full Perimeter	Transect[b]	The length of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at channel full discharge
Channel-full Hydraulic Radius	Transect[b]	A measure of hydraulic efficiency defined by the ratio between channel full area and channel full perimeter
Thalweg Position	Transect[a]	The position of the thalweg as a percent distance of the wetted width from left water's edge
Thalweg Depth	Transect[a]	The greatest depth of water along a transect
Dominant Particle Size	Transect[a]	A visual estimate of the dominant sediment size along a transect
Dominant Habitat	Transect[a]	A visual estimate of the dominant geomorphic channel unit along a transect
In-channel features	Transect[a]	A description of the in-channel features (e.g., bars or islands) that are present along a transect
Flood plain width	Transect[a]	The width(s) of flood plain(s) present along rivers left and/or right
Bank Undercut	Transect[a]	Where the bank overhangs the channel due to lateral erosion at the base of the bank
Bank Angle	Transect[a]	The dominant bank angle from active channel boundary to the top of the bank
Bank Sediment	Transect[a]	The dominant sediment composition of the channel banks
Bank Erosion	Transect[a]	The presence of and type erosion (e.g., lateral or slump) that is observed on the channel banks
Bank Cover	Transect[a]	A visual estimate of the percent of the channel banks that has vegetative cover

[a] collected at each standard transect (11 measurements).

[b] calculated at each detailed transect (3 per reach) using survey data collected using a total station.

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Appendix C. Survey Results for CONG001

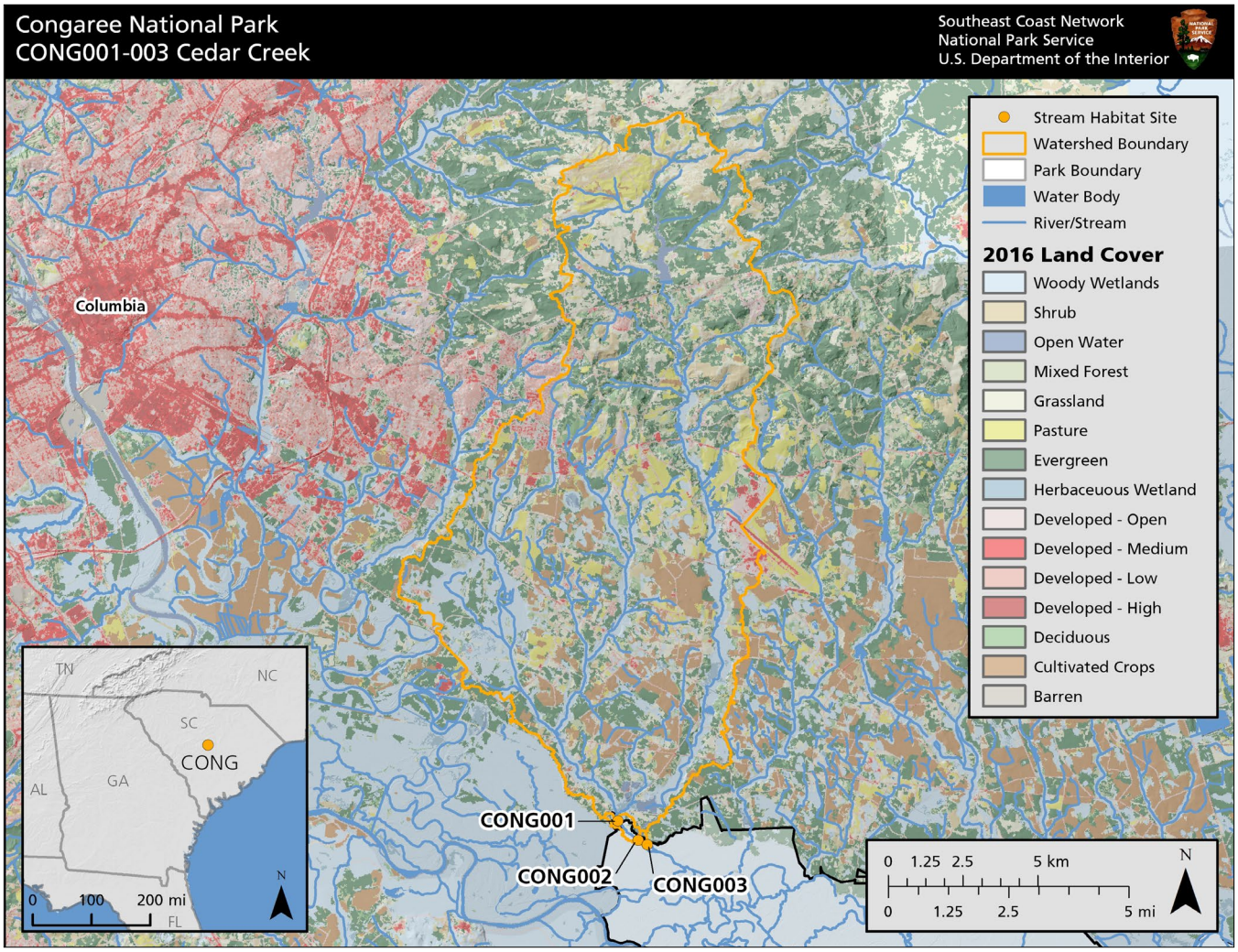


Figure C-1. Map showing the watershed draining to CONG001 at Congaree National Park. The land use and land cover (NLCD 2016, Homer et al. 2020), and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure C-2. Photograph taken on CONG001 looking upstream from T1 (detailed transect 1).



Figure C-3. Photograph taken on CONG001 looking downstream on T1 (detailed transect 1).



Figure C-4. Photograph taken on CONG001 looking at the left bank on T1 (detailed transect 1).



Figure C-5. Photograph taken on CONG001 looking at the right bank on T1 (detailed transect 1).



Figure C-6. Photograph taken on CONG001 looking upstream on T6 (detailed transect 2).



Figure C-7. Photograph taken on CONG001 looking downstream on T6 (detailed transect 2).



Figure C-8. Photograph taken on CONG001 looking at the left bank on T6 (detailed transect 2).



Figure C-9. Photograph taken on CONG001 looking at the right bank on T6 (detailed transect 2).



Figure C-10. Photograph taken on CONG001 looking upstream on T10 (detailed transect 3).



Figure C-11. Photograph taken on CONG001 looking downstream on T10 (detailed transect 3).



Figure C-12. Photograph taken on CONG001 looking at the left bank on T10 (detailed transect 3).



Figure C-13. Photograph taken on CONG001 looking at the right bank on T10 (detailed transect 3).

Table C-1. Land use and land cover characteristics from the National Land Cover Dataset, 2001 (Homer et al. 2001), 2006 (Fry et al. 2006), 2011 (Homer et al. 2015), and 2016 (Homer et al. 2020) for CONG001.

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed	2016 percent of watershed
Open Water	1	1	1	1
Developed—Open[a]	7	7	7	7
Developed—Low[a]	2	3	3	3
Developed—Medium[a]	0	1	1	1
Developed—High[a]	0	0	0	0
Barren	0	0	0	0
Deciduous	14	14	13	4
Evergreen	16	16	16	23
Mixed Forest	4	4	3	8
Shrub	0	2	3	5
Grassland	24	22	23	14
Pasture	8	8	8	8
Cultivated	9	9	9	9
Woody Wetland	13	13	13	17
Herbaceous Wetland	0	0	1	1

[a] refers to the intensity or type of development.

Table C-2. Geomorphic channel units (GCU) observed in the area between transects at CONG001. The data describe the percent coverage of each type of GCU [SD—standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	40	40	20	0
2–3	0	0	60	40	0
3–4	0	50	30	20	0
4–5	0	30	0	70	0
5–6	0	20	0	80	0
6–7	0	40	40	20	0
7–8	0	20	60	20	0
8–9	0	20	20	60	0
9–10	0	20	0	80	0
10–11	0	10	0	90	0
Frequency	0	9	6	10	0
Maximum (%)	0	50	60	90	0
Mean (%)	0	25	25	50	0
Median (%)	0	20	25	50	0
SD (%)	0	15	25	29	0

Table C-3. Characteristics of the large woody debris (LWD) observed at CONG001 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	2.19	0.16	0.04	11	None	Buried
2	1.42	0.15	0.03	10	None	Free
3	1.82	0.23	0.08	10	Sediment trap	Buried
4	1.69	0.14	0.03	10	Sediment trap	Buried
5	4.12	0.45	0.66	9	Organic trap	Buried
6	3.93	0.36	0.40	9	Organic trap	Ramp
7	1.31	0.22	0.05	9	Sediment trap	Buried
8	4.64	0.27	0.27	9	Sediment trap, Organic trap	Buried
9	2.09	0.21	0.07	8	Sediment trap	Buried
10	2.92	0.42	0.40	8	Sediment trap, Organic trap	Buried
11	7.40	0.21	0.26	8	Organic trap	Ramp
12	2.35	0.28	0.14	8	Sediment trap	Buried
13	2.70	0.22	0.10	7	Sediment trap	Buried
14	3.56	0.27	0.20	7	Sediment trap	Buried
15	2.16	0.21	0.07	6	Sediment trap	Buried
16	2.93	0.44	0.45	6	Bank protection	Buried
17	2.63	0.13	0.03	6	None	Free
18	8.86	0.28	0.55	6	Organic trap	Ramp
19	1.88	0.19	0.05	5	Bank protection	Buried
20	2.22	0.31	0.17	5	Bank protection	Buried
21	4.68	0.51	0.96	3	Bank protection	Buried, Ramp
22	3.77	0.38	0.43	2	None	Buried
23	2.99	0.37	0.32	2	Sediment trap	Buried
24	1.42	0.49	0.27	1	Sediment trap	Buried
25	3.25	0.47	0.56	1	None	Ramp
26	5.22	0.38	0.59	1	Sediment trap, Organic trap	Buried

Table C-4. Variability of canopy cover observed at CONG001 [SD—standard deviation; CV—coefficient of variance].

