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Natural Resource Stewardship and Science

Wadeable Stream Habitat Monitoring at Kennesaw Mountain National Battlefield Park

2017 Baseline Report

Natural Resource Report NPS/SECN/NRR—2019/2030



ON THE COVER

Picture looking upstream on transect 6 at the stream monitoring site on Noses Creek (KEMO 001) at Kennesaw Mountain National Battlefield Park on May 17, 2017. NPS photo / SECN

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Jacob M. McDonald[1,2] and Eric N. Starkey[2]

[1]University of North Georgia
Lewis F Rogers Institute for Environmental and Spatial Analysis
Watkins Building, Room 176
3820 Mundy Mill Road
Oakwood, Georgia 30566

[2]National Park Service
Southeast Coast Inventory and Monitoring Network
135 Phoenix Road
Athens, Georgia 30605

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Summary and Key Findings

The Southeast Coast Network (SECN) stream habitat monitoring protocol provides guidance for wadeable stream data collection in Southeast Coast Network parks. The results of this effort are intended to provide resource managers insight into the status of and trends in stream and near-channel habitat conditions (McDonald et al. 2018a). Wadeable stream assessments are currently implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park, Kennesaw Mountain National Battlefield, Ocmulgee Mounds National Historical Park, Chattahoochee River National Recreation Area, and Congaree National Park. Streams chosen for assessment were specifically targeted for management interest (e.g., trail erosion issues and upstream urban development) or to provide a context for similar-sized stream(s) within the park or network (McDonald and Starkey 2018a).

The objectives of the SECN 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.

On May 17, 2017, data were collected at Kennesaw Mountain National Battlefield Park (KEMO) to characterize the in-channel and near-stream habitat on Noses Creek (KEMO001) and John Ward Creek (KEMO002). These data, along with in-office 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 two stream reaches.

Noses Creek's watershed (KEMO001) is steep and forested and Ward Creek's watershed (KEMO002) has low slope/relief and is covered mostly by urban/suburban development. Based on the results of the pebble counts, the type/distribution of geomorphic channel units within each reach, and the presence or absence of large woody debris, in-stream habitat within the surveyed stream reaches were classified as "poor to fair" at KEMO001 and "poor" at KEMO002. 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 Kennesaw Mountain NBP. If the bed material at KEMO001 becomes finer and if the geomorphic channel units within the reach become more homogenous, the habitat classification may degrade to "poor". Alternatively, addition of large woody debris to KEMO001 may increase habitat diversity and provide more stability to the reach that could upgrade the classification to "fair." Habitat at KEMO002 will continue to be "poor" until stable (non-mobile) in-channel (non-bridging) large woody debris increases the diversity of habitat and upstream conditions reduce the amount of fine sediment that is delivered to the reach

(Allan and Castillo 2007). Currently, much of the existing large woody debris spans the channel and has minimal influence on geomorphic channel units.

Both streams are recovering from a legacy of poor land use practices, and their flow and sedimentation regimes are influenced by differing amounts of impervious surface cover and urban and suburban development within their respective watersheds. The surveyed reaches are beginning to develop a meandering planform inset within the entrenched channel-full surface. Additionally, Noses Creek is experiencing possible headward migration of a small knickpoint that may cause further bed degradation in the middle and upstream portions of the survey reach in the future. The rate at which this knickpoint migrates upstream is dependent on the sediment composition of the boundary layer (bed sediment), the amount of large woody debris available to increase bed and bank resistance, and the flow regime that shapes the stream. As a result of changes in bed elevation (from bed degradation or through the process of complex response), bank undercutting and slumping is a common process occurring in the park. Some of these slumps may become colonized by vegetation and become stable sediment sinks. Prior to becoming colonized by vegetation and in higher energy portions of the streams, these slumps will likely erode and contribute additional sediment to areas downstream. Neither of these streams have immediate management concerns. The biggest concern for visitors is that high banks need to be navigated to access the streams.

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 variation

DEM—Digital elevation model

FP—Floodplain

FPM—Floodplain 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

LT—Low terrace

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) 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 provided through this monitoring effort will provide park staff with information regarding the physical linkage between streams and park resources. Additionally, this monitoring program will provide 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 (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 and Starkey 2018a, McDonald and Starkey 2018b; McDonald 2019;). 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 2018d). Streams chosen for monitoring at Kennesaw Mountain NBP were specifically targeted due to management interest (e.g., trail erosion issues and upstream urban development) or to provide a context for similar-sized streams in the park (see suitability reports for each park [cited in this paragraph] for more information).

The objectives of SECN 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 referred to herein do not include non-perennial channel-like features typical of a highly disturbed and gullied landscape.

This report presents the wadeable stream survey results for the surveys completed at Kennesaw Mountain NBP during late spring 2017. This report provides park resource managers and partners with information about the physical characteristics of the surveyed stream reaches and provides a basin-scale context for the differences observed between the two reaches (KEMO001 and KEMO002). A regional context is provided by comparing the Kennesaw Mountain NBP streams to two similar-sized streams at Chattahoochee River NRA (Haw Creek [CHAT001] and Long Island Creek [CHAT013]; McDonald et al. 2019).

Study Area

The hydro-climatic conditions of the study area are characterized as humid subtropical with average annual rainfall around 50 inches (127 centimeters [cm]) per year; Wright et al. 2011). Snowfall is negligible and winters are mild; summers are hot and humid. Average monthly temperature ranges from a low in December of approximately 27ºF (-3°C) to a high in August of 92°F (33°C; Wright et al. 2011). Monthly rainfall totals are distributed rather evenly from October through May due to the influence of frontal systems that sweep through the region (Lecce 2000). Convective thunderstorms influence the region from late spring through early fall. While monthly precipitation tends to be high in the summer, the high levels of evapotranspiration attenuate streamflow during this part of the year (Lins 1997).

The natural condition of rivers 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). Beginning in the late 1800s, deforestation, increased row crop agriculture, and a general lack of soil conservation measures caused widespread erosion of topsoil from steeply sloped upland areas in the Appalachian Piedmont (Trimble 1969). Sediment was transported to streams and floodplains, burying biologically productive shoal and riffle habitats. Streams in the region were transformed, from the hard-bottomed, clear-flowing streams described by early land surveyors, into conduits of turbid water and sand. As row-crop agriculture became less dominant and forest cover increased, sediment delivery to streams was reduced and streambeds began to degrade (Schumm et al. 1984). Today, streambed elevations in many of the region's small streams have returned to historic or near historic levels though their geomorphic characteristics (width, depth, entrenchment) are quite different from early settlement conditions (Schoonover et al. 2007; Mukudan et al. 2011).

In addition to the legacy effects of agriculture, many Appalachian Piedmont streams (including those draining to and through Kennesaw Mountain NBP) have been further subjected to hydrologic alterations caused by urban/suburban development. Increases in impervious surface area associated with development creates conditions that increase the frequency and magnitude of peak discharges (Paul and Meyer 2001). Impervious surface area is also associated with lower-than-normal base flow during dry periods due to impaired groundwater recharge (Rose and Peters 2001). These flow alterations greatly influence available in- and near-stream habitats and can have a large impact on the biota found within a stream (Wenger et al. 2008).

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 sediment more sediment than flow regime can transport), degradation and narrowing (from a reduction in sediment and/or increased runoff), further degradation and widening, and finally stabilization and more natural reworking of in-channel alluvium (Figure 1). The exact stage that each stream is currently at is dependent on the location of the stream within its network and the unique history and current land use/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 quite unstable and subject to undercutting and slumping (Ruhlman and Nutter 1999).

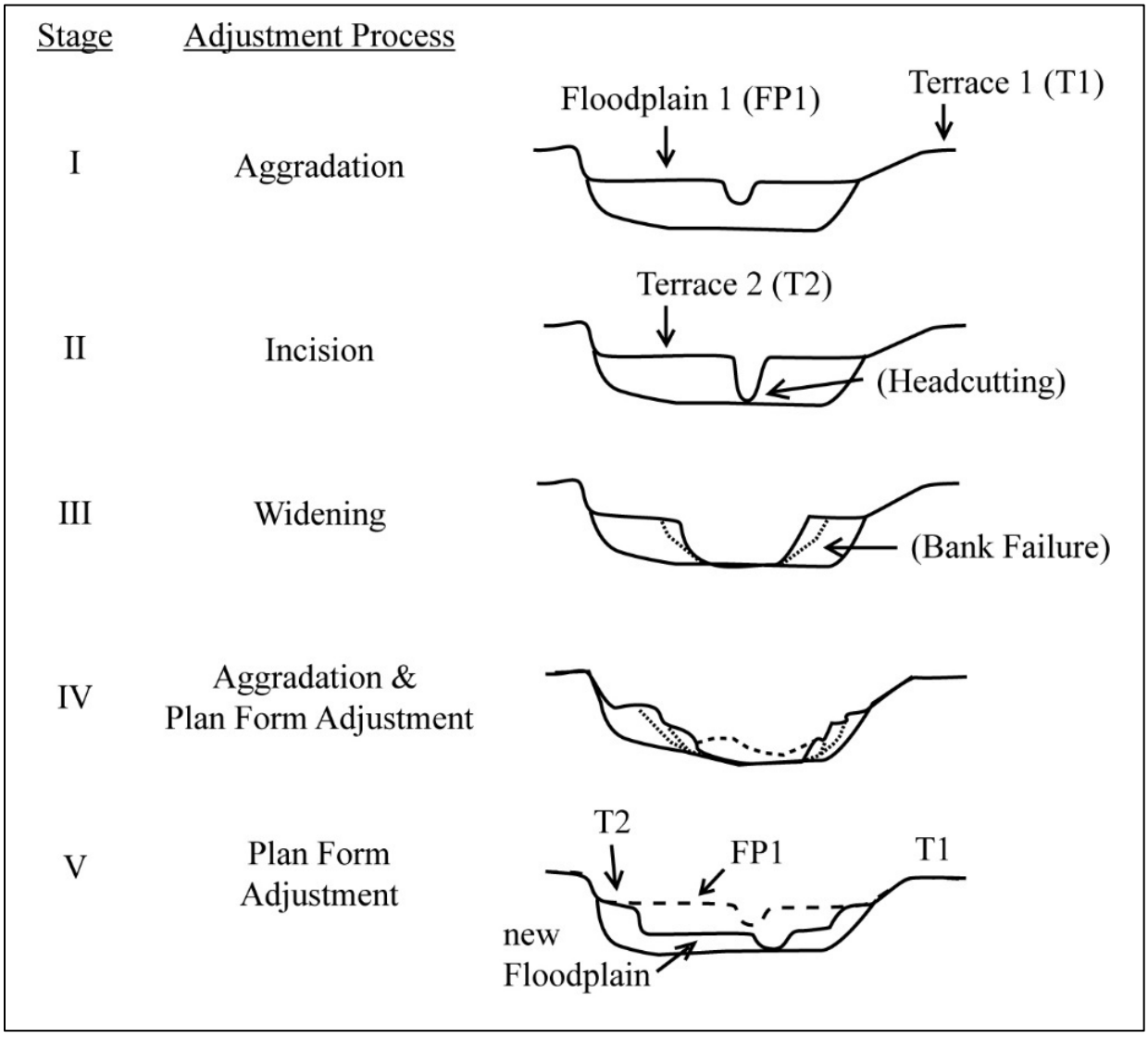


Figure 1. Generalized channel evolution model (modified from Schumm et al. 1984).

Kennesaw Mountain National Battlefield Park

Kennesaw Mountain National Battlefield Park consists of approximately 3,000 acres (1,214 hectares [ha]) of mixed hardwood pine forest and open fields. The park is located within the Atlanta metropolitan area in the Allatoona Mountain range (Figure 2). Kennesaw Mountain is the northern portion of the park and receives approximately 2.6 million visitors per year. Water resources include some small bog wetlands and mountain seeps (less than 10% of the area) and two perennial streams. These relatively small Strahler third order streams (Strahler 1957), Noses Creek and John Ward Creek, originate outside the park boundaries and drain mostly urban and suburban areas prior to flowing through the park. Due to the intense urban and suburban development outside the park, the hydrology of these streams has been substantially altered, and they exhibit flashy flows typical of streams in an urban setting (Gregory and Calhoun 2007; Gregory et al. 2012; Starkey 2015). The heavy visitor loads and popularity of horseback riding on trails throughout this park have created areas where stream bank erosion is a potential management concern (Stan Bond, former Park Superintendent, personal communication).