Transect	Canopy Cover (%)
1	82
2	74
3	91
4	88
5	91
6	87
7	85
8	93
9	94
10	81
11	81
Min (%)	74
Max (%)	94
Mean (%)	86
Median (%)	87
SD (%)	6
CV	0.07

Table C-5. Average reach-scale bank characteristics at KEMO001. 'n' is number of measurements taken, 'L' indicates left bank, 'R' indicates right bank, 'Min' is minimum,'Max' is maximum, 'SD' is standard deviation, 'CV' is coefficient of variation [m—meters].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)	SD (L)	SD (L)	CV (L)	CV (R)
Bank Height[a] (m)	11	11	1.10	1.41	3.23	2.74	1.99	2.05	1.98	2.04	0.60	0.43	0.30	0.21
Bankfull Height[a,b] (m)	5	1	1.10	–	2.16	–	1.63	1.41	1.48	–	0.43	–	0.26	–
Channel-full Height[a,b] (m)	11	11	1.39	1.45	3.23	2.74	2.13	2.07	2.08	2.04	0.53	0.41	0.25	0.20
Water Depth at Base[c] (m)	11	11	-0.82	-0.29	-0.05	0.20	-0.23	-0.17	-0.19	-0.22	0.21	0.14	–	–
Bank Undercut[b] (m)	2	1	0.41	–	0.59	–	0.50	0.55	0.50	–	0.13	–	0.25	–
Bank Angle (°)	11	11	22	13	90	82	59	51	67	55	24	22	0.41	0.43
Vegetation Cover (%)	11	11	10	5	95	100	64	44	70	50	29	31	0.45	0.70
Bank Stability[d]	11	11	Unstable	Unstable	Very Unstable	Very Unstable	Unstable	Very Unstable	Unstable	Unstable	1.27	1.34	0.09	0.09

[a] above thalweg.

[b] statistics are based on the transects where feature is present.

[c] a negative number indicates base of bank is above the water surface.

[d] see Table 1 for explanation of scores.

Table C-6. Cross-sectional characteristics for detailed transect 1 at CONG001 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	6.00	9.10	0.66	8.51	1.11	7.69
Channel-full	9.48	13.07	0.73	12.30	1.44	8.55
Ratio	1.58	1.44	1.10	1.44	1.30	1.11

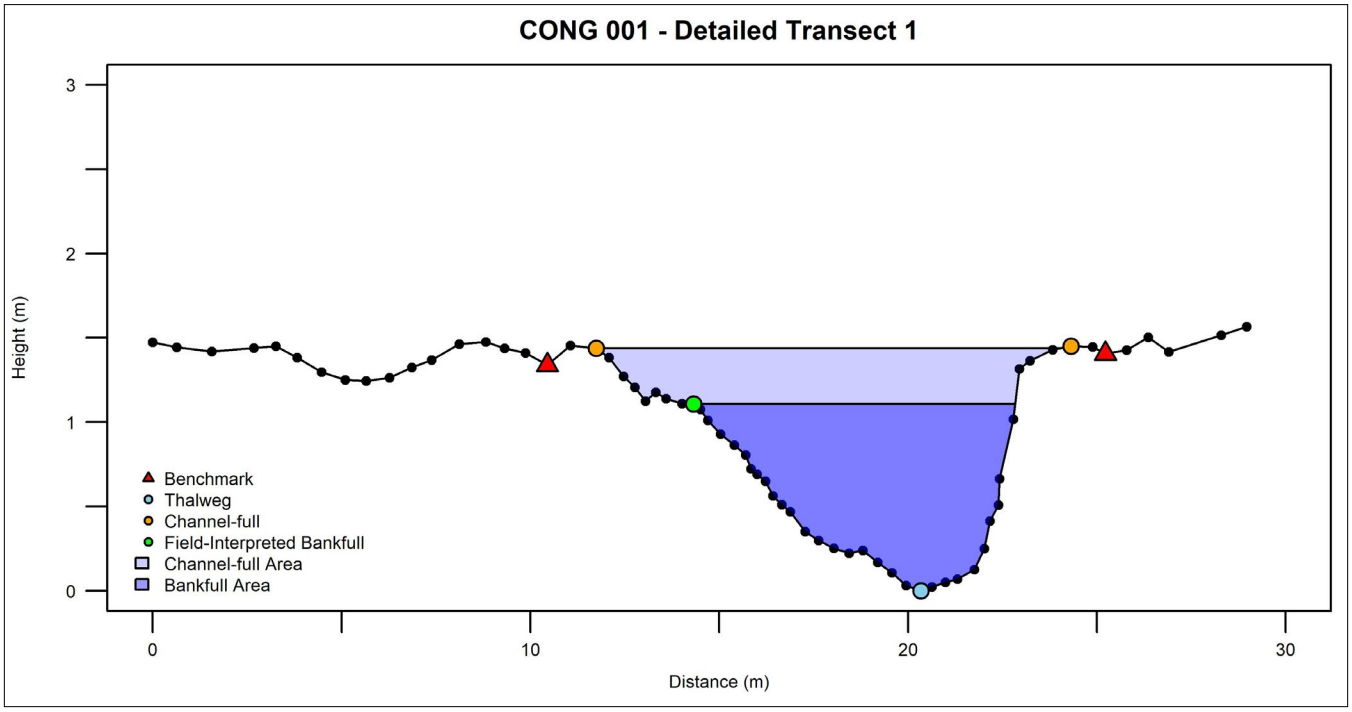


Figure C-14. Detailed transect 1 at CONG001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table C-7. Cross-sectional characteristics for detailed transect 2 at CONG001 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	11.62	11.38	1.02	9.41	2.06	4.57
Channel-full	12.71	14.95	0.85	12.95	2.15	6.03
Ratio	1.09	1.31	0.83	1.38	1.04	1.32

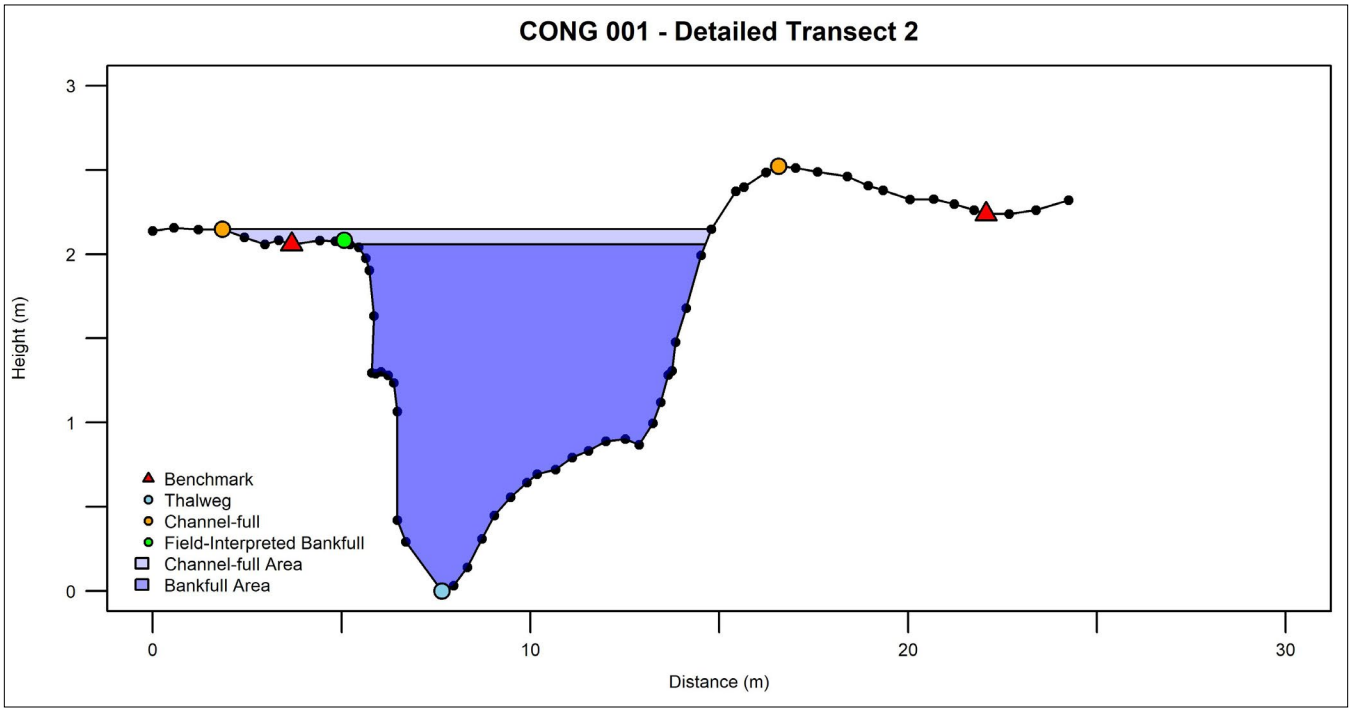


Figure C-15. Detailed transect 2 at CONG001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table C-8. Cross-sectional characteristics for detailed transect 3 at CONG001 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	14.42	12.91	1.12	11.41	1.57	7.27
Channel-full	16.45	14.14	1.16	12.54	1.74	7.20
Ratio	1.14	1.09	1.04	1.10	1.11	0.99

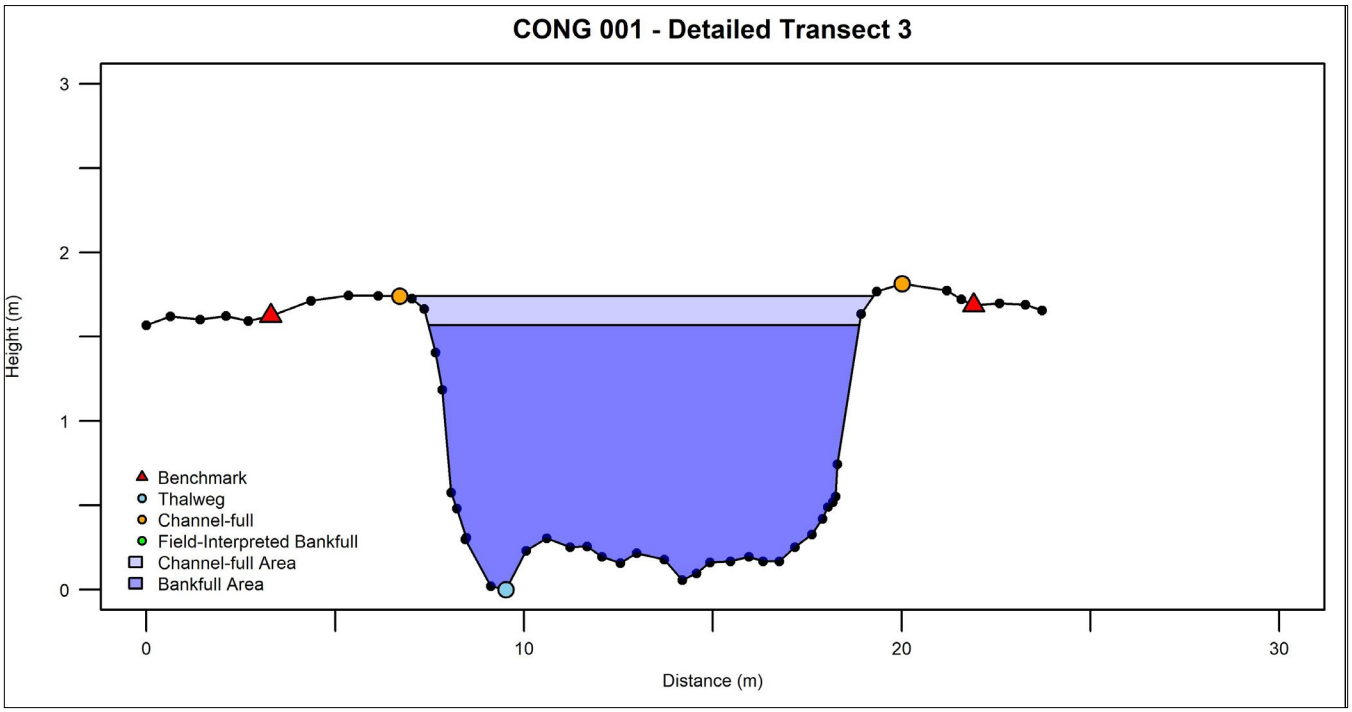


Figure C-16. Detailed transect 3 at CONG001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