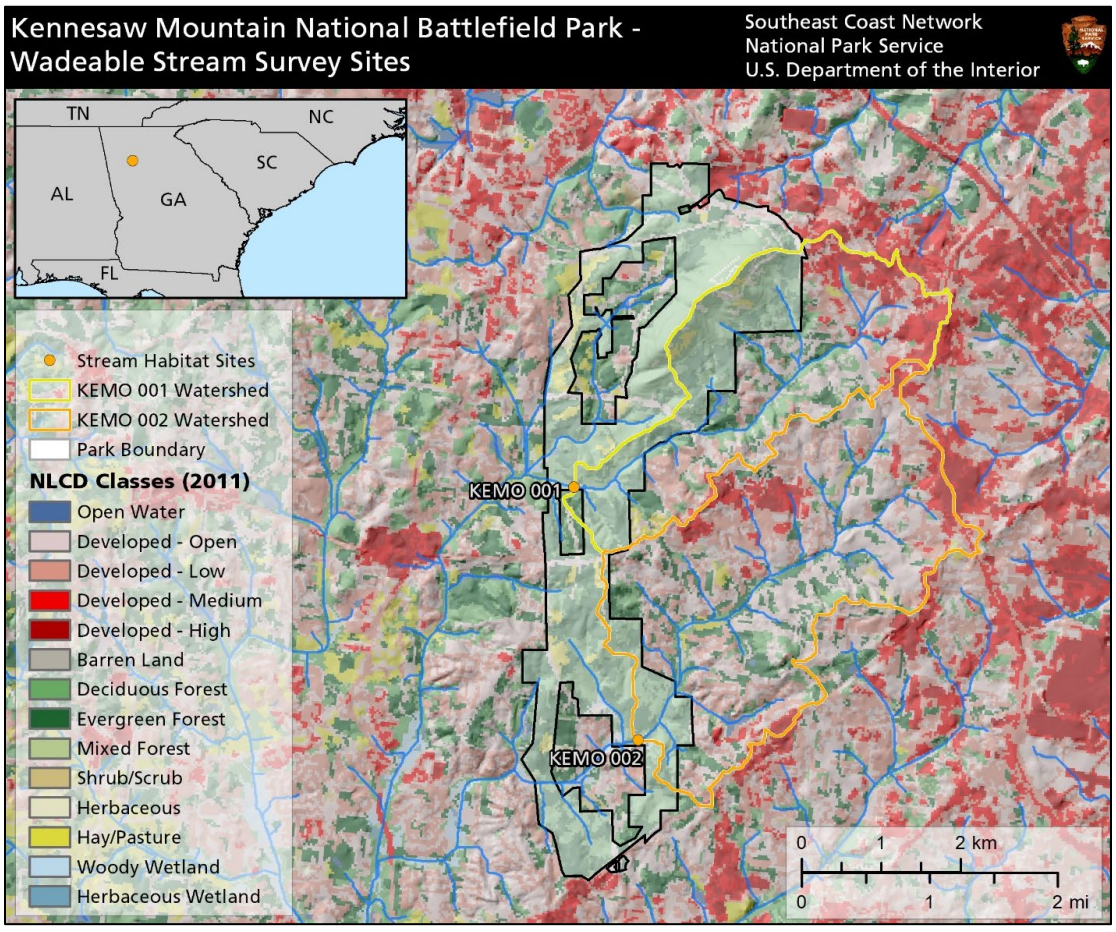


Figure 2. Map showing Kennesaw Mountain National Battlefield Park and its wadeable stream sites (KEMO001 and KEMO002). The watersheds draining to each study reach are shown to provide a context for the data presented in this report. The land use/land cover (NLCD 2011, Homer et al. 2015) and perennial streams (derived from a 10-meter digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

Methods

The habitat characteristics and geomorphic parameters that were selected for monitoring are based on those collected by other federal organizations (USGS, Fitzpatrick et al., 1998; USEPA, Hughes, 2000; and USFS, Harrelson et al. 1994). 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: (1) basin-scale characteristics; (2) reach-scale measurements, along and between eleven standard transects per reach, and; (3) detailed cross-sectional measurements, at three of the eleven transects per reach (Figure 3). A table containing a list and definitions of each variable collected under the protocol can be found in Appendix A. While summarized in this document, a list of standard operating procedures and an overview of the methods used to collect and process the survey data are available in McDonald et al. (2018a).

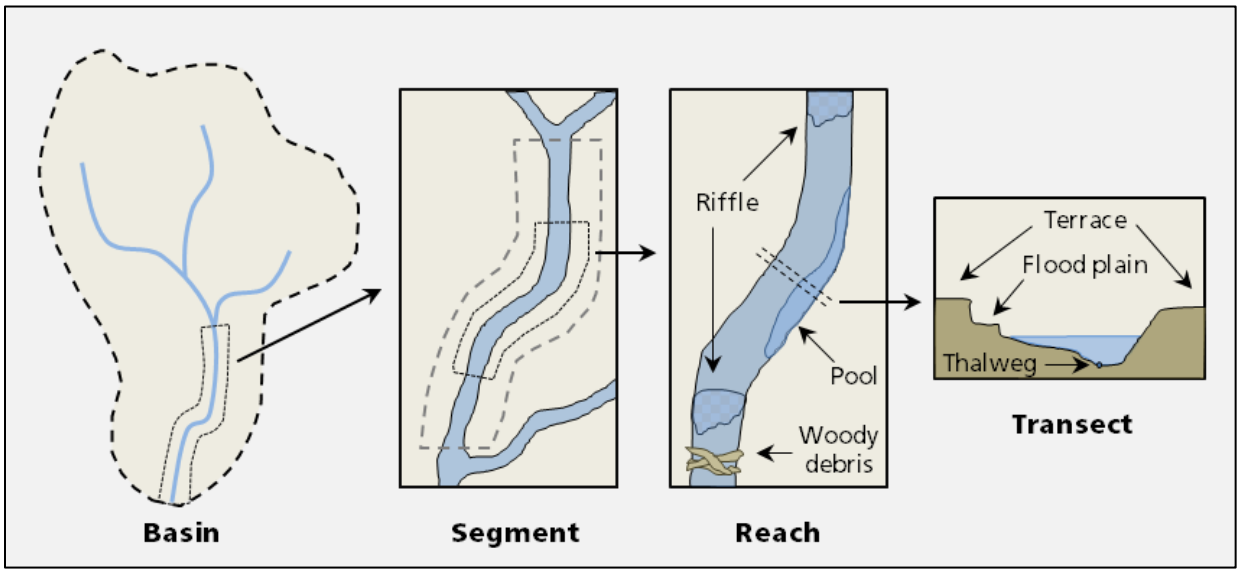


Figure 3. Spatial hierarchy of stream systems and scales of data collection (modified from Fitzpatrick et al. 1998).

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). Instructions for the GIS basin analysis can be found in SOP 1.2.15 *Wadeable Stream 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/angles. In addition to a qualitative description of bed sediment at 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/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 are scored as “at-risk” or “unstable.” This condition is consistent with expectations, given that many comparable streams in the region are currently reestablishing functional floodplains 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 versus low-energy pools), an inventory of large woody debris (LWD; defined as greater than 1 meter [3.3 ft] in length and greater than 10 centimeters [3.9 inches {in}] in diameter as defined in McDonald et al. 2018a) within the reach, and a description of in-channel features (e.g., sand/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 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. In addition to classifying each stream’s habitat, processes or events are identified that may affect these classifications; either leading to habitat improvement or degradation.

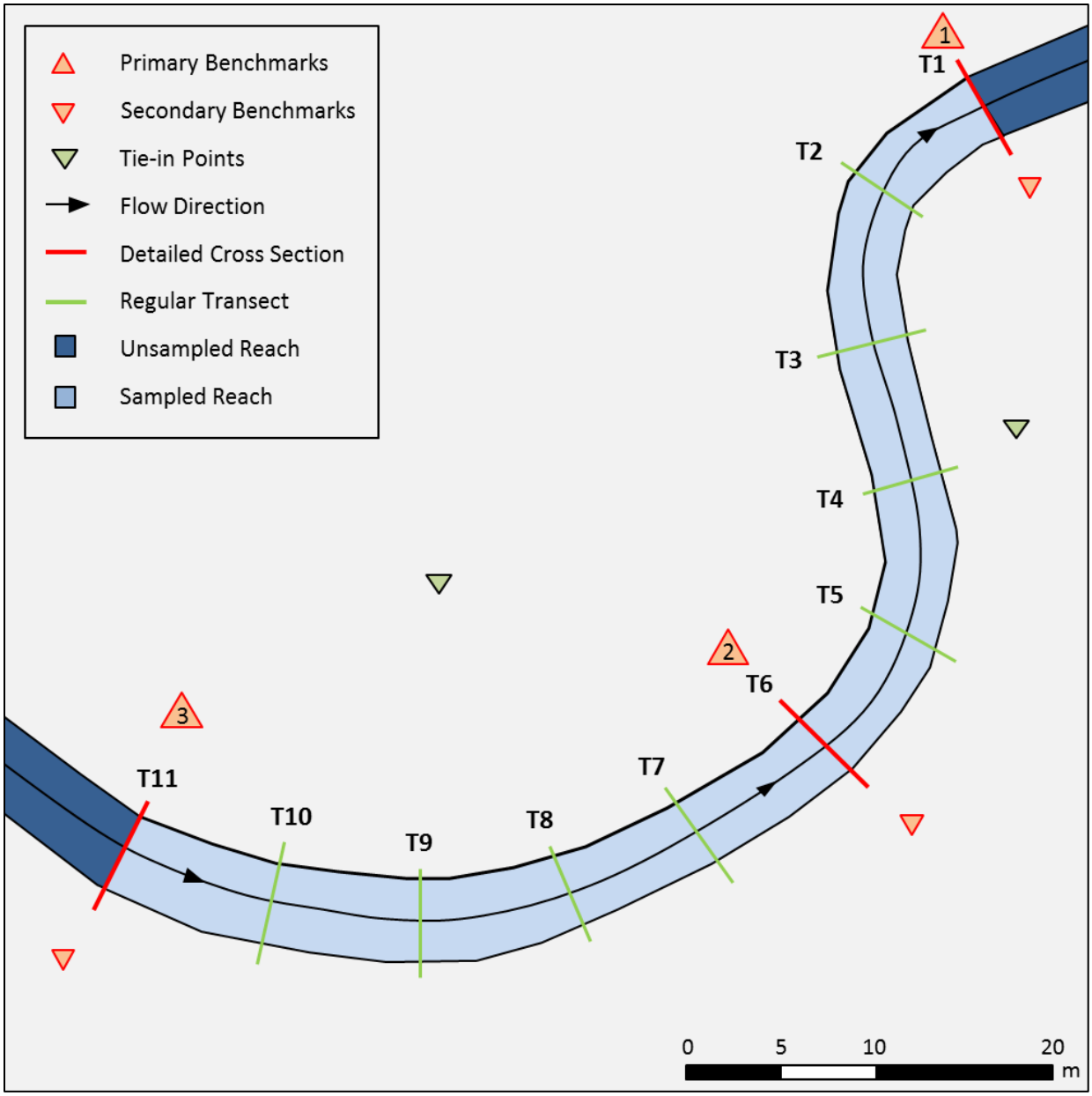


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.

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)[1].

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

[1] 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-millimeter 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 will be used to calculate bankfull and channel-full areas and will be used along with the bank stability index to assess the condition and stability of the reach.

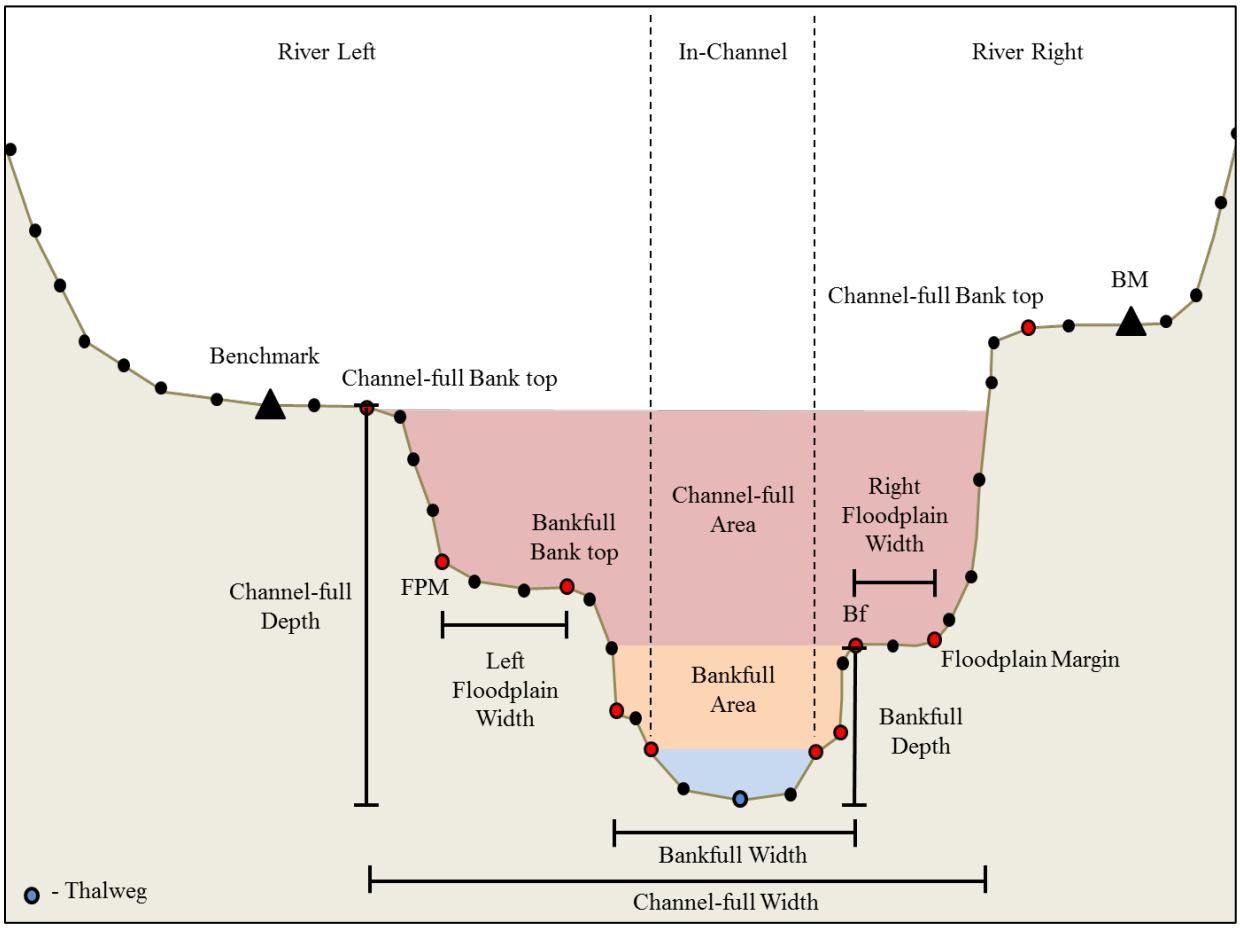


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes baseflow area (light blue) and bankfull area (orange). Channel-full area includes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

Statistical Analysis

The statistical significance of the difference between paired sites for nine variables was tested using two-sample t-tests. These nine variables included:

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 (%).

Bankfull width is not included in the statistical analysis because bankfull was not measured on each transect (due to lack of floodplain) and the number of bankfull measurements at each reach was not equal. Paired site identification, and the reason for their pairing, is briefly described in the Results section. A detailed explanation of the reason for the pairings can be found in McDonald and Starkey (2018a).

In addition to the difference between pairs tests, a one-way analysis of variance (ANOVA) test was conducted to determine if there are significant differences in the nine previously mention variables among streams of similar order. If the ANOVA showed a significant difference, a post hoc Tukey test was used to determine where the difference occurred (i.e. which reaches have statistically significant differences?).

Results

On May 17, 2017, two streams (Noses Creek [KEMO001] and John Ward Creek [KEMO002]) were surveyed following the methods outlined in SOP 1.2.16 *Wadeable Stream Reach-Scale Field Data Collection–Version 1.0* (McDonald et al. 2018c) and SOP 1.2.18 *Using a Total Station to Conduct a Stream Survey–Version 1.0* (McDonald et al. 2018d). Both surveyed reaches are on a third-order segment within their respective stream networks. Field surveys, in-office analyses, and statistical comparisons between the monitored reaches are presented in the following sections. Results and data summary tables for each reach are provided in Appendices B and C. A regional context is provided by including survey results from two third order streams previously surveyed at Chattahoochee River National Recreation Area (CHAT; McDonald et al. 2019).