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Appendix D. Survey Results for CONG002

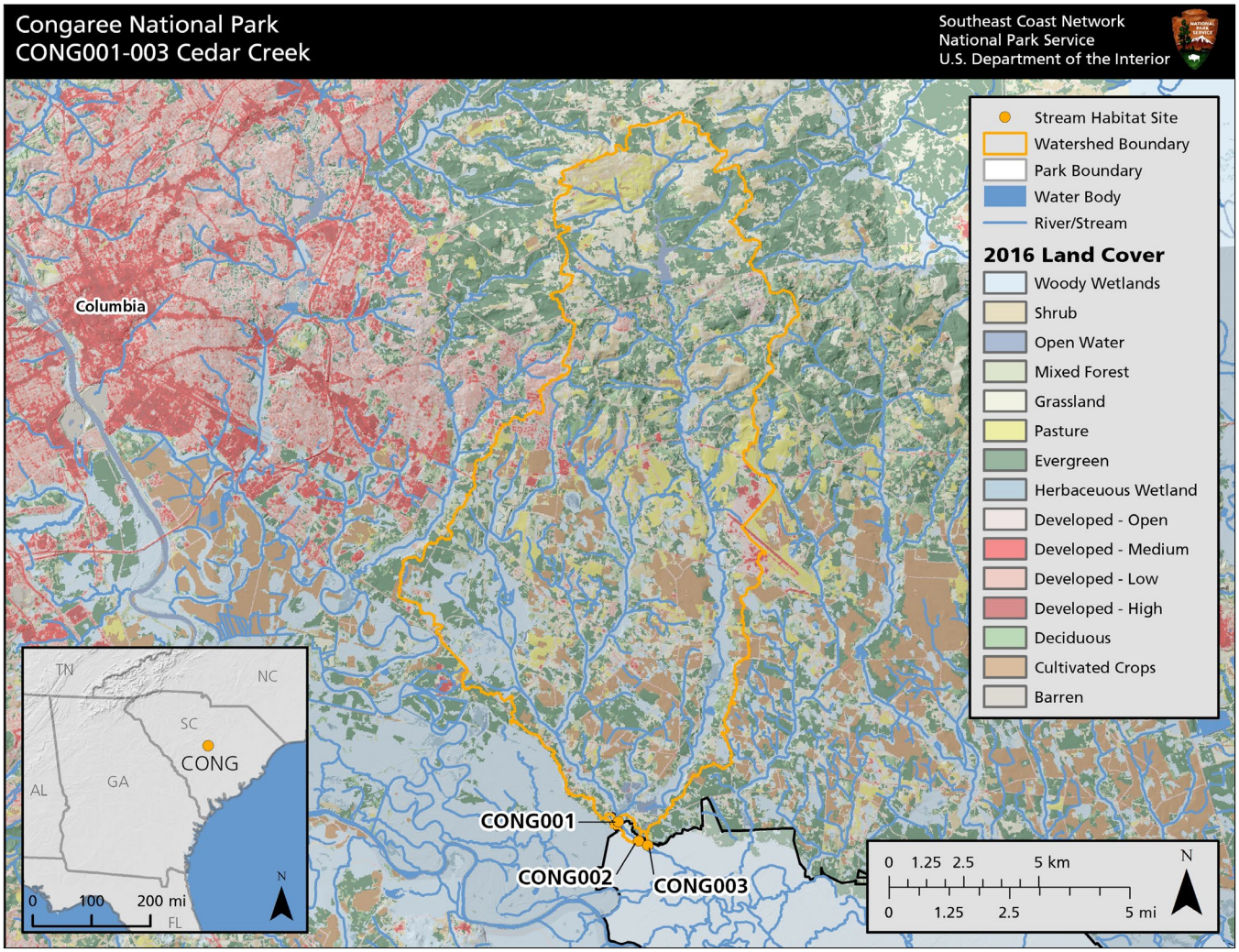


Figure D-1. Map showing the watershed draining to CONG002 at Congaree National Park. The land use and land cover (NLCD 2016, Homer et al. 2020), and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure D-2. Photograph taken on CONG002 looking upstream from T4 (detailed transect 1).



Figure D-3. Photograph taken on CONG002 looking downstream on T4 (detailed transect 1).



Figure D-4. Photograph taken on CONG002 looking at the left bank on T4 (detailed transect 1).



Figure D-5. Photograph taken on CONG002 looking at the right bank on T4 (detailed transect 1).



Figure D-6. Photograph taken on CONG002 looking upstream on T6 (detailed transect 2).



Figure D-7. Photograph taken on CONG002 looking downstream on T6 (detailed transect 2).



Figure D-8. Photograph taken on CONG002 looking at the left bank on T6 (detailed transect 2).



Figure D-9. Photograph taken on CONG002 looking at the right bank on T6 (detailed transect 2).



Figure D-10. Photograph taken on CONG002 looking upstream on T9 (detailed transect 3).



Figure D-11. Photograph taken on CONG002 looking downstream on T9 (detailed transect 3).



Figure D-12. Photograph taken on CONG002 looking at the left bank on T9 (detailed transect 3).



Figure D-13. Photograph taken on CONG002 looking at the right bank on T9 (detailed transect 3).

Table D-1. Land use and land cover characteristics from the National Land Cover Dataset, 2001 (Homer et al. 2001), 2006 (Fry et al. 2006), 2011 (Homer et al. 2015), and 2016 (Homer et al. 2020) for CONG002.

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed	2016 percent of watershed
Open Water	1	1	1	1
Developed—Open[a]	7	7	7	7
Developed—Low[a]	2	3	3	3
Developed—Medium[a]	0	1	1	1
Developed—High[a]	0	0	0	0
Barren	0	0	0	0
Deciduous	14	14	13	4
Evergreen	17	17	16	23
Mixed Forest	4	4	3	8
Shrub	0	2	3	5
Grassland	24	22	23	13
Pasture	8	8	9	8
Cultivated	9	9	9	9
Woody Wetland	13	13	13	17
Herbaceous Wetland	0	0	1	1

[a] refers to the intensity or type of development.

Table D-2. Geomorphic channel units (GCU) observed in the area between transects at CONG002. The data describe the percent coverage of each type of GCU [SD—standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	0	20	80	0
2–3	0	20	20	60	0
3–4	0	0	100	0	0
4–5	0	20	10	70	0
5–6	0	40	40	20	0
6–7	0	20	80	0	0
7–8	0	0	20	80	0
8–9	0	0	40	60	0
9–10	0	0	30	70	0
10–11	0	0	20	80	0
Frequency	0	4	10	8	0
Max (%)	0	40	100	80	0
Mean (%)	0	10	38	52	0
Median (%)	0	0	25	65	0
SD (%)	0	14	29	33	0

Table D-3. Characteristics of the large woody debris observed at CONG002 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	5.52	0.18	0.14	11	Bank protection	Buried
2	5.50	0.13	0.07	10	Jam	Free
3	2.70	0.12	0.03	10	Jam	Free
4	1.48	0.19	0.04	10	Jam	Free
5	1.82	0.23	0.08	9	Sediment trap	Buried
6	2.93	0.18	0.07	9	Bank protection	Buried
7	1.42	0.13	0.02	9	Bank protection	Buried
8	1.26	0.12	0.01	9	Sediment trap	Buried
9	1.44	0.18	0.04	9	Bank protection	Free
10	2.96	0.17	0.07	8	Bank protection, Sediment trap	Buried
11	4.96	0.26	0.26	8	Sediment trap	Buried
12	1.52	0.40	0.19	8	Jam	Buried
13	1.10	0.21	0.04	8	Jam	Buried
14	1.87	0.24	0.08	7	None	Free
15	5.57	0.27	0.32	7	Sediment trap	Buried
16	6.07	0.22	0.23	7	Bank protection	Buried
17	2.45	0.25	0.12	7	Sediment trap	Buried
18	1.52	0.29	0.10	6	Sediment trap	Buried
19	1.24	0.17	0.03	6	Sediment trap	Buried
20	4.98	0.18	0.13	6	Sediment trap	Buried
21	2.38	0.16	0.05	6	Bank protection	Buried
22	2.52	0.48	0.46	6	Sediment trap	Buried
23	2.28	0.15	0.04	5	Sediment trap	Buried
24	2.58	0.17	0.06	5	Organic trap, Jam	Jam
25	5.79	0.25	0.28	5	Jam	Jam
26	4.3	0.46	0.71	5	Sediment trap	Buried
27	3.47	0.16	0.07	5	Sediment trap	Buried
28	13.68	0.21	0.47	4	Bank protection	Jam
29	10.77	0.49	2.03	4	Jam	Jam
30	1.8	0.12	0.02	4	Sediment trap	Buried
31	1.58	0.18	0.04	4	Sediment trap	Buried
32	3.88	0.21	0.13	4	Sediment trap	Free
33	1.48	0.13	0.02	4	Sediment trap	Buried
34	6.28	0.16	0.13	4	None	Free
35	1.25	0.18	0.03	3	None	Free
36	1.22	0.18	0.03	2	Bank protection	Step
37	2.52	0.15	0.04	2	Bank protection	Buried
38	5.9	0.13	0.08	2	Sediment trap	Buried
39	1.13	0.16	0.02	2	Sediment trap	Buried
40	8.48	0.23	0.35	2	None	Free
41	2.31	0.33	0.20	1	Bank protection	Buried

Table D-4. Variability of canopy cover observed at CONG002. [SD—standard deviation; CV—coefficient of variance].