Reach Descriptions

KEMO001—Noses Creek

KEMO001 is located on Noses Creek approximately 450 meters (1,476 ft) downstream of the pedestrian bridge on Noses Creek Trail. A social trail passes within 2 meters (6.6 ft) of KEMO001's most upstream transect (T11) and an ephemeral drainage enters Noses Creek on river left just downstream from the most downstream transect (T1). KEMO001's channel is fairly entrenched though a few floodplain areas have developed within the reach (Figure 6). The reach that was surveyed was 80 meters (262.5 ft) long with 8 meters (26.25 ft) between transects. Water surface slope (longitudinal profile) for this section of Noses Creek was 0.0015 m/m (Figure 7; Table 2). Channel gradient is relatively consistent except for a large increase in slope between T1 and T2. The reach is very straight and has a very low sinuosity (1.02; Table 2) The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3; Figure 8). A point bar and floodplain have developed along detailed transect 1 (T1). Additionally, detailed transect 1 (T1) was incising into a clay bed along river left. An ephemeral channel enters the creek just downstream of T1. Sand and gravel bars were observed on detailed transects 2 (T6) and 3 (T11). Survey results for KEMO001 are in Appendix A.

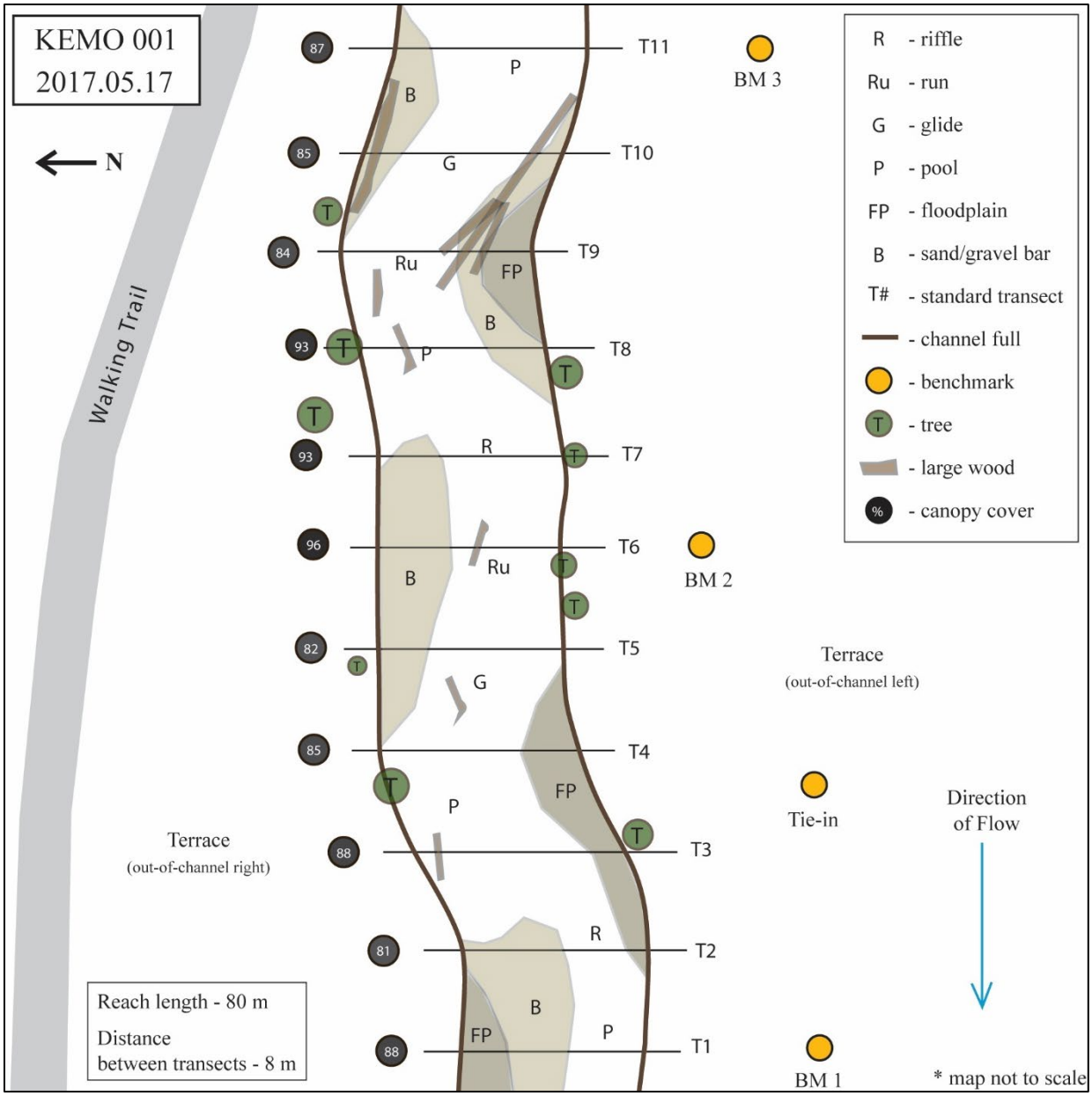


Figure 6. Reach-scale map of KEMO001. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Only the dominant GCUs are labeled on the map. Map is not to scale.

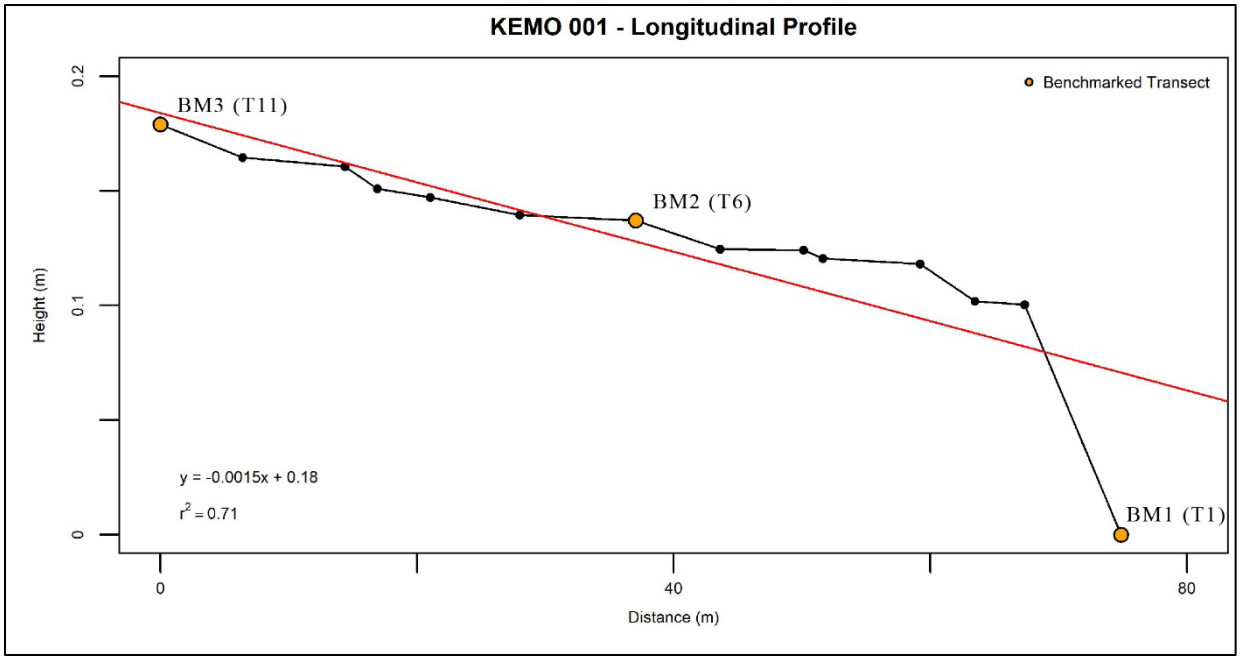


Figure 7. Longitudinal profile for KEMO001. The red line on the graph corresponds to the interpreted slope of the reach (0.0015 m/m). The r^2 value describes the strength of the trend line. The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

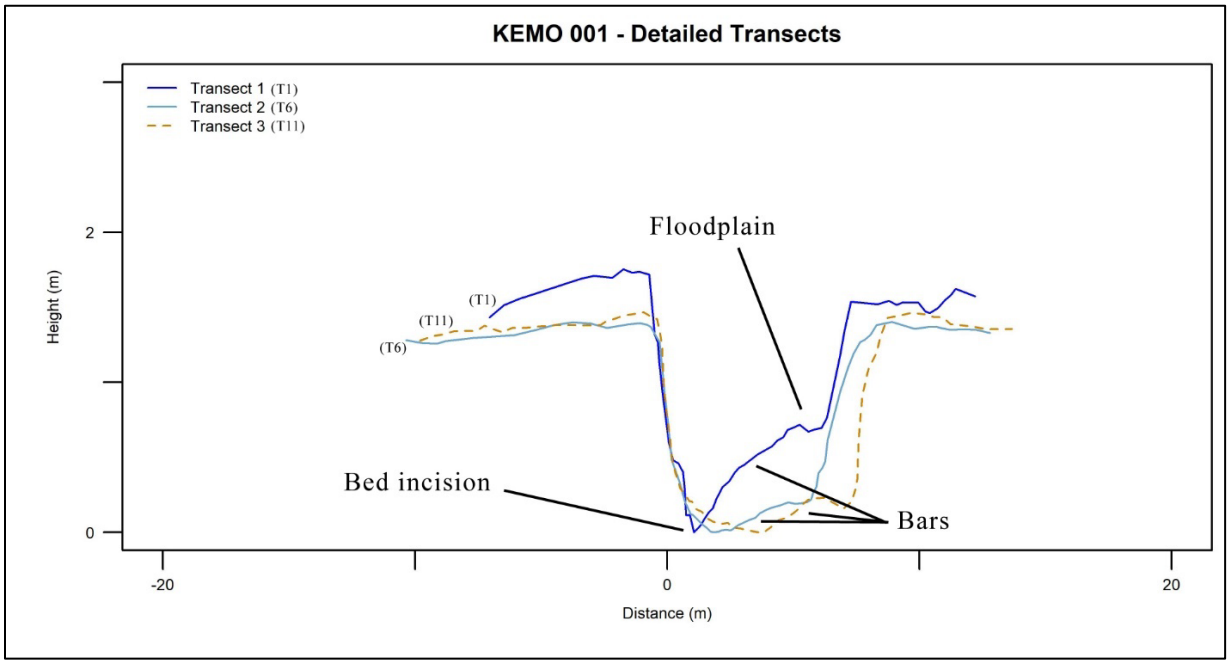


Figure 8. Comparison of the detailed transects at KEMO001. The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

Table 2. Comparison of average detailed transect characteristics at KEMO001 and KEMO002. Data for CHAT001 and CHAT013 are provided here and in Tables 3–14 for comparative purposes [m—meters; BF—Bankfull; CF—Channel full].

Site	n[1]	Reach Slope	Sinuosity	n[2]	BF Area (m^2)	BF Width (m)	BF Height (m)	CF Area (m^2)	CF Width (m)	CF Height (m)
KEMO001	14	-0.0015	1.02	3	3.31	6.34	0.74	8.67	8.76	1.45
KEMO002	11	-0.0019	1.09	3	3.15	6.68	0.70	7.53	8.67	1.28
CHAT001	14	-0.0074	1.07	3	3.97	9.74	0.71	41.40	22.13	2.57
CHAT013	17	-0.0044	1.14	3	5.08	11.39	0.63	26.27	16.72	2.09

[1] Number of measurements taken for reach slope and sinuosity

[2] Number of measurements taken for bankfull and channel full area, width, and height

KEMO002—Ward Creek

KEMO002 is located on John Ward Creek approximately 300 meters (984 ft) downstream of the pedestrian bridge and horse trail crossing on Kolb Farm Trail. A small ephemeral drainage enters KEMO002 between T10 and T11 on river right. A sewer right-of-way runs parallel to the stream on river right and is approximately 20 meters (65.6 ft) from the surveyed reach. KEMO002's channel is fairly entrenched though three areas have developed a floodplain (Figure 9). The low terrace between T7 and T9 is interpreted as being a rotational slump (Ritter et al. 2002). The reach that was surveyed was 70 meters (229.7 ft) long with 7 meters (23 ft) between transects. Water surface slope for this section of Ward Creek was 0.0019 m/m (Figure 10; Table 2). The longitudinal profile highlights the relatively flat downstream and middle portions of the stream and the influence of the step (increase in slope) between T9 and T10. The reach is fairly straight and is slightly more sinuous than KEMO001 (1.09 vs. 1.02; Table 2). The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3; Figure 11). A point bar and floodplain have developed along detailed transect 3 (T11). A potential slump/bench was surveyed on detailed transect 2 (T6; river left). Detailed transect 1's channel is entrenched (T1). Survey results for KEMO002 are in Appendix B.