Transect	Canopy Cover (%)
1	96
2	94
3	85
4	81
5	91
6	85
7	87
8	82
9	82
10	96
11	100
Min (%)	81
Max (%)	100
Mean (%)	89
Median (%)	87
SD (%)	7
CV	0.07

Table D-5. Average reach-scale bank characteristics at CONG002. 'L' indicates left bank and 'R' indicates right bank [m—meters; SD—standard deviation; CV—coefficient of variance].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)	SD (L)	SD (L)	CV (L)	CV (R)
Bank Height[a] (m)	11	11	0.88	0.98	1.85	1.69	1.47	1.40	1.38	1.46	0.28	0.20	0.19	0.14
Bankfull Height[a,b] (m)	7	11	0.88	0.98	1.78	1.69	1.37	1.40	1.36	1.46	0.28	0.20	0.20	0.14
Channel-full Height[a,b] (m)	5	1	1.38	–	1.85	–	1.64	1.56	1.66	–	0.17	–	0.10	–
Water Depth at Base[c] (m)	11	11	-0.15	-0.20	0.73	-0.06	0.06	-0.13	-0.09	-0.14	0.29	0.04	4.83	-0.31
Bank Undercut[b] (m)	2	0	0.30	–	1.17	–	0.74	–	0.74	–	0.62	–	0.84	–
Bank Angle (°)	11	11	27	21	90	74	62	35	71	27	24	17	0.39	0.49
Vegetation Cover (%)	11	11	5	5	100	100	63	46	60	45	30	35	0.48	0.76
Bank Stability[d]	11	11	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.25	1.44	0.10	0.11

[a] above thalweg.

[b] statistics are based on the transects where feature is present.

[c] a negative number indicates base of bank is above the water surface.

[d] see Table 1 for explanation of scores.

Table D-6. Cross-sectional characteristics for detailed transect 1 at CONG002 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	5.40	10.38	0.52	9.82	0.79	12.46
Channel-full	9.19	13.24	0.69	12.40	1.14	10.84
Ratio	1.70	1.28	1.34	1.26	1.45	0.87

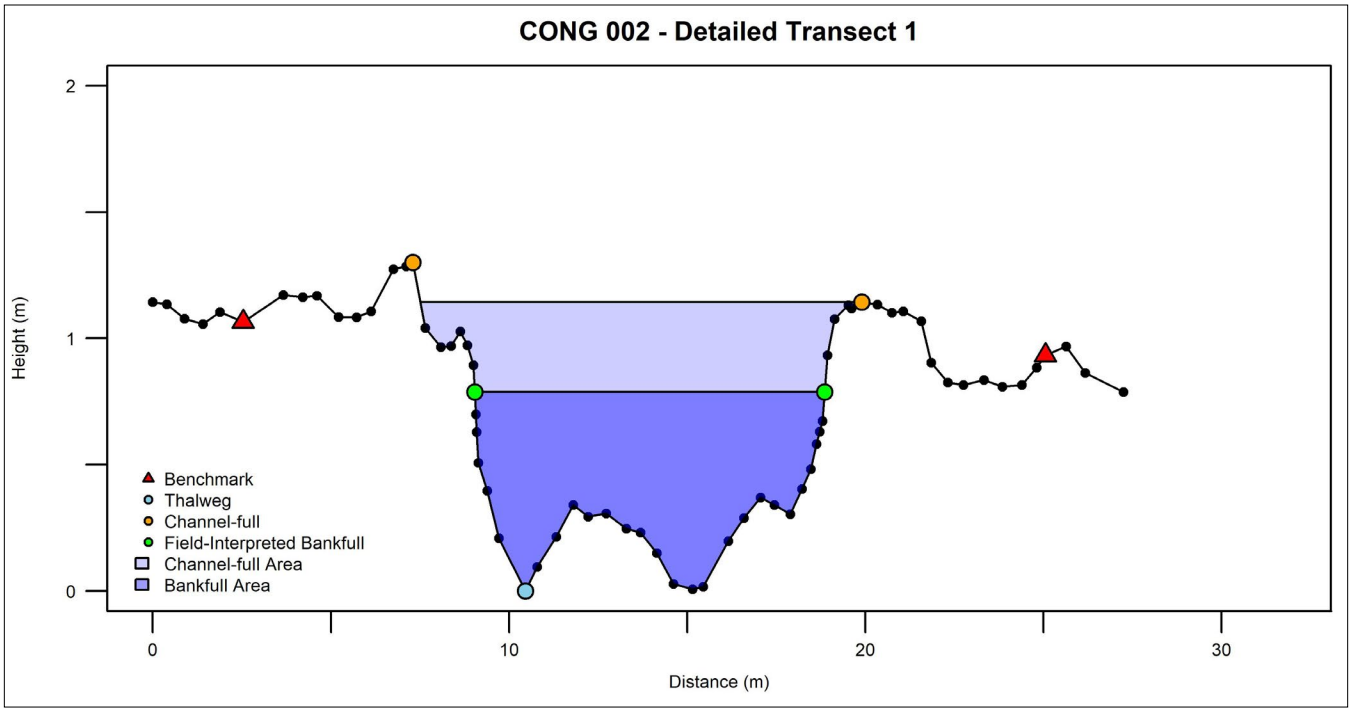


Figure D-14. Detailed transect 1 at CONG002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table D-7. Cross-sectional characteristics for detailed transect 2 at CONG002 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	5.13	14.27	0.36	13.61	0.95	14.33
Channel-full	9.53	16.54	0.58	15.56	1.25	12.41
Ratio	1.86	1.16	1.60	1.14	1.32	0.87

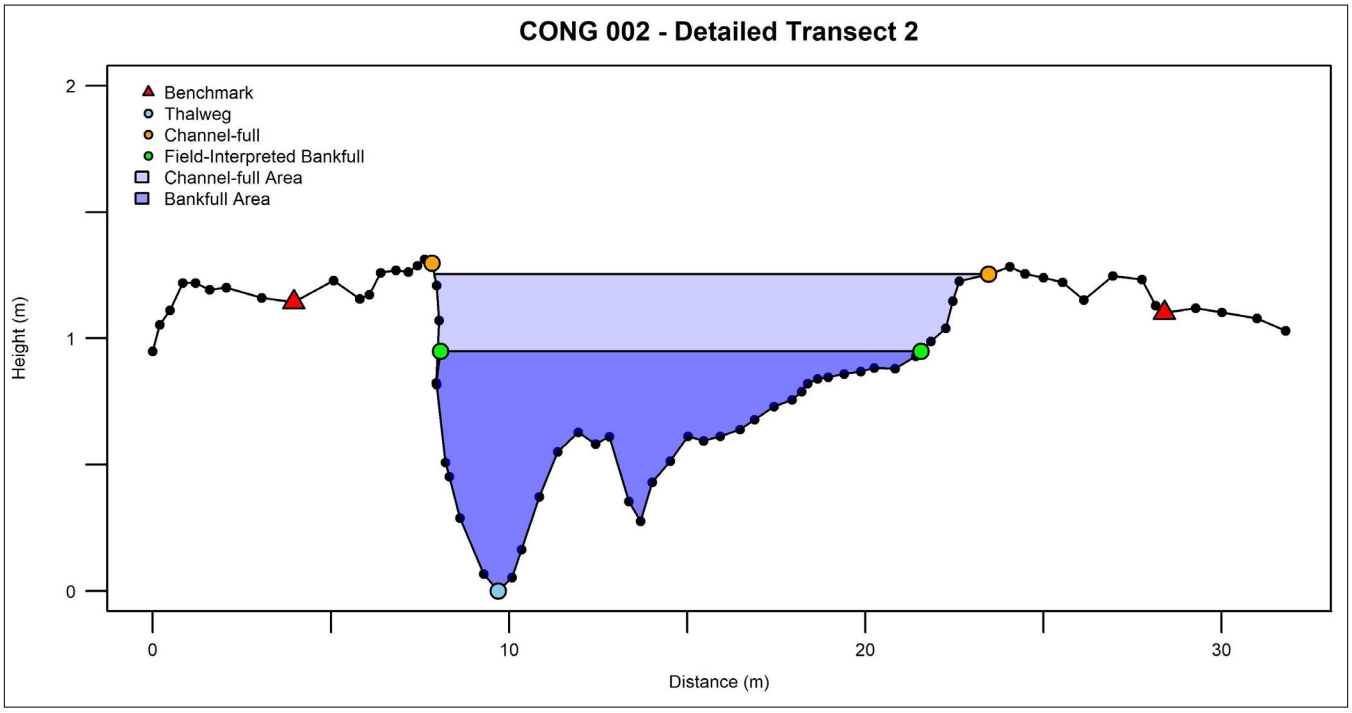


Figure D-15. Detailed transect 2 at CONG002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table D-8. Cross-sectional characteristics for detailed transect 3 at CONG002 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	6.33	11.96	0.53	11.65	0.76	15.32
Channel-full	7.72	13.19	0.59	12.85	0.87	14.69
Ratio	1.22	1.10	1.11	1.10	1.15	0.96

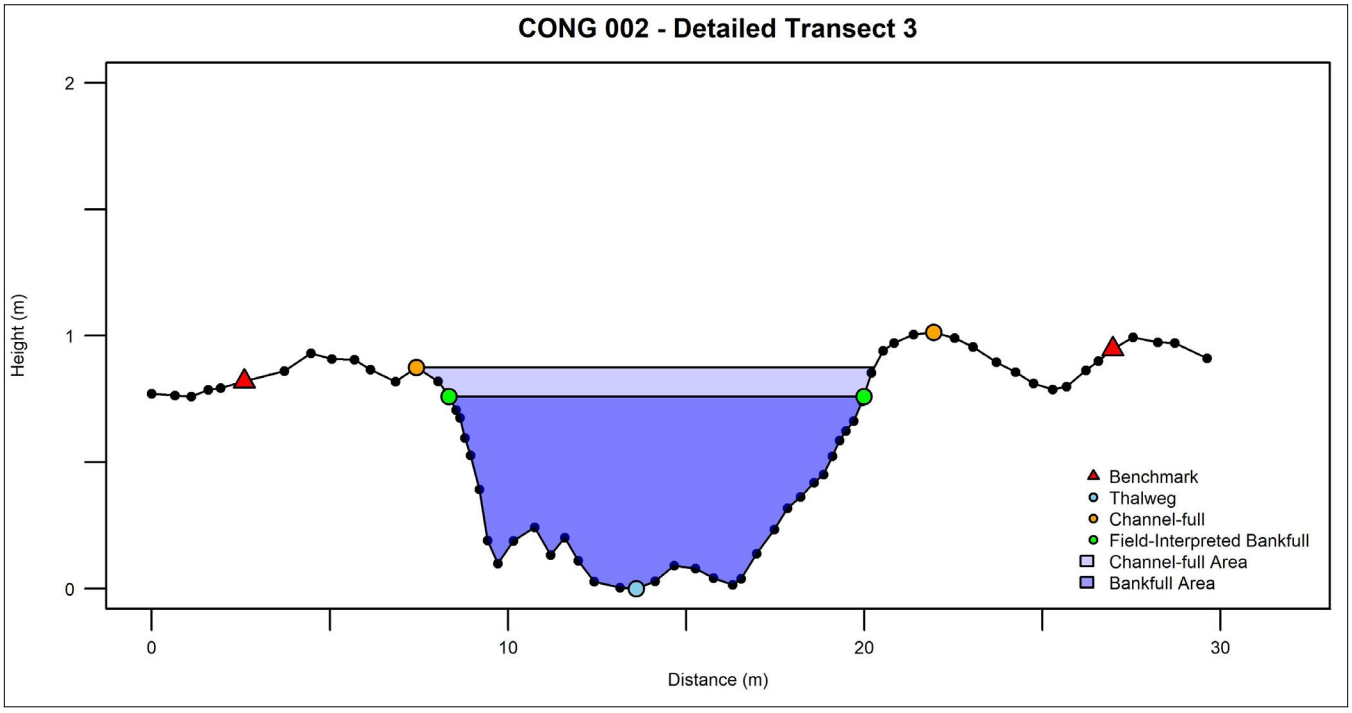


Figure D-16. Detailed transect 3 at CONG002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