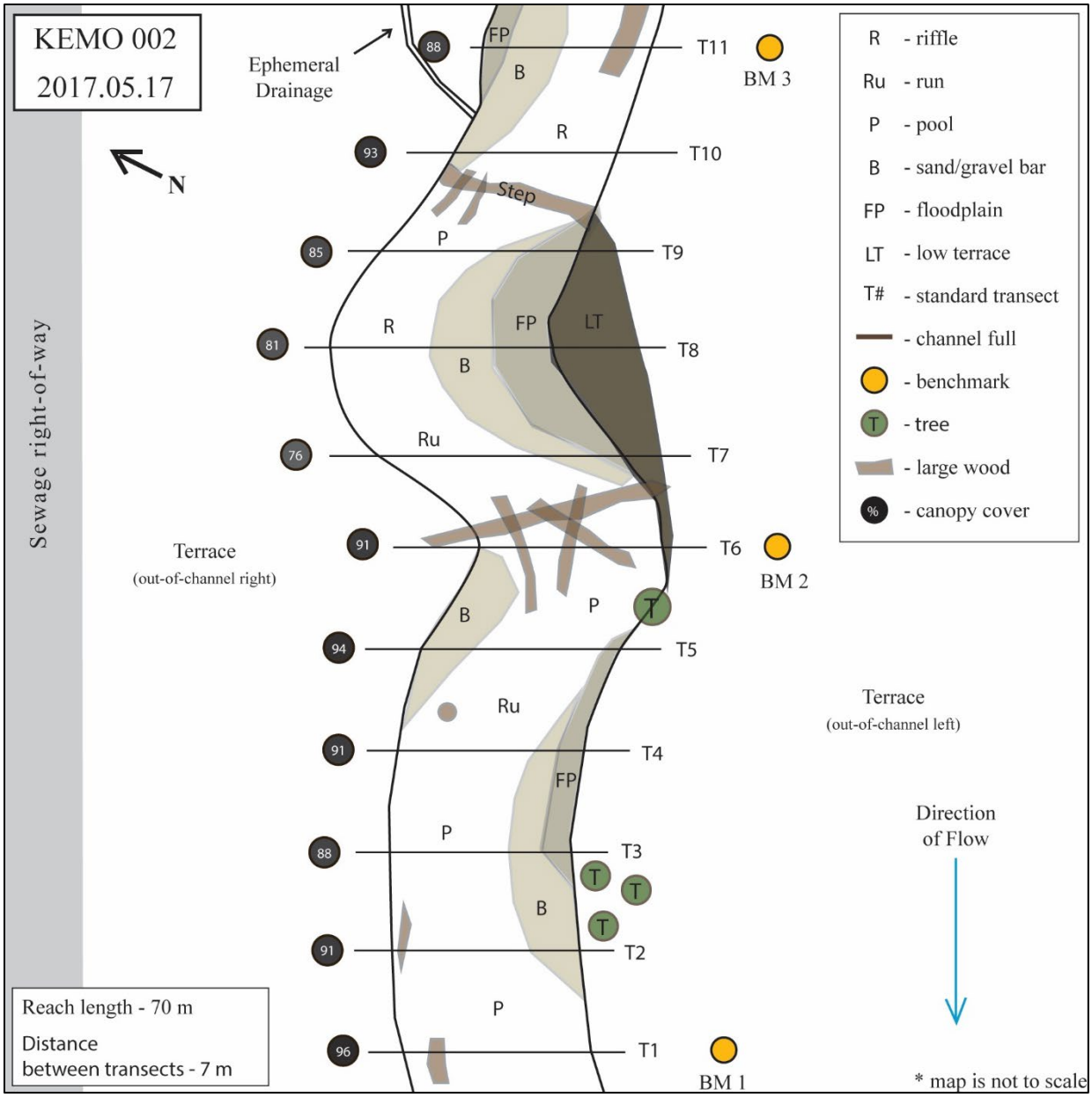


Figure 9. Reach-scale map of KEMO002. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Only the dominant GCUs are labeled on the map.

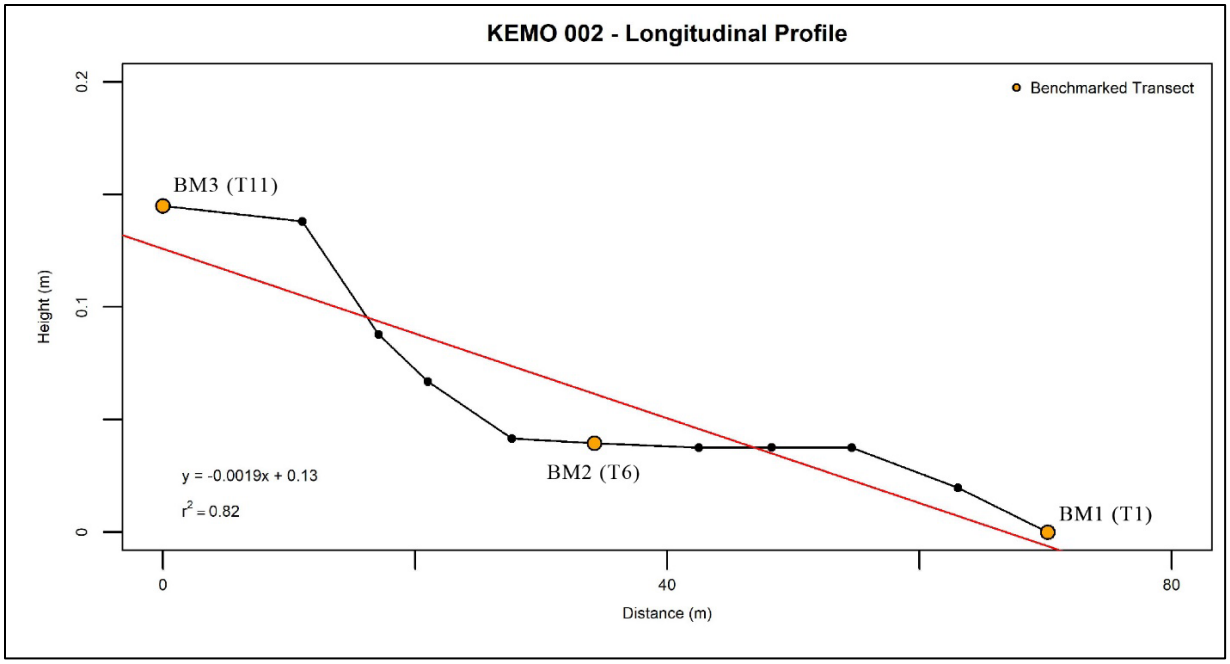


Figure 10. Longitudinal profile for KEMO002. The red line on the graph corresponds to the interpreted slope of the reach (0.0019 m/m). The r^2 value describes the strength of the trend line. The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

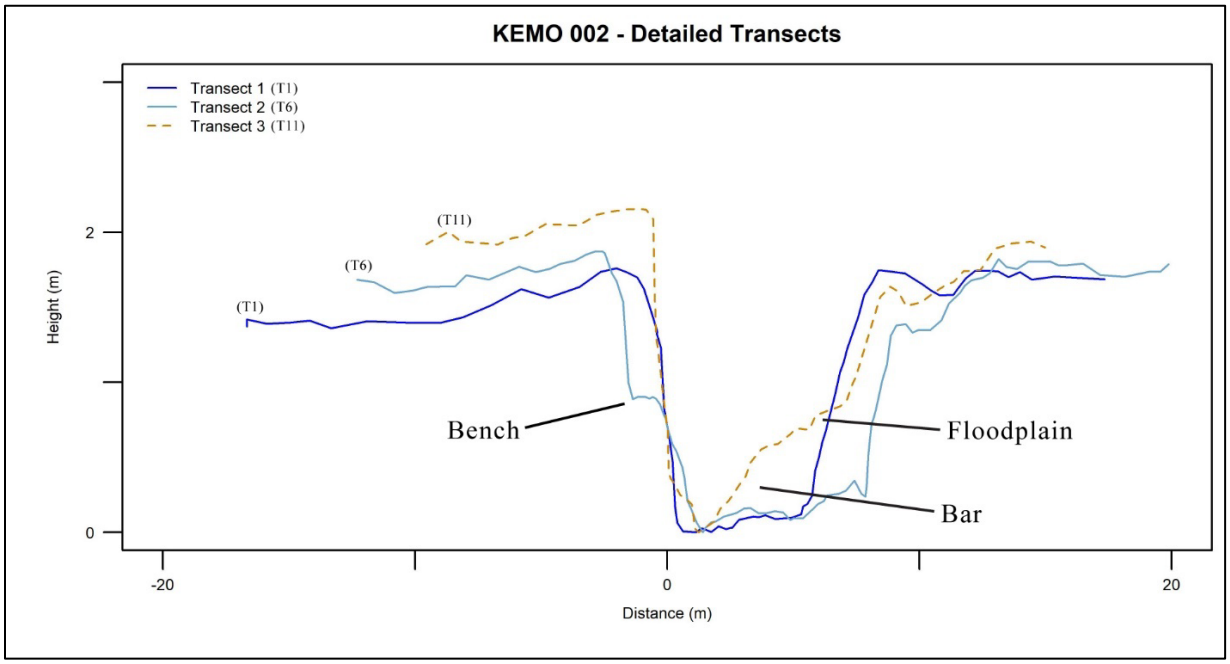


Figure 11. Comparison of the detailed transects at KEMO001. The location of the left channel full points for each transect are normalized to allow for comparisons between transects.

Basin Characteristics

The watersheds drain 8.30 square kilometers (3.20 square miles [sq mi]; KEMO001) and 12.66 square kilometers (4.89 sq mi; KEMO002; Table 3). Kennesaw Mountain NBP manages 34% of KEMO001's watershed and 8% of KEMO002's watershed. The main geomorphic difference between the two watersheds is their relief and slope. KEMO001's watershed, which drains the southeastern side of Kennesaw Mountain, has more relief and has higher slope than KEMO002's watershed. KEMO001's basin relief ratio is also higher than both of the CHAT watersheds. Both watersheds have higher basin shape than the CHAT watersheds (Haw Creek, CHAT001; Long Island Creek, CHAT013). KEMO002 has a high drainage density but a low segment slope. The land use/land cover for the watersheds draining to the two sites is also quite different. While both watersheds have similar amounts of medium- and high-intensity development, KEMO002 has more suburban land cover (Open and low-intensity development) than KEMO001 (Table 4). KEMO001 has more forest cover than KEMO002, as well as both CHAT watersheds. The higher percent forest cover for KEMO001 is attributable to the higher percent of the watershed that is managed by the National Park Service, which includes forested hillslopes along the southeastern side of Kennesaw Mountain (Figure 2). The other main distinguishing characteristic between the two KEMO watersheds is that Ward Creek is heavily influenced by beavers just upstream of the park.

Habitat Characteristics

The geomorphic channel units (GCUs) of the two reaches are quite different (Table 5). KEMO001 has a mixture of GCUs with two well-developed riffle areas separated by a relatively deep pool (T2-T7; Figure 5). The GCUs at KEMO002 are mostly pools with two poorly-developed riffles present near T8 and T10 (Figure 9). Though channel slopes are similar (Figures 7 and 10; Table 2), the bed sediment at KEMO002 is much finer than the bed sediment at KEMO001 (Table 6). Not only is the mean bed sediment particle size significantly different (Table 7), the D_5 and D_{16} of the bed sediment at KEMO002 is also much smaller. Bed sediment at both KEMO reaches was significantly smaller than both CHAT reaches (Table 8).

Eleven pieces of LWD were found at KEMO001 and 25 pieces were found at KEMO002 (Table 9). In addition to having more pieces of LWD, the average length and diameter of the pieces of LWD at KEMO002 were also greater than the pieces at KEMO001. These differences contribute to an order of magnitude difference in the volume of LWD per channel area between the two reaches. The volume of LWD per channel area at KEMO002 is also more than two times the volume at either of the CHAT reaches. Average canopy cover was 87% at KEMO001 and 89% KEMO002 (Table 10). Average canopy cover at the KEMO reaches was greater than the CHAT reaches.

Thalweg depths were on average 0.22 meters (0.72 ft) at KEMO001 and 0.32 meters (1.05 ft) at KEMO002 (Table 11). Though thalweg depths at KEMO002 were slightly greater than at KEMO001, the differences were not statistically significant (Table 7). Differences between the average thalweg position at both KEMO reaches and CHAT013 (Long Island Creek) were significant (Table 8). Variability in thalweg positions (coefficient of variation [CV]) was 0.68 at KEMO001 and 0.84 at KEMO002. The higher CV in thalweg position for KEMO002 (compared to the other three third-order reaches) indicates that the thalweg at KEMO002 was more sinuous.

Table 3. Watershed characteristics for KEMO001 and KEMO002 are calculated using the National Elevation Dataset (NED) 10m digital elevation model. Please refer to McDonald et al. (2018a) for definitions of the variables [km—kilometers].

Basin Characteristic	KEMO001	KEMO002	CHAT001	CHAT013
Drainage Area (km^2)	8.30	12.66	8.78	16.88
NPS Managed Area (km^2)	2.80	1.00	0.03	0.29
NPS Managed Area (%)	34%	8%	0.4%	2%
Total Stream Length (km)	12.68	20.82	13.97	27.11
Drainage Density	1.53	1.94	1.59	1.61
Strahler Order	3	3	3	3
Bifurcation Ratio	1.60	1.77	1.57	1.52
Entire Stream Gradient[1]	0.011	0.008	0.015	0.007
Segment Gradient[2]	0.005	0.001	0.007	0.007
Slope – Average	6.69	4.50	7.1	8.7
Slope – Standard Deviation	5.75	3.06	5.1	5.8
Slope – Coefficient of Variation	0.86	0.68	0.71	0.67
Basin Length (km)	6.35	7.14	7.74	10.66
Basin Shape[3]	0.21	0.25	0.15	0.15
Basin Relief (m)	261	88	125	109
Basin Relief Ratio	0.041	0.012	0.016	0.010
Elevation – Standard Deviation (m)	33	15	21	23

[1] Entire stream gradient calculated by dividing the difference between the elevations at 10% and 85% stream length by the length of stream between.

[2] 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.

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

Table 4. Land use/land cover characteristics in 2011 for KEMO001 and KEMO002. The data included in this table are from the National Land Cover Dataset.

NLCD Classes	KEMO001	KEMO002	CHAT001	CHAT013
Developed Open & Low (%)	34	60	54	48
Developed Med. & High (%)	12	9	4	12
Forested (%)	50	29	37	40
Grassland (%)	3	1	4	0
Cultivated (%)	0	0	0	0

Table 5. Comparison of geomorphic channel units (GCUs) observed in the area between transects at KEMO001 and KEMO002. The data describe the percent coverage of each type of GCU.

GCU Type	Site	Frequency	Max (%)	Mean (%)	Standard deviation (%)
Riffle	KEMO001	8	90	49	33
	KEMO002	2	25	5	11
	CHAT001	6	100	24	32
	CHAT013	10	85	46	24
Run	KEMO001	6	40	13	14
	KEMO002	5	80	26	33
	CHAT001	5	70	17	23
	CHAT013	3	15	4	6
Glide	KEMO001	1	50	5	16
	KEMO002	1	20	2	6
	CHAT001	1	75	8	24
	CHAT013	1	60	39	27
Pool	KEMO001	9	80	33	27
	KEMO002	10	100	65	32
	CHAT001	8	100	53	39
	CHAT013	10	95	39	27

Table 6. Comparison of the particle size distributions of bed sediment (in millimeters) from the pebble counts conducted at KEMO001 and KEMO002. The subscripts indicate the percent of the sample that is smaller than the reported diameter.