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Fry, J. A., G. Xian, S. Jin, J. A. Dewitz, C. G. Homer, L. Yang, C. A. Barnes, N. D. Herold, J. D. Wickham. 2006. Completion of the 2006 National Land Cover Database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 77, no. 9, p. 858–864.

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Appendix E. Survey Results for CONG003

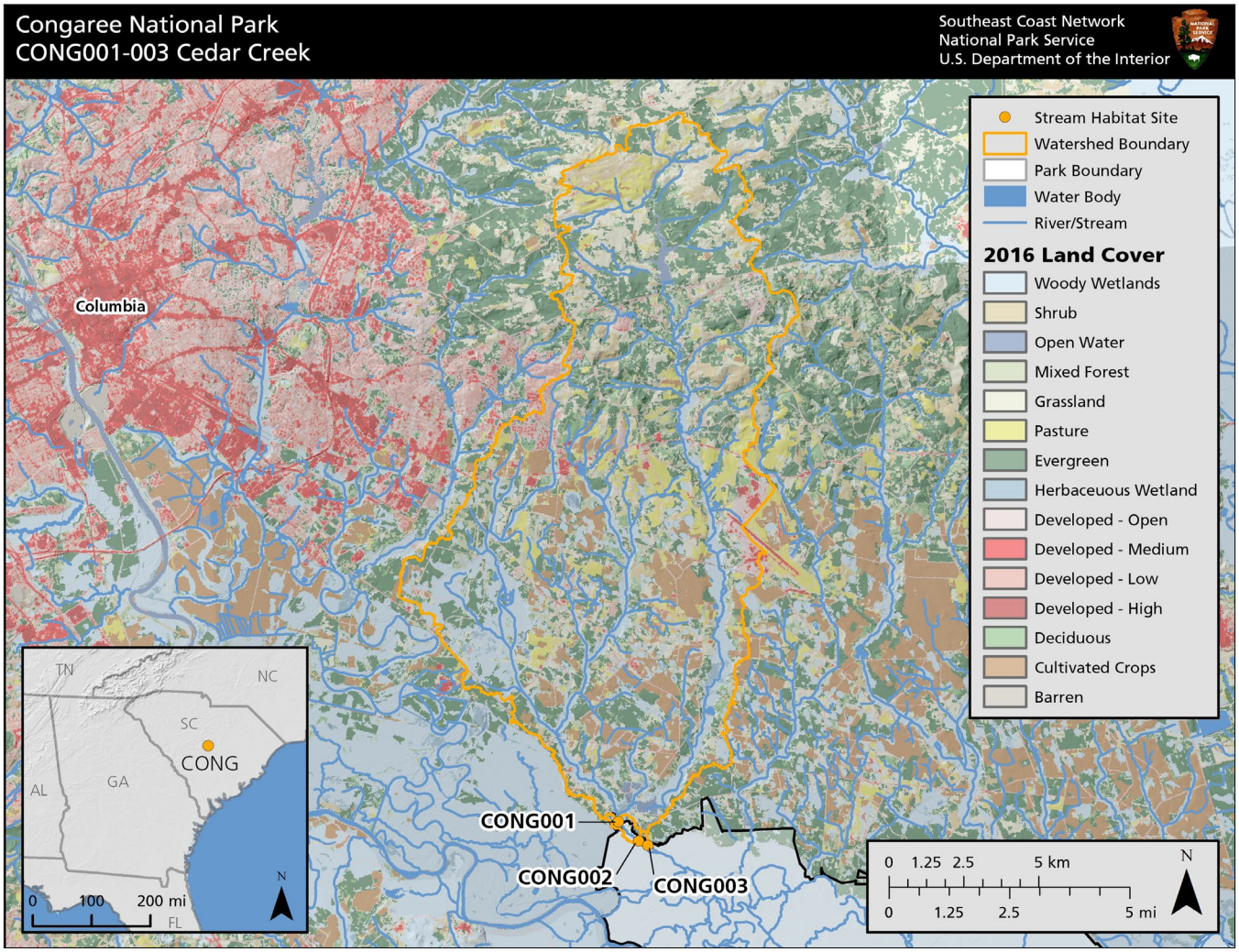


Figure E-1. Map showing the watershed draining to CONG003 at Congaree National Park. The land use and land cover (NLCD 2016, Homer et al. 2020), and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure E-2. Photograph taken on CONG003 looking upstream from T1 (detailed transect 1).



Figure E-3. Photograph taken on CONG003 looking downstream on T1 (detailed transect 1).



Figure E-4. Photograph taken on CONG003 looking at the left bank on T1 (detailed transect 1).



Figure E-5. Photograph taken on CONG003 looking at the right bank on T1 (detailed transect 1).



Figure E-6. Photograph taken on CONG003 looking upstream on T6 (detailed transect 2).



Figure E-7. Photograph taken on CONG003 looking downstream on T6 (detailed transect 2).



Figure E-8. Photograph taken on CONG003 looking at the left bank on T6 (detailed transect 2).



Figure E-9. Photograph taken on CONG003 looking at the right bank on T6 (detailed transect 2).



Figure E-10. Photograph taken on CONG003 looking upstream on T9 (detailed transect 3).



Figure E-11. Photograph taken on CONG003 looking downstream on T9 (detailed transect 3).



Figure E-12. Photograph taken on CONG003 looking at the left bank on T9 (detailed transect 3).



Figure E-13. Photograph taken on CONG003 looking at the right bank on T9 (detailed transect 3).

Table E-1. Land use and land cover characteristics from the National Land Cover Dataset, 2001 (Homer et al. 2001), 2006 (Fry et al. 2006), 2011 (Homer et al. 2015), and 2016 (Homer et al. 2020) for CONG003.

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed	2016 percent of watershed
Open Water	1	1	1	1
Developed—Open[a]	7	7	7	7
Developed—Low[a]	2	3	3	3
Developed—Medium[a]	0	1	1	1
Developed—High[a]	0	0	0	0
Barren	0	0	0	0
Deciduous	14	14	13	4
Evergreen	17	17	16	23
Mixed Forest	4	4	3	8
Shrub	0	2	3	5
Grassland	24	22	23	13
Pasture	8	8	8	8
Cultivated	9	9	9	9
Woody Wetland	13	13	13	18
Herbaceous Wetland	0	0	1	1

[a] refers to the intensity or type of development.

Table E-2. Geomorphic channel units (GCU) observed in the area between transects at CONG003. The data describe the percent coverage of each type of GCU [SD—standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	0	80	20	0
2–3	0	0	30	70	0
3–4	0	40	60	0	0
4–5	0	0	20	80	0
5–6	0	20	80	0	0
6–7	0	70	0	30	0
7–8	0	70	0	30	0
8–9	0	40	30	30	0
9–10	0	70	0	30	0
10–11	0	30	0	70	0
Frequency	0	7	6	8	0
Max (%)	0	70	80	80	0
Mean (%)	0	34	30	36	0
Median (%)	0	35	25	30	0
SD (%)	0	29	33	28	0

Table E-3. Characteristics of the large woody debris (LWD) observed at CONG003 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	7.33	0.63	2.28	11	Sediment trap	Buried
2	3.21	0.20	0.10	9	Sediment trap	Buried
3	2.96	0.40	0.37	9	Sediment trap	Buried
4	5.94	0.31	0.45	8	Sediment trap	Buried
5	2.51	0.15	0.04	8	Organic trap	Buried
6	2.16	0.23	0.09	8	Sediment trap	Buried
7	1.96	0.26	0.10	8	Sediment trap	Buried
8	3.38	0.15	0.06	8	Sediment trap, Organic trap	Buried
9	2.93	0.27	0.17	8	Organic trap	Jam
10	3.24	0.28	0.20	7	Sediment trap, Organic trap	Jam
11	6.27	0.25	0.31	7	Sediment trap	Buried
12	4.54	0.30	0.32	6	Sediment trap	Buried
13	2.93	0.16	0.06	5	Sediment trap	Buried
14	2.76	0.12	0.03	5	Sediment trap	Buried
15	5.92	0.14	0.09	5	Sediment trap, Organic trap	Buried
16	2.91	0.15	0.05	4	Sediment trap	Buried
17	2.64	0.23	0.11	3	Sediment trap	Buried
18	2.73	0.16	0.05	3	Sediment trap	Buried
19	6.46	0.41	0.85	3	Bank protection	Jam
20	2.46	0.15	0.04	3	Bank protection	Ramp
21	3.07	0.39	0.37	2	Sediment trap	Buried
22	3.03	0.26	0.16	1	Sediment trap	Buried
23	2.83	0.20	0.09	1	Sediment trap	Buried
24	2.75	0.28	0.17	1	Sediment trap	Buried
25	2.52	0.40	0.32	1	Organic trap	Ramp
26	2.19	0.16	0.04	1	Sediment trap	Buried

Table E-4. Variability of canopy cover observed at CONG003 [SD—standard deviation; CV—coefficient of variance].

Transect	Canopy Cover (%)
1	78
2	88
3	88
4	85
5	90
6	94
7	91
8	93
9	88
10	93
11	85
Min (%)	78
Max (%)	94
Mean (%)	89
Median (%)	88
SD (%)	5
CV	0.05

Table E-5. Average reach-scale bank characteristics at CONG003. 'L' indicates left bank and 'R' indicates right bank [m—meters; SD—standard deviation; CV—coefficient of variance].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)	SD (L)	SD (L)	CV (L)	CV (R)
Bank Height[a] (m)	11	11	0.78	0.83	1.75	1.80	1.29	1.35	1.24	1.40	0.34	0.31	0.26	0.23
Bankfull Height[a,b] (m)	10	7	0.78	0.83	1.75	1.80	1.24	1.40	1.21	1.41	0.32	0.35	0.26	0.25
Channel-full Height[a,b] (m)	9	9	0.88	0.90	1.75	1.75	1.29	1.33	1.23	1.37	0.32	0.30	0.25	0.23
Water Depth at Base[c] (m)	11	11	-0.13	-0.17	0.16	0.44	-0.02	0.00	-0.03	-0.07	0.09	0.18	–	–
Bank Undercut[b] (m)	1	0	–	–	–	–	0.17	–	–	–	–	–	–	–
Bank Angle (°)	11	11	4	3	90	90	43	47	38	40	29	30	0.67	0.64
Vegetation Cover (%)	11	11	15	5	90	90	59	50	60	50	23	35	0.39	0.70
Bank Stability[d]	11	11	At-Risk	Stable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.40	3.18	0.12	0.30

[a] above thalweg.

[b] statistics are based on the transects where feature is present.

[c] a negative number indicates base of bank is above the water surface.

[d] see Table 1 for explanation of scores.

Table E-6. Cross-sectional characteristics for detailed transect 1 at CONG003 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.83	8.19	0.59	7.44	1.31	5.67
Channel-full	11.86	53.26	0.22	52.45	1.59	32.92
Ratio	2.45	6.50	0.38	7.05	1.21	5.81

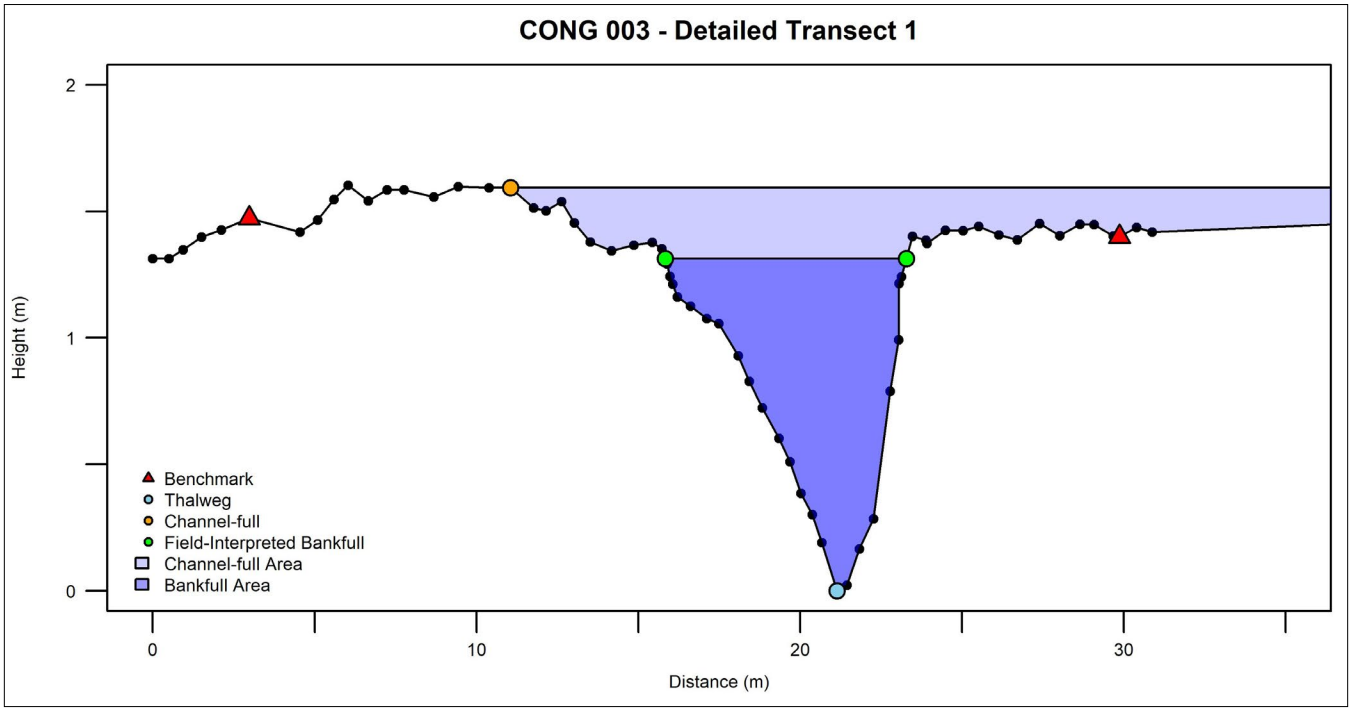


Figure E-14. Detailed transect 1 at CONG003. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table E-7. Cross-sectional characteristics for detailed transect 2 at CONG003 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.42	9.37	0.47	8.89	0.73	12.09
Channel-full	5.88	11.33	0.52	10.75	0.89	12.14
Ratio	1.33	1.21	1.10	1.21	1.21	1.00

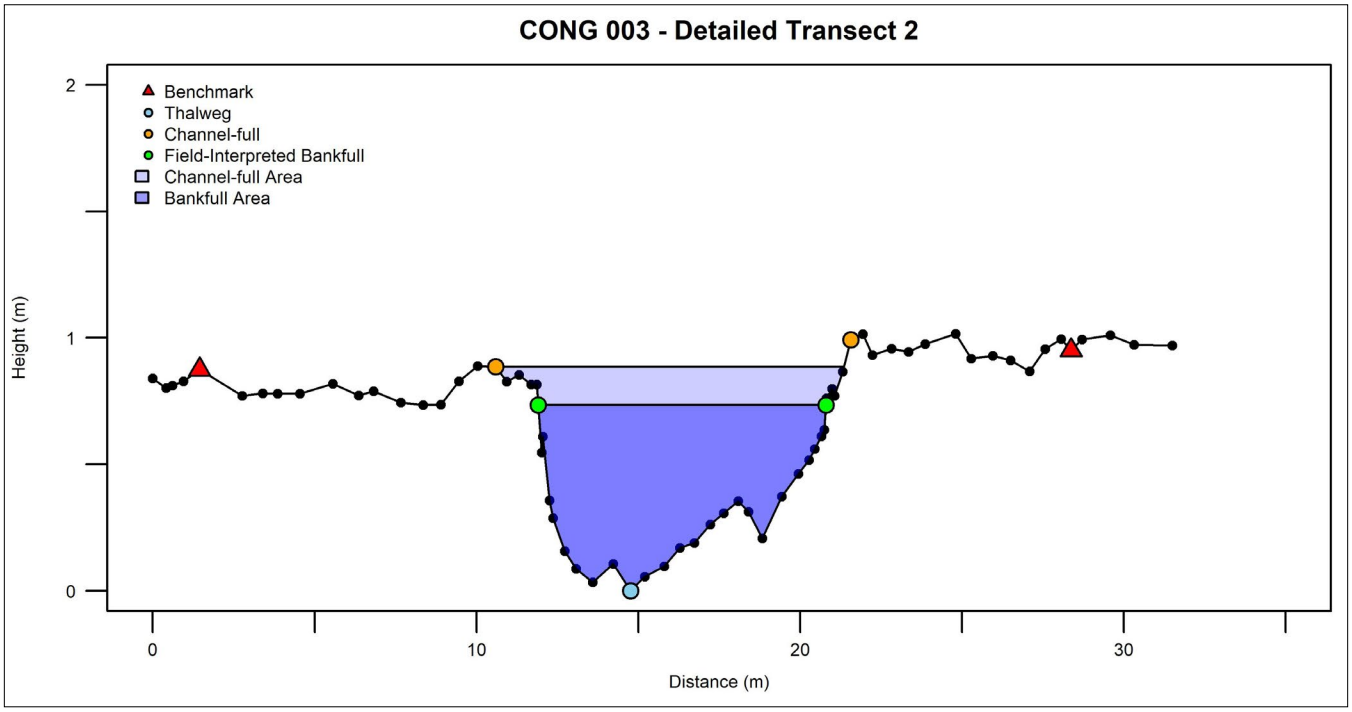


Figure E-15. Detailed transect 2 at CONG003. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table E-8. Cross-sectional characteristics for detailed transect 3 at CONG003 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.51	10.50	0.43	9.97	0.83	12.02
Channel-full	8.23	16.70	0.49	16.03	1.11	14.50
Ratio	1.82	1.59	1.15	1.61	1.33	1.21

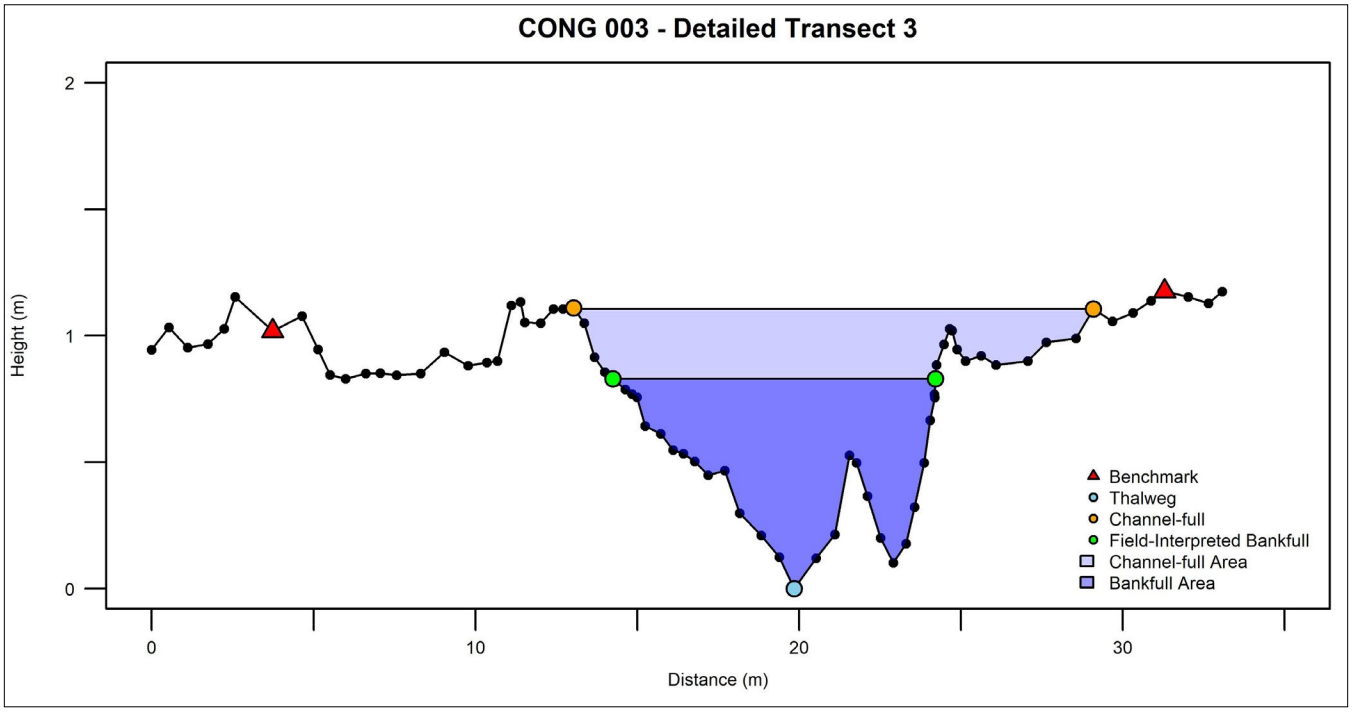


Figure E-16. Detailed transect 3 at CONG003. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

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Fry, J. A., G. Xian, S. Jin, J. A. Dewitz, C. G. Homer, L. Yang, C. A. Barnes, N. D. Herold, J. D. Wickham. 2006. Completion of the 2006 National Land Cover Database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 77, no. 9, p. 858–864.