Statistic	KEMO001 (n = 100)	KEMO002 (n = 100)	CHAT001 (n=100)	CHAT013 (n=100)
Min	< 0.06	< 0.06	2.00	0.06
D_5	3.00	1.00	4.90	2.00
D_{16}	7.00	1.00	15.00	9.00
D_{50}	16.00	12.00	44.00	25.00
Mean	17.76	12.39	46.10	24.76
D_{84}	27.00	20.84	74.16	41.16
D_{95}	37.90	29.95	100.35	50.00
Max	50	57	187.00	65.00

Table 7. Difference in means t-test results comparing KEMO001 and KEMO002.

Measurement	n	KEMO001	KEMO002	P-value	Significance[1]
Pebble Count (mm)	100	17.76	12.39	< 0.001	***
Thalweg Depth (m)	11	0.22	0.32	0.087	–
Thalweg Position (%)	11	41	43	0.896	–
Wetted Width (m)	11	3.04	4.37	0.010	**
Active Channel (m)	11	5.61	5.40	0.689	–
Channel-full Width (m)	11	8.51	8.75	0.485	–
Channel-full Height (m)	22	1.44	1.72	0.002	**
Bank Angle (º)	22	40	56	0.034	*
Vegetative Cover (%)	22	40	18	0.004	**

[1] The significance of the differences is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001 [mm—millimeters; m—meters].

Table 8. Significance of the differences in means in the pebble counts, thalweg depths, and thalweg positions of the third-order streams based on a post-hoc Tukey analysis.

	Pebble Count				Thalweg Depth				Thalweg Position		
Pairs	**n[1]**	**(mm)[2]**	**P-value**	**Sig.[3]**	**n[4]**	**(m)[5]**	**P-value**	**Sig.[3]**	**(%)[6]**	**P-value**	**Sig.[3]**
KEMO002–KEMO001	100	-5.37	0.194	–	11	0.095	–	–	0.02	0.999	–
KEMO001 - CHAT001	100	-28.34	< 0.001	***	11	-0.173	–	–	-0.15	0.618	–
KEMO001 - CHAT013	100	-7.00	0.049	*	11	-0.048	–	–	-0.36	0.035	*
KEMO002 - CHAT001	100	-33.71	< 0.001	***	11	-0.077	–	–	-0.14	0.706	–
KEMO002 - CHAT013	100	-12.37	< 0.001	***	11	0.047	–	–	-0.34	0.049	*
CHAT013 - CHAT001	100	-21.34	< 0.001	***	11	-0.125	–	–	0.20	0.382	–

[1] Number of pebbles

[2] $F(4,100) = 59.96$, $p < 0.001$

[3] The significance of the differences in means are indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001. F-value and p-value of one-way ANOVA results are reported as footnotes [mm—millimeters; m—meters; sig—significance].

[4] Number of measurements taken for thalweg depth and position

[5] $F(4,11) = 2.05$, $p = 0.122$

[6] $F(4,11) = 3.42$, $p = 0.026$

Table 9. Comparison of the summary statistics for the large woody debris measured at KEMO001 and KEMO002 [m—meters].

Statistic	Site	n	Length (m)	Diameter (m)	Volume (m^3)
Min	KEMO001	11	0.56	0.10	0.01
	KEMO002	25	0.94	0.10	0.01
	CHAT001	16	2.51	0.12	0.04
	CHAT013	30	1.06	0.10	0.01
Mean	KEMO001	11	2.91	0.12	0.03
	KEMO002	25	3.89	0.19	0.13
	CHAT001	16	6.60	0.18	0.20
	CHAT013	30	2.94	0.21	0.15
Max	KEMO001	11	10.00	0.16	0.10
	KEMO002	25	9.59	0.47	0.48
	CHAT001	16	13.17	0.43	0.74
	CHAT013	30	7.17	0.46	0.82
SD	KEMO001	11	3.02	0.02	0.03
	KEMO002	25	2.66	0.10	0.13
	CHAT001	16	3.20	0.08	0.20
	CHAT013	30	1.54	0.10	0.19
Sum	KEMO001	11	–	–	0.34
	KEMO002	25	–	–	3.31
	CHAT001	16	–	–	3.23
	CHAT013	30	–	–	4.51
Per Channel Area (m^3/m^2)	KEMO001	–	–	–	0.0005
	KEMO002	–	–	–	0.0054
	CHAT001	–	–	–	0.0015
	CHAT013	–	–	–	0.0019

Table 10. Comparison of the variability in canopy cover at KEMO001 and KEMO002 [SD—Standard deviation; CV—Coefficient of variation].

Site	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
KEMO001	11	81	87	96	5	0.05
KEMO002	11	76	89	96	6	0.07
CHAT001	11	34	75	99	21	0.29
CHAT013	11	75	85	93	6	0.07

Table 11. Comparison of reach-scale averaged thalweg conditions at KEMO001 and KEMO002. Position is the percent distance of the total active channel width measured from the left bank [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Thalweg Characteristic	Site	n	Min	Mean	Max	SD	CV
Depth (m)	KEMO001	11	0.09	0.22	0.44	0.12	0.52
	KEMO002	11	0.09	0.32	0.49	0.13	0.42
	CHAT001	11	0.13	0.40	0.71	0.22	0.56
	CHAT013	11	0.14	0.27	0.77	0.19	0.70
Position (%)	KEMO001	11	10	41	90	28	0.68
	KEMO002	11	5	43	90	36	0.84
	CHAT001	11	5	56	90	33	0.58
	CHAT013	11	30	77	95	20	0.26

Channel Morphology

Wetted widths were on average 3.04 meters (9.97 ft) on Noses Creek (KEMO001) and 4.37 meters (14.34 ft) on Ward Creek (KEMO002; Table 12). The differences in mean wetted widths between the KEMO reaches were statistically significant (Table 7). The average wetted widths of the KEMO reaches were significantly smaller (Table 13) and less variable (Table 12) than the wetted widths of the CHAT reaches. Active channel widths were on average 5.40 meters (17.72 ft) at KEMO002 and to 5.61 meters (18.41 ft) at KEMO001. While active channel widths were less variable at KEMO001 than at KEMO002, the differences between active channel widths at the KEMO reaches were not statistically significant (Table 7). The differences in active channel widths between the KEMO reaches and the CHAT reaches were statistically significant (Table 13). Bankfull widths were on average 6.00 meters (19.69 ft) at KEMO002 and 6.37 meters (20.90 ft) at KEMO001 (Table 10). Bankfull widths at the KEMO reaches were smaller than the bankfull widths on the CHAT reaches. As mentioned earlier, differences in mean bankfull width were not statistically compared because of the inconsistent number of bankfull widths available to measure within each reach. Variability in bankfull widths (CV) at the KEMO reaches were similar. Channel-full widths were on average 8.51

meters (27.92 ft) at KEMO001 and 8.75 meters (28.71 ft) at KEMO002 (Table 12). Differences between channel-full widths at KEMO were not statistically significant (Table 7). Differences between channel-full widths at both KEMO reaches were statistically significant from both CHAT reaches (Table 13). The variability in channel-full widths at the KEMO reaches were lower than at the CHAT reaches (Table 12).

Minimum bank heights (lowest bank height on a transect) were on average 1.31 meters (4.30 ft) at KEMO001 and 1.49 meters (4.89 ft) at KEMO002 (Table 14). Variability in minimum bank heights (CV) was low at KEMO001 and moderate at KEMO002. Bankfull heights were on average 0.73 meters (2.40 ft) at KEMO001 and 0.75 meters (2.46 ft) at KEMO002. Variability in bankfull heights was slightly higher at KEMO002 than at KEMO001 (Table 14). Channel-full heights were on average 1.44 meters (4.72 ft) at KEMO001 and 1.72 meters (5.64 ft) at KEMO002. Differences in channel-full heights at the KEMO reaches were not statistically significant (Table 7). However, differences between channel-heights at the KEMO reaches compared to the CHAT reaches were statistically significant (Table 15). Variability in channel-full heights was low at KEMO001 and moderate at KEMO002.

Table 12. Comparison of reach-scale width characteristics of KEMO001 and KEMO002 [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Widths	Site	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Wetted	KEMO001	11	1.71	3.04	4.44	0.96	0.31
	KEMO002	11	2.48	4.37	6.11	1.20	0.27
	CHAT001	11	4.34	6.59	12.26	2.30	0.35
	CHAT013	11	3.27	6.68	9.30	2.27	0.34
Active Channel	KEMO001	11	4.65	5.61	7.16	0.70	0.13
	KEMO002	11	3.33	5.40	7.36	1.52	0.28
	CHAT001	11	5.70	8.01	14.55	2.45	0.31
	CHAT013	11	6.35	8.95	14.00	2.27	0.25
Bankfull	KEMO001	5	4.80	6.37	7.70	1.06	0.17
	KEMO002	7	4.86	6.00	7.49	0.97	0.16
	CHAT001	6	7.16	9.44	12.76	2.14	0.23
	CHAT013	3	10.55	11.09	11.75	0.61	0.05
Channel-full	KEMO001	11	7.55	8.51	9.65	0.76	0.09
	KEMO002	11	7.36	8.75	9.55	0.81	0.09
	CHAT001	11	8.97	14.14	20.95	3.72	0.26
	CHAT013	11	10.46	14.77	26.65	4.44	0.30

Table 13. Significance of the differences in means in the wetted widths, active channel widths, and channel-full widths of the third-order streams based on a post-hoc Tukey analysis.

	Wetted Width				Active Channel Width				Channel-full Width		
Pairs	**n[1]**	**(m)[2]**	**P-value**	**Sig[3]**	**n[4]**	**(m)[5]**	**P-value**	**Sig[3]**	**(m)[6]**	**P-value**	**Sig[3]**
KEMO002 - KEMO001	11	1.330	0.315	–	11	-0.206	0.994	–	0.238	0.998	–
KEMO001 - CHAT001	11	-3.547	< 0.001	***	11	-2.399	0.022	*	-5.629	< 0.001	***
KEMO001 - CHAT013	11	-3.638	< 0.001	***	11	-3.345	0.001	**	-6.262	< 0.001	***
KEMO002 - CHAT001	11	-2.217	0.029	*	11	-2.605	0.011	*	-5.391	0.001	**
KEMO002 - CHAT013	11	-2.308	0.022	*	11	-3.552	< 0.001	***	-6.024	< 0.001	***
CHAT013 - CHAT001	11	0.091	0.999	–	11	0.946	0.638	–	0.633	0.958	–

[1] Number of measurements for wetted width

[2] $F(4,11) = 10.85$, $p < 0.001$

[3] 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 one-way ANOVA results are reported as footnotes.

[4] Number of measurements for active and full-channel width

[5] $F(4,11) = 9.79$, $p < 0.001$

[6] $F(4,11) = 14.43$, $p = 0.001$

Table 14. Comparison of average reach-scale bank characteristics at KEMO001 and KEMO002 [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	Site	n	Min	Mean	Max	SD	CV
Minimum Bank Height[1] (m)	KEMO001	22	0.51	1.31	1.74	0.32	0.24
	KEMO002	22	0.34	1.49	2.20	0.54	0.36
	CHAT001	22	0.57	1.84	3.15	0.83	0.45
	CHAT013	22	0.47	2.17	2.99	0.62	0.28
Bankfull Height[1,3] (m)	KEMO001	5	0.51	0.73	1.01	0.19	0.26
	KEMO002	7	0.34	0.75	1.02	0.23	0.31
	CHAT001	6	0.57	0.94	1.34	0.26	0.28
	CHAT013	3	0.47	0.74	1.19	0.39	0.54
Channel-full Height[1] (m)	KEMO001	22	1.18	1.44	1.74	0.14	0.10
	KEMO002	22	0.96	1.72	2.20	0.36	0.21
	CHAT001	22	0.74	2.09	3.15	0.75	0.36
	CHAT013	22	1.96	2.37	2.99	0.29	0.12
Bank Undercut[3] (m)	KEMO001	1	–	0.14	–	–	–
	KEMO002	2	0.37	0.44	0.51	0.10	0.22
	CHAT001	5	0.20	0.59	1.62	0.60	1.02
	CHAT013	7	0.09	0.21	0.54	0.15	0.71
Bank Angle (°)	KEMO001	22	3	40	72	20	0.50
	KEMO002	22	9	56	90	27	0.48
	CHAT001	22	14	48	118	27	0.57
	CHAT013	22	6	60	88	27	0.46
Vegetation Cover (%)	KEMO001	22	0	40	85	28	0.69
	KEMO002	22	0	18	50	18	0.99
	CHAT001	22	5	53	100	31	0.58
	CHAT013	22	0	34	60	19	0.54
Bank Stability[4]	KEMO001	22	11.50	13.50	16.00	1.28	0.09
	KEMO002	22	11.50	14.43	15.75	1.30	0.09
	CHAT001	22	7.00	12.73	17.00	2.25	0.18
	CHAT013	22	9.00	13.70	18.00	2.51	0.18

[1] above thalweg

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

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

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

Table 15. Significance of the differences in means in the channel-full heights, bank angles, and vegetative cover of the third-order streams based on a post-hoc Tukey analysis.

	Channel-full Height				Bank Angle			Vegetative Cover		
Pairing	n[1]	(m)[2]	P-value	Sig.[3]	Degree[4]	P-value	Sig.[3]	(%)[5]	P-value	Sig.[3]
KEMO002 - KEMO001	22	0.282	0.166	–	15.841	–	–	-22.273	0.019	*
KEMO001 - CHAT001	22	-0.647	< 0.001	***	-7.405	–	–	-12.955	0.308	–
KEMO002 - CHAT001	22	-0.365	0.040	*	8.436	–	–	-35.227	< 0.001	***
KEMO001 - CHAT013	22	-0.929	< 0.001	***	-19.382	–	–	6.136	0.842	–
KEMO002 - CHAT013	22	-0.647	< 0.001	***	-3.541	–	–	-16.136	0.140	–
CHAT013 - CHAT001	22	0.282	0.166	–	11.977	–	–	-19.091	0.057	–

[1] Number of measurements for channel-full height, bank angle, and vegetative cover

[2] $F(4,22) = 18.21$, $p < 0.001$

[3] 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 one-way ANOVA results are reported as footnotes.