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Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown. 2015. Completion of the 2011 national land cover database for the conterminous United States—representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing. 81:345–354.

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Appendix F. Survey Results for CONG004

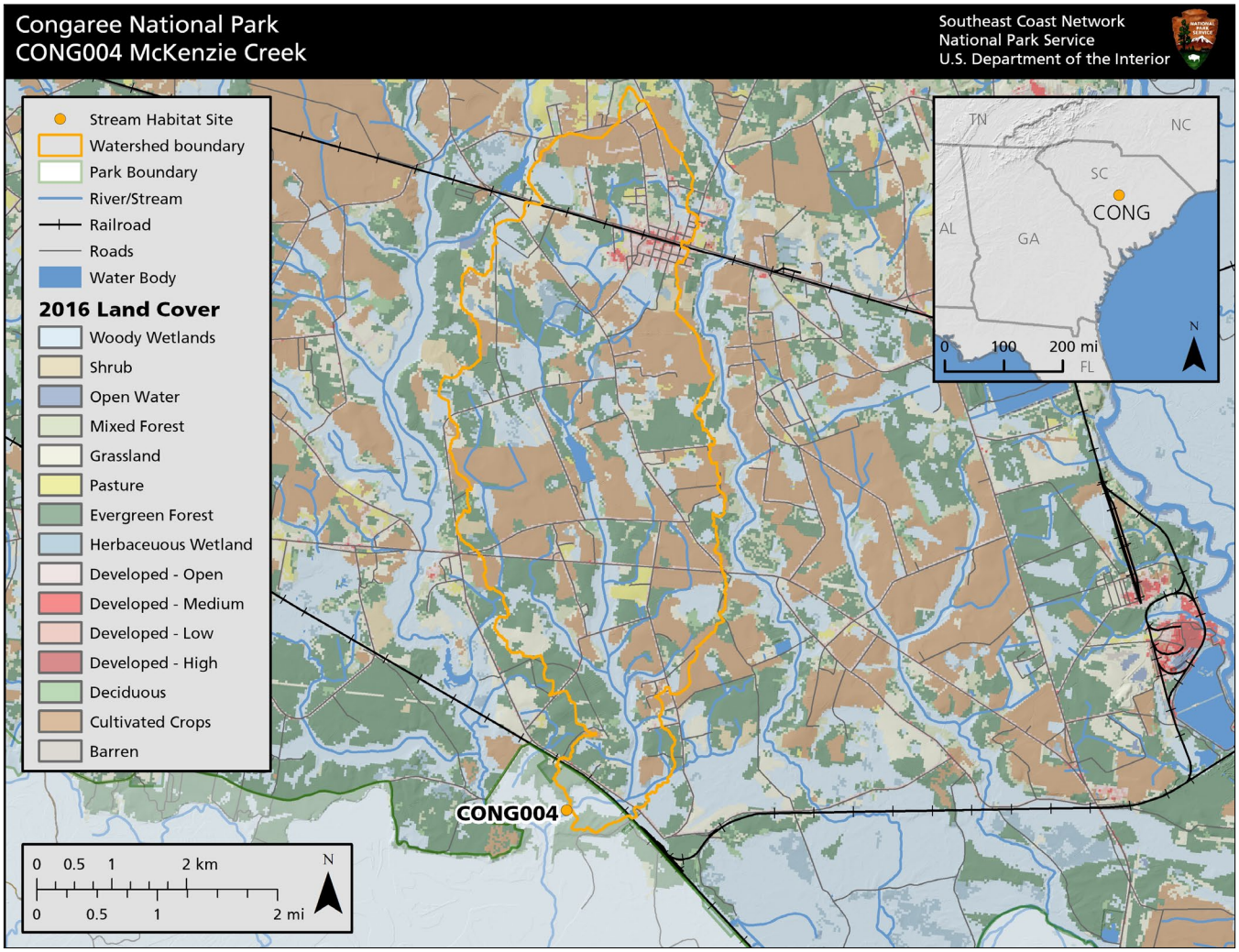


Figure F-1. Map showing the watershed draining to CONG004 at Congaree National Park. The land use and land cover (NLCD 2016, Homer et al. 2020), road network, railroads and perennial streams (derived from a 10-meter [32.8 ft] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure F-2. Photograph taken on CONG004 looking upstream from T1 (detailed transect 1).



Figure F-3. Photograph taken on CONG004 looking downstream on T1 (detailed transect 1).



Figure F-4. Photograph taken on CONG004 looking at the left bank on T1 (detailed transect 1).



Figure F-5. Photograph taken on CONG004 looking at the right bank on T1 (detailed transect 1).



Figure F-6. Photograph taken on CONG004 looking upstream on T6 (detailed transect 2).



Figure F-7. Photograph taken on CONG004 looking downstream on T6 (detailed transect 2).



Figure F-8. Photograph taken on CONG004 looking at the left bank on T6 (detailed transect 2).



Figure F-9. Photograph taken on CONG004 looking at the right bank on T6 (detailed transect 2).



Figure F-10. Photograph taken on CONG004 looking upstream on T11 (detailed transect 3).



Figure F-11. Photograph taken on CONG004 looking downstream on T11 (detailed transect 3).



Figure F-12. Photograph taken on CONG004 looking at the left bank on T11 (detailed transect 3).



Figure F-13. Photograph taken on CONG004 looking at the right bank on T11 (detailed transect 3).

Table F-1. Land use and land cover characteristics from the National Land Cover Dataset, 2001 (Homer et al. 2001), 2006 (Fry et al. 2006), 2011 (Homer et al. 2015), and 2016 (Homer et al. 2020) for CONG004.

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed	2016 percent of watershed
Open Water	0	0	0	0
Developed—Open[a]	5	5	5	5
Developed—Low[a]	3	3	3	3
Developed—Medium[a]	0	0	0	0
Developed—High[a]	0	0	0	0
Barren	0	0	0	0
Deciduous	5	5	5	1
Evergreen	29	27	26	25
Mixed Forest	0	0	0	2
Shrub	0	2	1	1
Grassland	24	19	20	8
Pasture	4	4	4	1
Cultivated	21	22	24	30
Woody Wetland	7	11	10	21
Herbaceous Wetland	0	1	2	2

[a] refers to the intensity or type of development.

Table F-2. Geomorphic channel units (GCU) observed in the area between transects at CONG004. The data describe the percent coverage of each type of GCU [SD—standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	0	0	100	0
2–3	0	0	0	100	0
3–4	0	0	0	100	0
4–5	0	0	0	100	0
5–6	5	0	0	95	0
6–7	10	0	0	30	60
7–8	60	0	0	40	0
8–9	0	0	0	100	0
9–10	0	80	0	20	0
10–11	40	40	0	20	0
Frequency	4	2	0	10	1
Max (%)	60	80	0	100	60
Mean (%)	12	12	0	71	6
Median (%)	0	0	0	98	0
SD (%)	21	27	0	37	19

Table F-3. Characteristics of the large woody debris (LWD) observed at CONG004 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	1.16	0.18	0.03	3	Bank protection	Free
2	1.44	0.63	0.45	4	Sediment trap	Buried
3	1.70	0.14	0.03	6	None	Free
4	4.43	0.27	0.25	6	Jam	Jam
5	1.63	0.15	0.03	6	Jam	Jam
6	2.80	0.19	0.08	6	Jam	Jam
7	1.04	0.15	0.02	7	None	Free
8	1.24	0.17	0.03	7	Organic trap	Buried
9	1.89	0.17	0.04	9	Bank protection	Buried

Table F-4. Variability of canopy cover observed at CONG004 [SD—standard deviation; CV—coefficient of variance].

Transect	Canopy Cover (%)
1	91
2	91
3	88
4	96
5	100
6	99
7	94
8	96
9	94
10	82
11	87
Min (%)	82
Max (%)	100
Mean (%)	93
Median (%)	94
SD (%)	5
CV	0.06

Table F-5. Average reach-scale bank characteristics at CONG004. 'L' indicates left bank and 'R' indicates right bank [m—meters; SD—standard deviation; CV—coefficient of variance].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)	SD (L)	SD (L)	CV (L)	CV (R)
Bank Height[a] (m)	11	11	0.49	0.32	1.00	0.86	0.68	0.62	0.68	0.61	0.13	0.15	0.19	0.25
Bankfull Height[a,b] (m)	11	10	0.49	0.32	1.00	0.78	0.68	0.60	0.68	0.61	0.13	0.14	0.19	0.23
Channel-full Height[a,b] (m)	11	11	0.55	0.39	1.11	0.95	0.78	0.71	0.79	0.69	0.14	0.15	0.18	0.21
Water Depth at Base[c] (m)	11	11	-0.24	-0.27	-0.14	-0.13	-0.19	-0.20	-0.19	-0.19	0.03	0.05	–	–
Bank Undercut[b] (m)	2	0	0.11	–	0.14	–	0.13	–	0.13	–	0.02	–	0.17	–
Bank Angle (°)	11	11	16	3	82	76	49	46	44	50	21	25	0.43	0.54
Vegetation Cover (%)	11	11	5	5	90	90	48	45	50	50	28	34	0.58	0.76
Bank Stability[d]	11	11	Unstable	Unstable	Unstable	Very Unstable	Unstable	Unstable	Unstable	Unstable	0.86	1.63	0.07	0.13

[a] above thalweg.