[4] $F(4,22) = 2.53$, $p < 0.063$

[5] $F(4,22) = 7.74$, $p = 0.001$

In comparison to the surveyed CHAT reaches, the KEMO reaches had much less undercutting (Table 14). One undercut was observed at KEMO001 (depth of 0.14 meters [0.46 ft]; Table 14). Two undercuts were observed at KEMO002 (depths of 0.37 and 0.51 meters [1.21 and 1.67 ft]). Bank angles were on average 40° at KEMO001 and 56° at KEMO002. Variability in bank angles was similar. Differences in bank angles between the KEMO reaches were statistically significant (Table 7). Differences in bank angles between the KEMO reaches and the CHAT reaches were not statistically significant (Table 15). Bank vegetation cover was on average 18% at KEMO002 and 40% at KEMO001. Differences in bank vegetation cover were significant between the KEMO reaches (Table 7) as well as between KEMO002 and CHAT001 (Table 15). The average bank stability scores for the KEMO reaches were classified as "unstable" (see Methods section for how to interpret bank stability scores). The minimum bank stability scores for both KEMO reaches were also classified as "unstable." The maximum bank stability scores were classified as "very unstable." Variability in bank stability scores on the KEMO reaches was roughly half that of the CHAT reaches.

Channel slope ranged from 0.0015 m/m (KEMO001) to 0.0019 m/m (KEMO002; Table 2). Reach sinuosity was low for both reaches. Bankfull cross-sectional area was on average 3.15 square meters (33.90 square feet [sq ft]) at KEMO002 and 3.31 square meters (35.63 sq ft) at KEMO001. Bankfull heights were similar at Kennesaw Mountain NBP and Chattahoochee River NRA. Bankfull widths

were narrower at Kennesaw Mountain NBP compared to Chattahoochee River NRA. Channel-full cross-sectional area was on average 7.53 square meters (81.05 sq ft) at KEMO002 and 8.67 square meters (93.32 sq ft) at KEMO001. Channel-full cross-sectional areas at Kennesaw Mountain NBP were much lower than at Chattahoochee River NRA. These differences were driven by the much wider channel-full widths at Chattahoochee River NRA and the higher channel-full heights. The large channel-full areas for the CHAT reaches were due to the wider incipient floodplain areas that have developed beneath the historical terraces along these streams by lateral channel migration and slumping (McDonald et al. 2019).

Implications and Synthesis of Results

This section describes the processes observed at each reach and the potential changes that may occur between surveys (next field surveys scheduled for Spring/Summer 2019). The processes that are described will be 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).

KEMO001—Noses Creek

KEMO001's watershed is steep and is covered by forested areas as well as development. Approximately 46% of Noses Creek's watershed is developed and 50% is forested (Table 4). KEMO001's watershed has a high entire stream gradient, a lower segment gradient, and the lowest reach gradient (Tables 2 and 3). KEMO001's watershed has average slope, low drainage density, high basin shape, and the highest basin relief ratio. Though the high forest cover and relatively low drainage density likely attenuate flood flows, the high relief (due to Kennesaw Mountain) and more circular basin (relatively high basin shape) suggest Noses Creek has a flashier flow regime than Ward Creek, but gage data are needed to confirm this interpretation.

The reach surveyed on Noses Creek (KEMO001) is close to a walking trail and visitors were seen using the stream where the banks were lower (upstream near the bridge). In-stream habitat was 49% riffle, 13% run, 5% glide, and 33% pool (Table 5). Habitat was evenly distributed throughout the reach with riffle areas separating the large pools (Figure 6). KEMO001's bed material was significantly coarser than at KEMO002 (mean of 17.76 millimeters vs. 12.39 millimeters [0.70 in vs. 0.49 in]) but much finer than the sediment at both of the CHAT streams (mean of 46.10 millimeters [1.81 in; CHAT001] and 24.76 millimeters [0.97 in; CHAT013]; Tables 6 and 8). Although the reach slope of Noses Creek is slightly less than that of Ward Creek (0.0015 m/m vs. 0.0019 m/m), the differences in bed material between KEMO001 and KEMO002 may be due to the differences in watershed relief as well as differences in entire stream and segment gradients. The statistically significant differences in bed material at KEMO001 compared to the CHAT streams is likely due to the large differences in channel slope between the stream reaches (0.0015 m/m vs. 0.0074 m/m and 0.0044 m/m; Table 2; Walters et al. 2001). The fine bed material compared to Chattahoochee River NRA may also be due to differences in sediment delivery, different geologies, or differences in the stages of channel development. Additionally, the on average slightly less stable banks at KEMO001 compared to the CHAT reaches may indicate that fine sediment inputs from these unstable banks is contributing to the fining of the bed along this reach.

KEMO001 had by far the lowest volume of LWD per channel area (0.0005 m^3/m^2 vs 0.0054 m^3/m^2 at KEMO002; Table 9). The lack of LWD coupled with fine bed material along KEMO001 suggest that bed sediment on this reach is highly mobile, which may put the stream at greater risk of habitat degradation for benthic dwelling invertebrates (Allan and Castillo 2007). Based on the GCUs, bed sediment, and LWD within the reach, KEMO001's in-stream habitat was classified as "poor to fair." This classification is 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 at KEMO001. If the bed material at KEMO001 becomes finer and if the GCUs within the reach become more homogenous, the habitat classification may degrade to "poor." Alternatively, addition of LWD to the reach may increase habitat diversity and provide more stability to the reach that could upgrade the classification to "fair" (Allan and Castillo 2007).

The major defining characteristics of the stream were the presence of alternating sand and gravel bars, the relatively high variability in thalweg position, and the large increase in channel slope between T1 and T2. Though the reach had the lowest sinuosity (1.02 vs. 1.14 at CHAT013), the relatively high variability of thalweg position and the presence of alternating sand/gravel bars within the reach indicates the stream is beginning to reestablish a meandering planform inset within the high terrace (Simon and Darby 1999). Such spatial patterns in thalweg position and alternate bar formation coupled with the presence of floodplain surfaces throughout the reach indicate that the stream is beginning to reestablish a more "natural" system inset within the higher terrace surface. Due to the highly entrenched nature of the stream, the cohesive banks, and the relatively high frequency of slumping, lateral migration is not significantly affecting the reach. As the stream begins to reestablish a meandering planform, lateral migration will also become an important contributor to the amount of sediment produced by the reach. The knickpoint (i.e., significant increase in channel slope) that has developed between T1 and T2 may cause the reach to incise headward in the future, particularly since there is little cobble-sized or larger sediment or LWD within the reach to prevent or mitigate downcutting. The knickpoint is likely related to the influence of an ephemeral channel that enters the reach just downstream of T1. The large increase in stream power in this area has cause the stream bed to degrade in the area just downstream of the reach.

KEMO002—Ward Creek

KEMO002's watershed has low slope and relief and has low forest cover. Approximately 69% of Ward Creek's watershed is developed and 29% is forested (Table 4). KEMO002's watershed has a low entire stream gradient, the lowest segment gradient (one-fifth of KEMO001 and one-seventh of the CHAT reaches), and a low reach gradient (two to nearly four times less than the CHAT reaches; Tables 2 and 3). KEMO002's watershed has the lowest slope, the highest drainage density, a high basin shape, and a low basin relief ratio (nearly four times smaller than KEMO001). Though the watershed has high developed land cover, the low slope and relief coupled with the low network and segment gradients suggest Ward Creek does not have a flashy flow regime, though gage data are needed to confirm this interpretation.

The reach surveyed on Ward Creek (KEMO002) is within 10 to 15 meters (32.8 to 49.2 ft) of a sewer right-of-way (that is used as a walking trail). Visitors and their dogs were observed using the stream where the banks were lower (upstream near the bridge). Habitat was mostly low energy runs and pools (Figure 9). In-stream habitat was 5% riffle, 26% run, 2% glide, and 65% pool (Table 5). Bed material was significantly finer than all the other third-order streams (two to four times finer than the bed sediment at CHAT; Table 6 and 8). The fine bed material observed at KEMO002 is interpreted as being a result of the low watershed slope and relief, the low entire stream, segment, and channel gradients, as well as a legacy of upstream disturbance when the sewer lines were installed. Though the channel gradient at KEMO002 is slightly greater than at KEMO001 (0.0019 m/m vs. 0.0015 m/m; Table 2), the large differences in watershed and segment characteristics are interpreted to be affecting bed sediment to a much greater degree. Additionally, the on average less stable banks at KEMO002 compared to KEMO001, and the CHAT reaches, may indicate that fine sediment inputs from these unstable banks is contributing to the fining of the bed along this reach.

KEMO002 had by far the highest volume of LWD per channel area (an order of magnitude more than KEMO001 and at least twice as much as in the CHAT reaches; Table 9). The high volume of LWD in the reach is likely related to the highly entrenched and straight stream channel upstream of the reach funneling LWD into the reach and the highly active beaver population upstream supplying LWD to the system. The majority of the LWD within the reach was located just upstream of the relatively sharp meander bend between T5 and T7. This flow constriction is likely one factor contributing to the large volume of LWD trapped within the reach. LWD can positively contribute to benthic macroinvertebrate communities by creating a diversity of habitat (Allan and Castillo 2007). However, at KEMO002 the large amount of LWD has contributed to the low energy GCUs that are present and to the fining of the bed (trapped behind jams and steps). Based on the GCUs, bed sediment, and LWD within the reach, KEMO002's in-stream habitat was classified as "poor." This classification is 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 at KEMO002. Habitat at KEMO002 will continue to be "poor" until stable (non-mobile) in-channel (non-bridging) LWD increases the diversity of habitat and upstream conditions reduce the amount of fine sediment that is delivered to the reach (Allan and Castillo 2007). Currently, much of the existing LWD spans the channel and has minimal influence on GCUs.

The major defining characteristics of the stream were the high variability in thalweg position and the rotational slump between T6 and T9. Though the reach had relatively low sinuosity, it had the most variable thalweg position. The variable thalweg position coupled with alternating sand/gravel bars indicates the reach is beginning to reestablish a meandering planform inset within the high terrace (Simon and Darby 1999). The rotational slump between T6 and T9 is an indication that the stream is equilibrating to its sediment and flow regimes and beginning to widen the area that is subject to flooding (Thorne 1999). While slumping can cause a large increase in sediment delivery, these slumps can also create important out-of-channel areas for flood waters and can be a sediment sink if vegetation can become established and the slump/bench is stabilized (Royall et al. 2010). Due to the highly entrenched nature of the stream, the cohesive banks, and the high frequency of slumping,

lateral migration is not significantly affecting the reach. As the stream begins to reestablish a meandering planform, lateral migration will also become an important contributor to the amount of sediment produced by the reach.

Conclusion

Noses Creek's watershed (KEMO001) is steep and forested and Ward Creek's watershed (KEMO002) has low slope/relief and is covered mostly by urban and suburban development. Based on the geomorphic and land cover characteristics of the two watersheds, Noses Creek is interpreted to be flashier than Ward Creek; though stream gages are needed to determine each stream's flow regime. Based on the results of the pebble counts, the type/distribution of GCUs within each reach, and the presence/absence of LWD, in-stream habitat within both surveyed streams were classified as "poor to fair" on KEMO001 and "poor" on KEMO002. 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 Kennesaw Mountain NBP. If the bed material at KEMO001 becomes finer and if the GCUs within the reach become more homogenous, the habitat classification may degrade to "poor." Alternatively, the addition of LWD to KEMO001 may increase habitat diversity and provide more stability to the reach that could upgrade the classification to "fair." Habitat at KEMO002 will continue to be "poor" until stable (non-mobile) in-channel (non-bridging) LWD increases the diversity of habitat and upstream conditions reduce the amount of fine sediment that is delivered to the reach (Allan and Castillo 2007). Currently, much of the existing LWD spans the channel and has minimal influence on GCUs.

Both stream reaches are recovering from a legacy of poor land use practices, and they are influenced by varying amounts of impervious surface cover and urban and suburban development in their watersheds. The surveyed reaches have begun to develop a meander planform inset within the entrenched channel-full surface. Additionally, Noses Creek is experiencing possible headward migration of a small knickpoint that may cause further bed degradation in the middle and upstream portions of the survey reach in the future. The rate at which this knickpoint migrates upstream is dependent on the sediment composition of the boundary layer (bed sediment), the amount of LWD available to increase bed and bank resistance, and the flow regime that shapes the stream.

As a result of changes in bed elevation (from bed degradation or through the process of complex response), bank undercutting and slumping is a common process occurring in the park. Some of these slumps may become colonized by vegetation and become stable sediment sinks. Prior to colonization by vegetation and in higher energy portions of the streams, these slumps will erode and contribute additional sediment to areas downstream. Due to the highly entrenched nature of the channels along these reaches, the cohesive banks, and the relatively high frequency of slumping, lateral migration is not a significant process affecting channel evolution. As these streams begin to reestablish a meandering planform, lateral migration will also become a significant process contributing sediment to the system. Neither of these streams have immediate management concerns. The biggest concern for visitors is the high banks that need to be navigated to access the streams.

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Appendix A. Explanation of Variables

Table A-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.