[b] statistics are based on the transects where feature is present.

[c] a negative number indicates base of bank is above the water surface.

[d] see Table 1 for explanation of scores.

Table F-6. Cross-sectional characteristics for detailed transect 1 at CONG004 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.17	4.32	0.27	4.15	0.42	9.84
Channel-full	2.63	18.63	0.14	18.39	0.54	33.88
Ratio	2.25	4.31	0.52	4.43	1.29	3.44

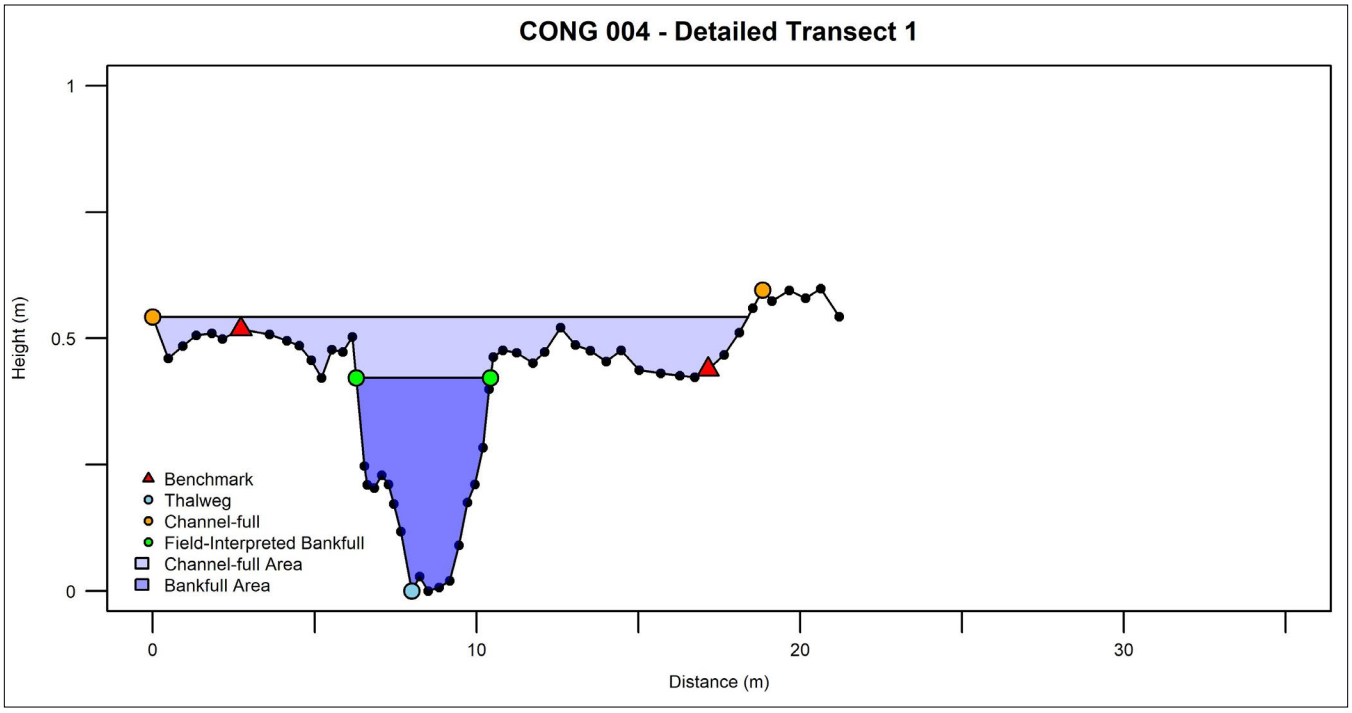


Figure F-14. Detailed transect 1 at CONG004. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table F-7. Cross-sectional characteristics for detailed transect 2 at CONG004 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.56	4.59	0.34	4.03	0.49	8.20
Channel-full	3.88	17.24	0.23	16.50	0.75	21.99
Ratio	2.48	3.75	0.66	4.09	1.53	2.68

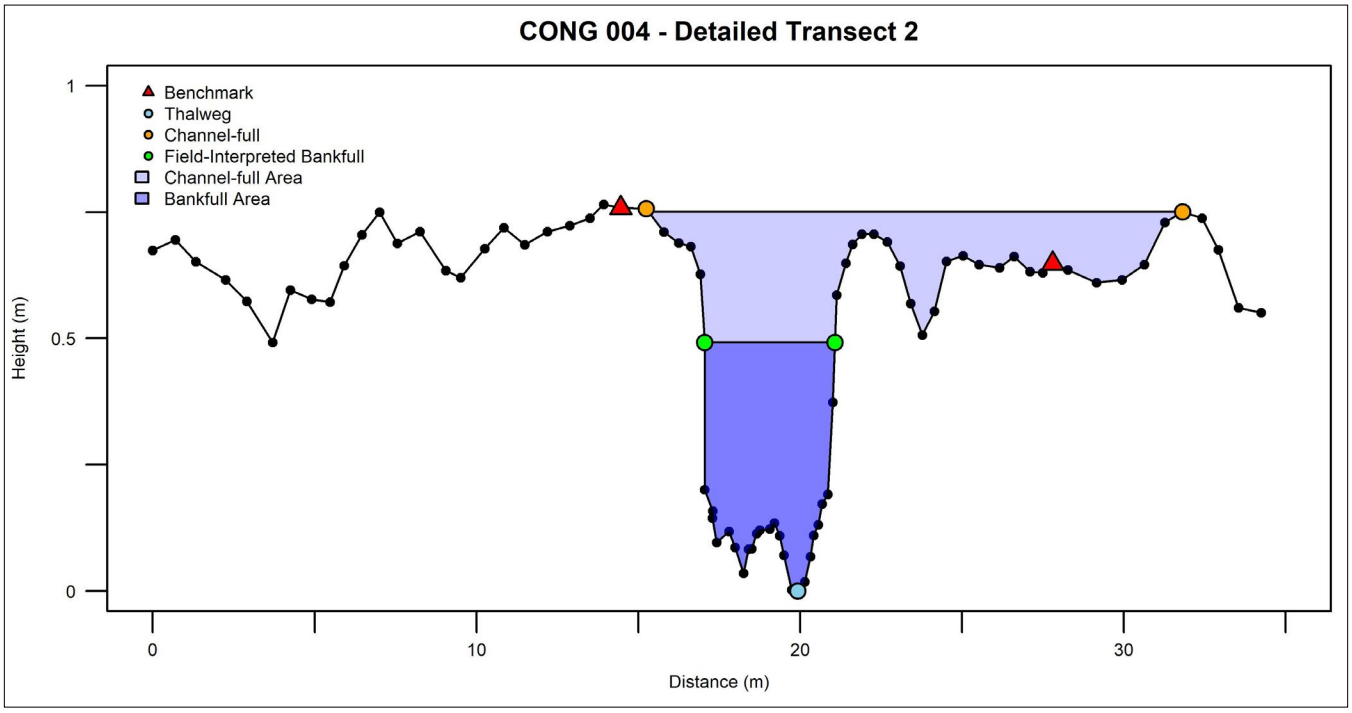


Figure F-15. Detailed transect 2 at CONG004. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

Table F-8. Cross-sectional characteristics for detailed transect 3 at CONG004 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	0.17	1.71	0.10	1.66	0.15	10.87
Channel-full	2.52	15.03	0.17	14.72	0.53	27.96
Ratio	14.82	8.77	1.69	8.86	3.44	2.57

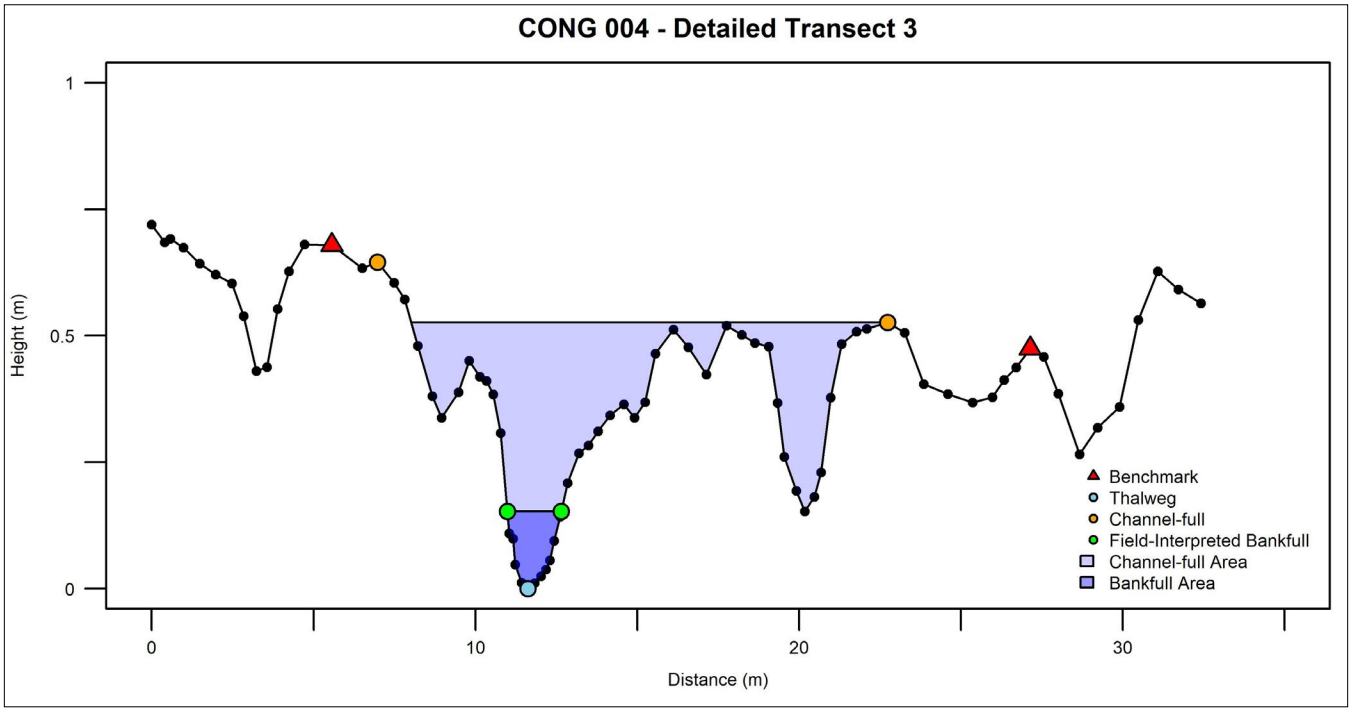


Figure F-16. Detailed transect 3 at CONG004. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction (river left is on the left side of the diagram).

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