[1] collected at each standard transect (11 measurements)

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

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

Variable	Variable Scale	Description
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 m and are 1 m or longer.
Pebble Count	Reach	The size and distribution of 100 particles (pebble count) from a representative riffle (Wolman 1954).
Canopy Closure	Reach[1]	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[1]	Wetted channel width is measured where water is flowing (including undercuts)
Active Channel Width	Transect[1]	Active channel width is measured to the beginning of vegetation within the stream channel
Bankfull Width	Transect[1,2]	Bankfull widths should only be measured if there is a floodplain (or incipient floodplain) present
Bankfull Height	Transect[1,2]	The height of the channel bank where a floodplain is present
Bankfull Area	Transect[2]	The cross-sectional area of a stream channel at bankfull stage (height) measured perpendicular to flow
Bankfull Perimeter	Transect[2]	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[2]	A measure of hydraulic efficiency defined by the ratio between bankfull area and bankfull perimeter
Channel-full Width	Transect[1,2]	Channel full widths are measured from the top of the lowest bank that is not a floodplain.
Channel-full Height	Transect[1,2]	The height of the channel bank where a floodplain is not present (channel-full height is also measured where a floodplain is inset within an entrenched channel)
Channel-full Area	Transect[2]	The cross-sectional area of a stream channel at bankfull stage measured perpendicular to flow

[1] collected at each standard transect (11 measurements)

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

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

Variable	Variable Scale	Description
Channel-full Perimeter	Transect[2]	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[2]	A measure of hydraulic efficiency defined by the ratio between channel full area and channel full perimeter
Thalweg Position	Transect[1]	The position of the thalweg as a percent distance of the wetted width from left water's edge
Thalweg Depth	Transect[1]	The greatest depth of water along a transect
Dominant Particle Size	Transect[1]	A visual estimate of the dominant sediment size along a transect
Dominant Habitat	Transect[1]	A visual estimate of the dominant geomorphic channel unit along a transect
In-channel features	Transect[1]	A description of the in-channel features (e.g., bars or islands) that are present along a transect
Floodplain width	Transect[1]	The width(s) of floodplain(s) present along rivers left and/or right
Bank Undercut	Transect[1]	Where the bank overhangs the channel due to lateral erosion at the base of the bank
Bank Angle	Transect[1]	The dominant bank angle from active channel boundary to the top of the bank
Bank Sediment	Transect[1]	The dominant sediment composition of the channel banks
Bank Erosion	Transect[1]	The presence of and type erosion (e.g., lateral or slump) that is observed on the channel banks
Bank Cover	Transect[1]	A visual estimate of the percent of the channel banks that has vegetative cover

[1] collected at each standard transect (11 measurements)

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

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Appendix B. Survey Results for KEMO001

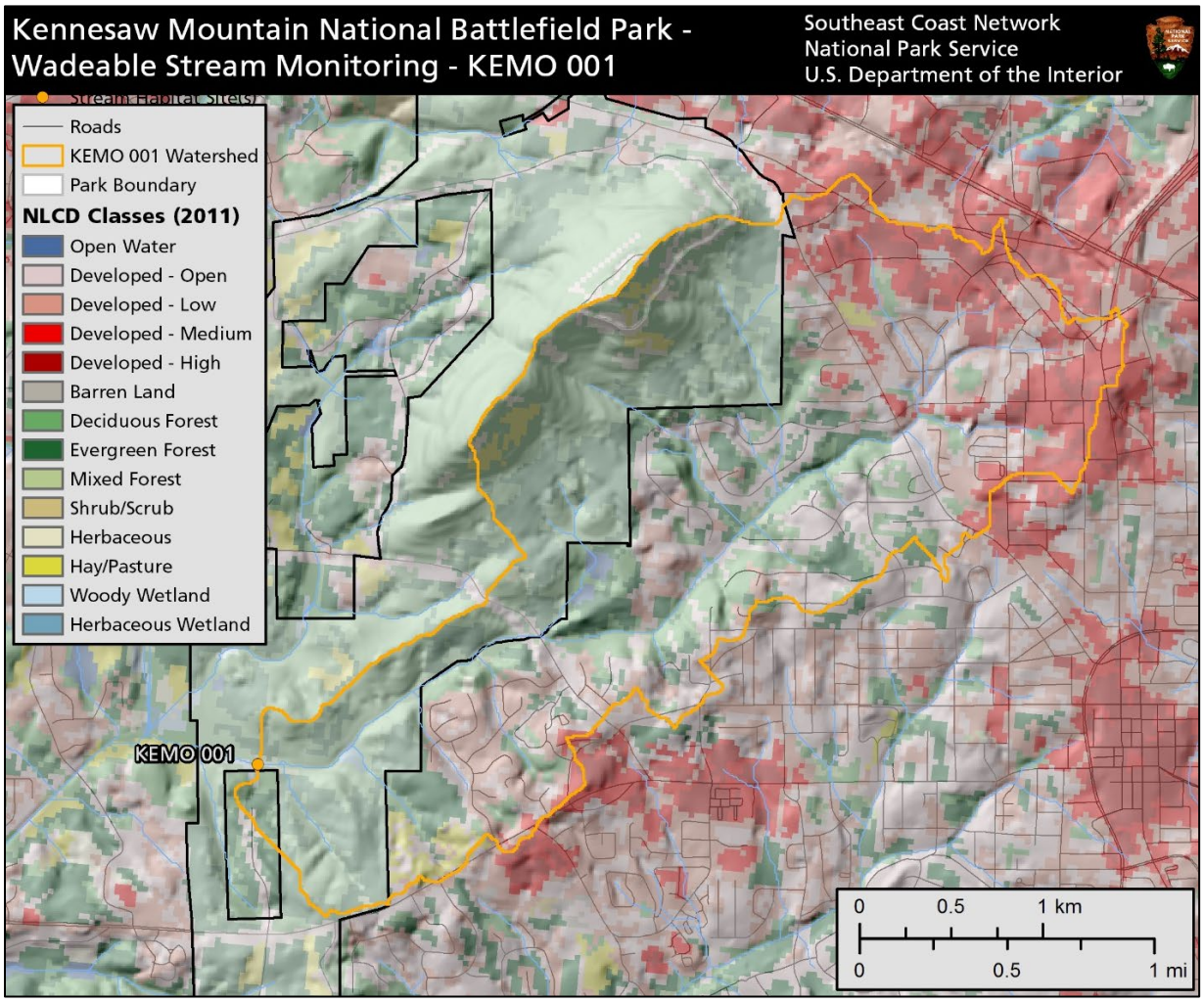


Figure B-1. Map showing the watershed draining to KEMO001 at Kennesaw Mountain National Battlefield. The land use/land cover (2011 NLCD, Homer et al. 2015), road network (U.S. Census 2011), and perennial streams (derived from a 10-meter digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure B-2. Photograph taken on KEMO001 looking upstream from T1 (detailed transect 1).



Figure B-3. Photograph taken on KEMO001 looking downstream on T1 (detailed transect 1).



Figure B-4. Photograph taken on KEMO001 looking at the left bank on T1 (detailed transect 1).



Figure B-5. Photograph taken on KEMO001 looking at the right bank on T1 (detailed transect 1).



Figure B-6. Photograph taken on KEMO001 looking upstream on T6 (detailed transect 2).



Figure B-7. Photograph taken on KEMO001 looking downstream on T6 (detailed transect 2).



Figure B-8. Photograph taken on KEMO001 looking at the left bank on T6 (detailed transect 2).



Figure B-9. Photograph taken on KEMO001 looking at the right bank on T6 (detailed transect 2).



Figure B-10. Photograph taken on KEMO001 looking upstream on T11 (detailed transect 3).



Figure B-11. Photograph taken on KEMO001 looking downstream on T11 (detailed transect 3).



Figure B-12. Photograph taken on KEMO001 looking at the left bank on T11 (detailed transect 3).



Figure B-13. Photograph taken on KEMO001 looking at the right bank on T11 (detailed transect 3).

Table B-1. Land use/land cover characteristics for 2001, 2006, and 2011 for KEMO001. The data included in this table are from the National Land Cover Dataset (Homer et al. 2001, Fry et al. 2006; Homer et al. 2015).

NLCD Class	2001 % watershed	2006 % watershed	2011 % watershed
Open Water	0	0	0
Developed—Open[1]	18	20	19
Developed—Low[1]	14	16	15
Developed—Medium[1]	6	7	8
Developed—High[1]	3	3	4
Barren	0	0	0
Deciduous	33	31	31
Evergreen	21	19	19
Mixed Forest	1	1	1
Shrub	0	0	0
Grassland	2	1	1
Pasture	2	2	2
Cultivated	0	0	0
Woody Wetland	0	0	0
Herbaceous Wetland	0	0	0

[1] refers to the intensity or type of development

Table B-2. Geomorphic channel units (GCU) observed in the area between transects at KEMO001. The data describe the percent coverage of each type of GCU.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	90	0	0	10	0
2–3	25	25	0	50	0
3–4	0	20	0	80	0
4–5	65	10	0	25	0
5–6	0	25	50	25	0
6–7	60	40	0	0	0
7–8	75	10	0	15	0
8–9	70	0	0	30	0
9–10	80	0	0	20	0
10–11	25	0	0	75	0
Frequency	8	6	1	9	0
Max (%)	90	40	50	80	0
Mean (%)	49	13	5	33	0
Median (%)	63	10	0	25	0
SD (%)	33	14	16	27	0

Table B-3. Characteristics of the large woody debris observed at KEMO001 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	1.87	0.16	0.04	3	None	Free
2	0.60	0.13	0.01	5	Jam	Buried, Jam
3	2.49	0.11	0.02	6	None	Buried
4	0.56	0.12	0.01	6	Bank Protection	Buried
5	1.15	0.14	0.02	8	Sediment trap, Habitat creation	Buried
6	2.04	0.11	0.02	9	None	Free
7	1.07	0.10	0.01	9	Jam, Organic and Sediment trap, Habitat creation	Buried
8	10.00	0.11	0.10	10	Bank protection, Organic trap	Ramp
9	6.34	0.12	0.07	10	None	Free
10	5.15	0.10	0.04	10	Organic trap	Free
11	0.70	0.14	0.01	11	Sediment trap	Buried

Table B-4. Variability of canopy cover observed at KEMO001.

Transect	Canopy Cover (%)
1	88
2	81
3	88
4	85
5	82
6	96
7	93
8	93
9	84
10	85
11	87
Min (%)	81
Mean (%)	87
Median (%)	87
Max (%)	96
SD (%)	5
CV	0.05

Table B-5. Average reach-scale bank characteristics at KEMO001. [L—indicates left bank; R—indicates right bank; m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	SD (L)	SD (R)	CV (L)	CV (R)
Bank Height[1] (m)	11	11	1.11	0.98	1.35	1.33	1.20	1.24	0.08	0.10	0.06	0.08
Floodplain Height[1,2] (m)	4	1	0.51	0.82	1.01	0.82	0.71	0.82	0.21	–	0.30	–
Channel-full Height[1] (m)	11	11	1.26	1.18	1.74	1.68	1.42	1.46	0.15	0.14	0.10	0.10
Water Depth at Base[3] (m)	11	11	-0.14	-0.15	0.31	0.10	-0.01	-0.04	0.13	0.09	–	–
Bank Undercut[2] (m)	0	1	–	0.14	–	0.14	–	0.14	–	–	–	–
Bank Angle (°)	11	11	12	3	71	72	37	43	20	21	0.54	0.49
Vegetation Cover (%)	11	11	0	0	50	85	23	58	20	24	0.88	0.42
Bank Stability[4]	11	11	Unstable	Unstable	Very Unstable	Very Unstable	Unstable	Unstable	1.49	1.54	0.10	0.12

[1] above thalweg

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

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

[4] See Table 1 for explanation of scores

Table B-6. Cross-sectional characteristics for detailed transect 1 at KEMO001. *Bankfull to channel-full ratio[m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.47	5.17	0.28	4.77	0.68	6.97
Channel-full	7.48	9.06	0.83	7.91	1.54	5.15
Ratio*	5.09	1.75	2.91	1.66	2.24	0.74

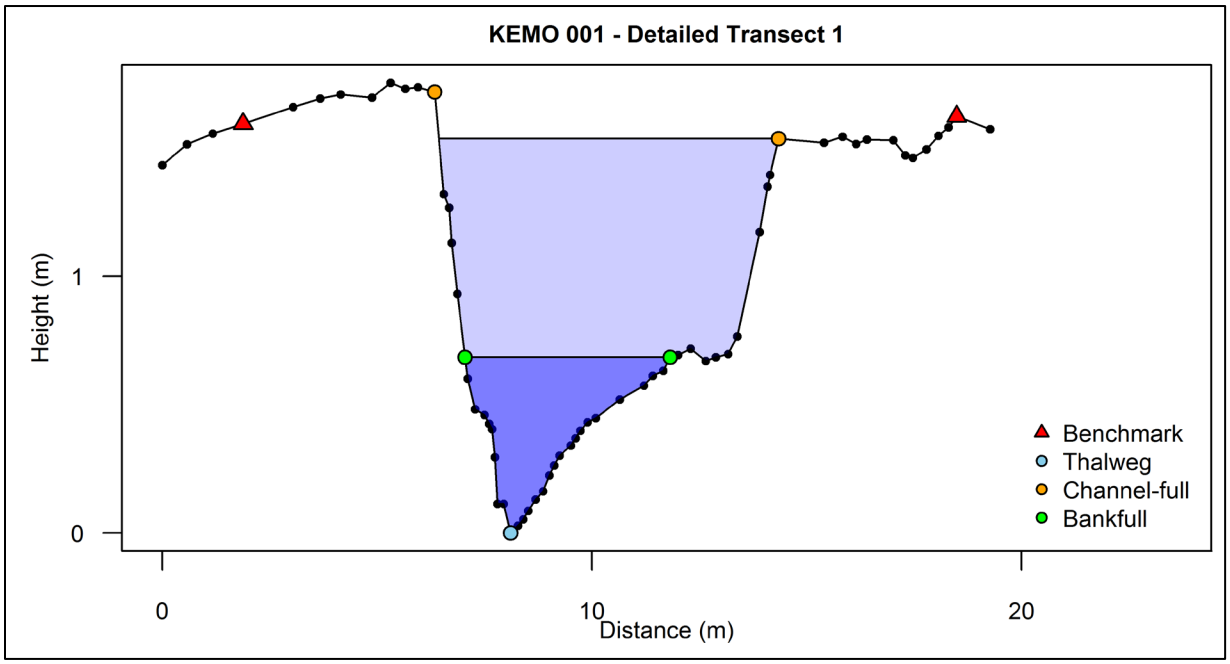


Figure B-14. Detailed transect 1 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Additionally, the channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

Table B-7. Cross-sectional characteristics for detailed transect 2 at KEMO001. *Bankfull to channel-full ratio [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	3.79	7.04	0.54	6.59	0.77	8.61
Channel-full	8.38	9.95	0.84	9.07	1.38	6.56
Ratio*	2.21	1.41	1.56	1.38	1.81	0.76

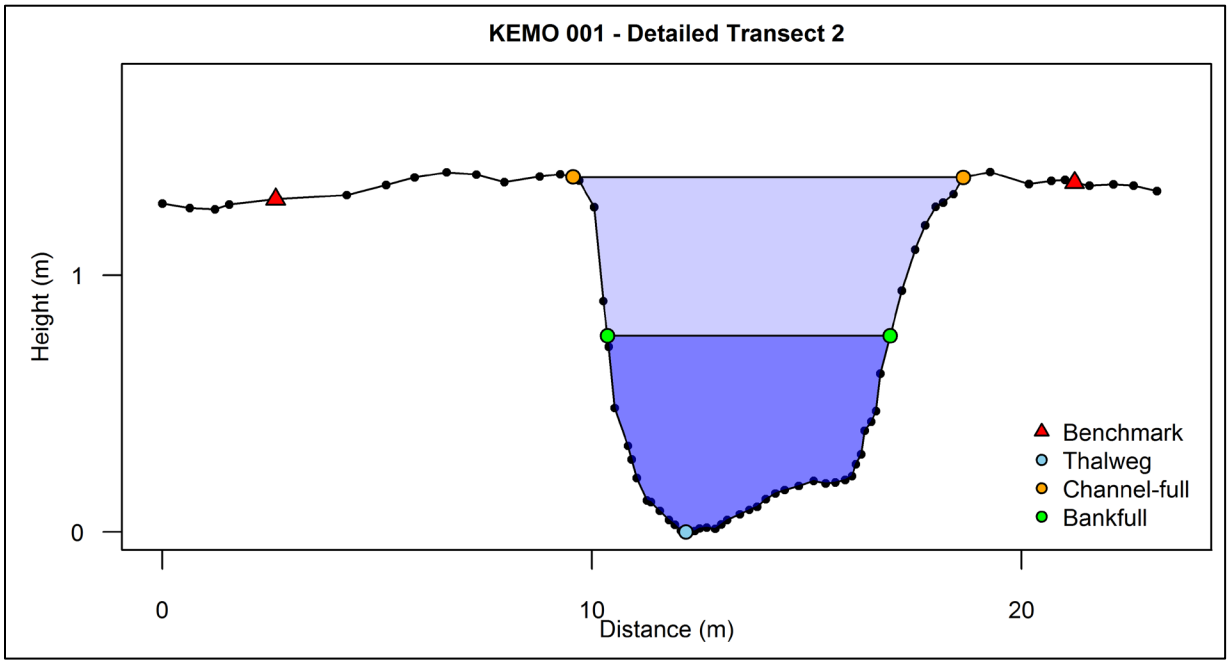


Figure B-15. Detailed transect 2 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

Table B-8. Cross-sectional characteristics for detailed transect 3 at KEMO001 [m-meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.66	8.26	0.56	7.66	0.77	10.01
Channel-full	10.15	10.53	0.96	9.30	1.43	6.50
Ratio*	2.18	1.27	1.71	1.21	1.87	0.65

* Bankfull to channel-full ratio [m—meters].

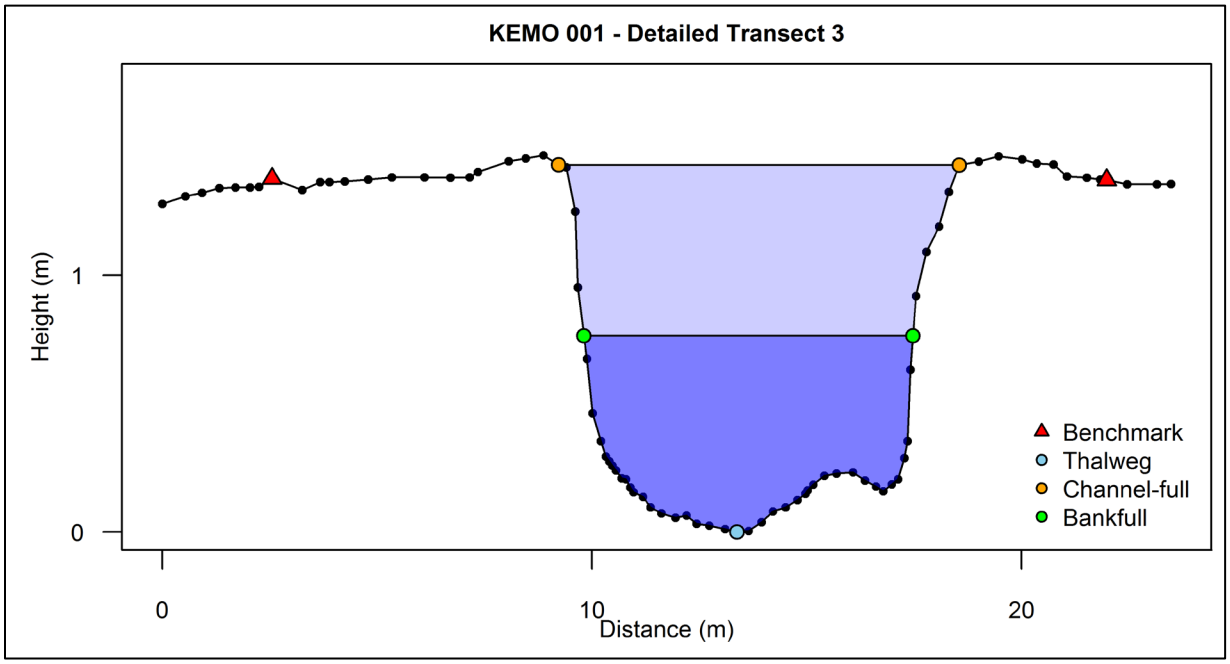


Figure B-16. Detailed transect 3 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

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Appendix C. Survey Results for KEMO002

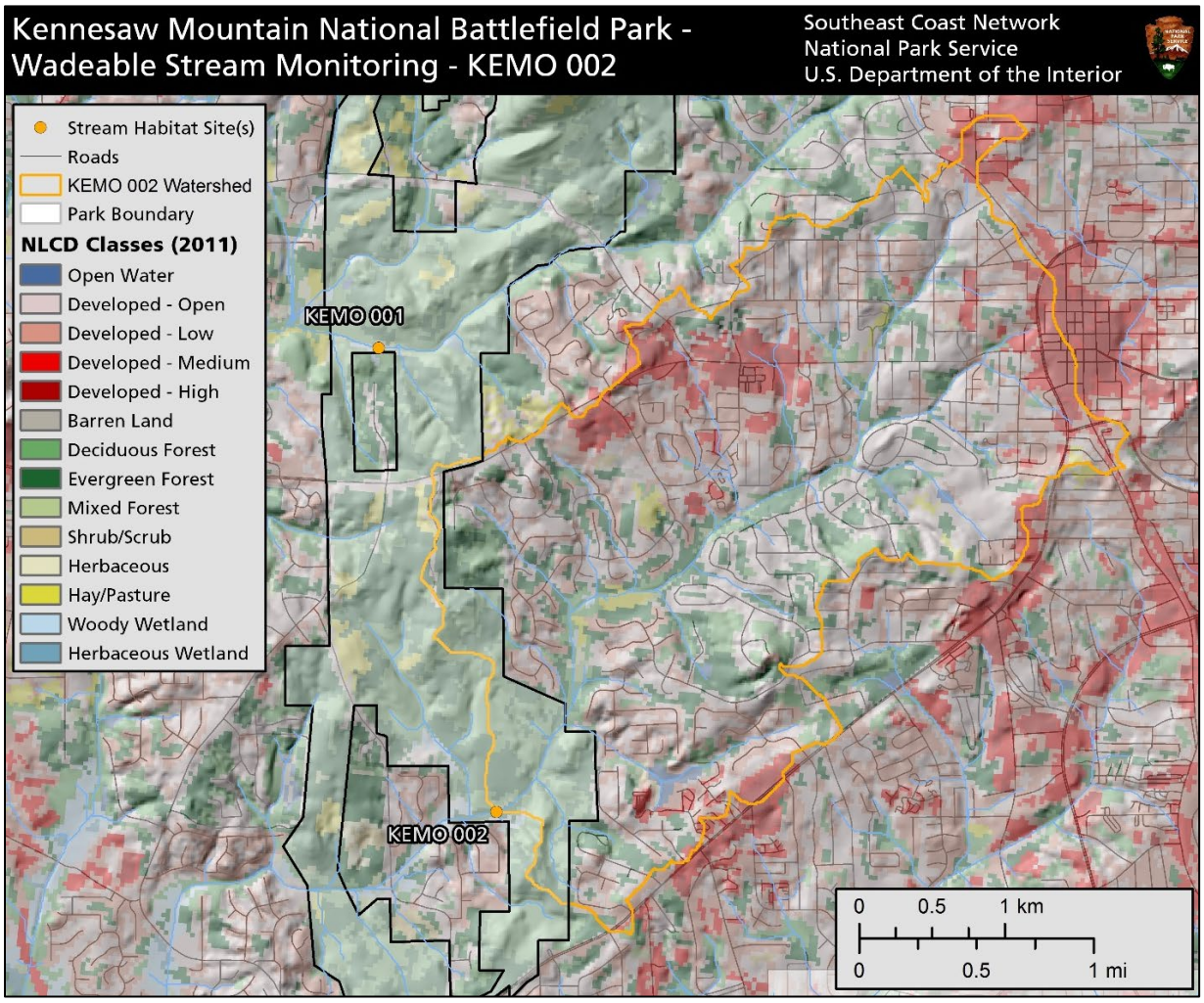


Figure C-1. Map showing the watershed draining to KEMO002 at Kennesaw Mountain National Battlefield. The land use/land cover (2011 NLCD, Homer et al. 2015), road network (U.S. Census 2011), and perennial streams (derived from a 10-meter digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure C-2. Photograph taken on KEMO002, looking upstream on T1 (detailed transect 1).



Figure C-3. Photograph taken on KEMO002, looking downstream on T1 (detailed transect 1).



Figure C-4. Photograph taken on KEMO002, looking at the left bank on T1 (detailed transect 1).



Figure C-5. Photograph taken on KEMO002, looking at the right bank on T1 (detailed transect 1).



Figure C-6. Photograph taken on KEMO002, looking upstream on T6 (detailed transect 2).



Figure C-7. Photograph taken on KEMO002, looking downstream on T6 (detailed transect 2).



Figure C-8. Photograph taken on KEMO002, looking at the left bank on T6 (detailed transect 2).



Figure C-9. Photograph taken on KEMO002, looking at the right bank on T6 (detailed transect 2).



Figure C-10. Photograph taken on KEMO002, looking upstream on T11 (detailed transect 3).



Figure C-11. Photograph taken on KEMO002, looking downstream on T11 (detailed transect 3).



Figure C-12. Photograph taken on KEMO002, looking at the left bank on T11 (detailed transect 3).



Figure C-13. Photograph taken on KEMO002, looking at the right bank on T11 (detailed transect 3).

Table C-1. Land use/land cover characteristics for 2001, 2006, and 2011 for KEMO002. The data included in this table are from the National Land Cover Dataset (Homer et al. 2001; Fry et al. 2006; Homer et al. 2015).

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed
Open Water	1	1	1
Developed—Open[1]	37	38	38
Developed—Low[1]	22	22	22
Developed—Medium[1]	5	5	6
Developed—High[1]	3	3	3
Barren	0	0	0
Deciduous	12	12	12
Evergreen	17	17	17
Mixed Forest	1	1	1
Shrub	0	0	0
Grassland	0	0	0
Pasture	2	1	1
Cultivated	0	0	0
Woody Wetland	0	0	0
Herbaceous Wetland	0	0	0

[1] refers to the intensity or type of development

Table C-2. Geomorphic channel units (GCU) observed in the area between transects at KEMO002. The data describe the percent coverage of each type of geomorphic channel unit.

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	70	0	30	0
5–6	0	10	0	90	0
6–7	0	80	0	20	0
7–8	0	50	0	50	0
8–9	25	0	0	75	0
9–10	25	0	0	50	25
10–11	0	50	20	30	0
Frequency	2	5	1	10	1
Max (%)	25	80	20	100	25
Mean (%)	5	26	2	65	3
Median (%)	0	5	0	63	0
SD (%)	11	33	6	32	8

Table C-3. Characteristics of the large woody debris observed at KEMO002 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	1.22	0.10	0.01	1	None	Buried
2	0.97	0.15	0.02	2	Bank Protection	Buried
3	1.42	0.12	0.02	2	None	Free
4	3.16	0.15	0.06	6	Jam	Buried, Jam
5	2.71	0.12	0.03	6	Jam	Jam
6	4.00	0.19	0.11	6	Jam	Jam
7	8.89	0.20	0.28	6	Jam	Buried
8	9.59	0.14	0.15	6	Bank Protection	Free
9	1.43	0.16	0.03	6	Jam	Free
10	5.02	0.17	0.11	6	Jam	Jam
11	7.80	0.15	0.14	6	Jam	Jam
12	4.15	0.20	0.13	6	Bank Protection	Buried
13	3.71	0.35	0.36	9	Jam	Jam
14	2.74	0.47	0.48	9	Habitat Creation	Buried
15	1.97	0.16	0.04	9	None	Free
16	2.32	0.13	0.03	9	None	Buried
17	1.86	0.13	0.02	9	Bank Protection	Buried
18	2.84	0.28	0.17	9	Jam	Jam
19	5.81	0.18	0.15	9	Habitat Creation	Step
20	3.21	0.10	0.03	9	Jam	Jam
21	5.46	0.24	0.25	10	Bank Protection	Free
22	9.32	0.15	0.16	10	None	Bridge
23	1.33	0.40	0.17	10	Bank Protection	Buried
24	0.94	0.12	0.01	10	Habitat Creation	Buried
25	5.47	0.29	0.36	11	Habitat Creation	Free

Table C-4. Variability of canopy cover observed at KEMO002.

Transect	Canopy Cover (%)
1	96
2	91
3	88
4	91
5	94
6	91
7	76
8	81
9	85
10	93
11	88
Min (%)	76
Max (%)	96
Mean (%)	89
Median (%)	91
SD (%)	6
CV	0.07

Table C-5. Average reach-scale bank characteristics at KEMO002. [L—indicates left bank; R—indicates right bank; m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	SD (L)	SD (R)	CV (L)	CV (R)
Bank Height[1] (m)	11	11	0.54	0.54	2.20	2.20	1.40	1.40	0.54	0.54	0.39	0.39
Floodplain Height[1,2] (m)	5	2	0.54	0.34	1.02	0.80	0.82	0.57	0.17	0.33	0.21	0.57
Channel-full Height[1] (m)	11	11	0.96	1.17	2.20	2.03	1.66	1.78	0.43	0.28	0.26	0.16
Water Depth at Base[3] (m)	11	11	-0.10	-0.11	0.38	0.12	0.03	0.02	0.12	0.07	–	–
Bank Undercut[2] (m)	1	1	0.51	0.37	0.51	0.37	0.51	0.37	–	–	–	–
Bank Angle (°)	11	11	9	10	86	90	54	58	28	27	0.52	0.47
Vegetation Cover (%)	11	11	0	0	40	50	12	24	16	19	1.29	0.78
Bank Stability[4]	11	11	Unstable	Unstable	Very Unstable	Very Unstable	Very Unstable	Unstable	0.85	1.21	0.06	0.09

[1] above thalweg

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

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

[4] See Table 1 for explanation of scores

Table C-6. Cross-sectional characteristics for detailed transect 1 at KEMO002 [m-meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	3.58	6.90	0.52	6.32	0.70	9.02
Channel-full	8.78	9.38	0.94	8.17	1.43	5.71
Ratio*	2.45	1.36	1.81	1.29	2.04	0.63

* Bankfull to channel-full ratio [m—meters].

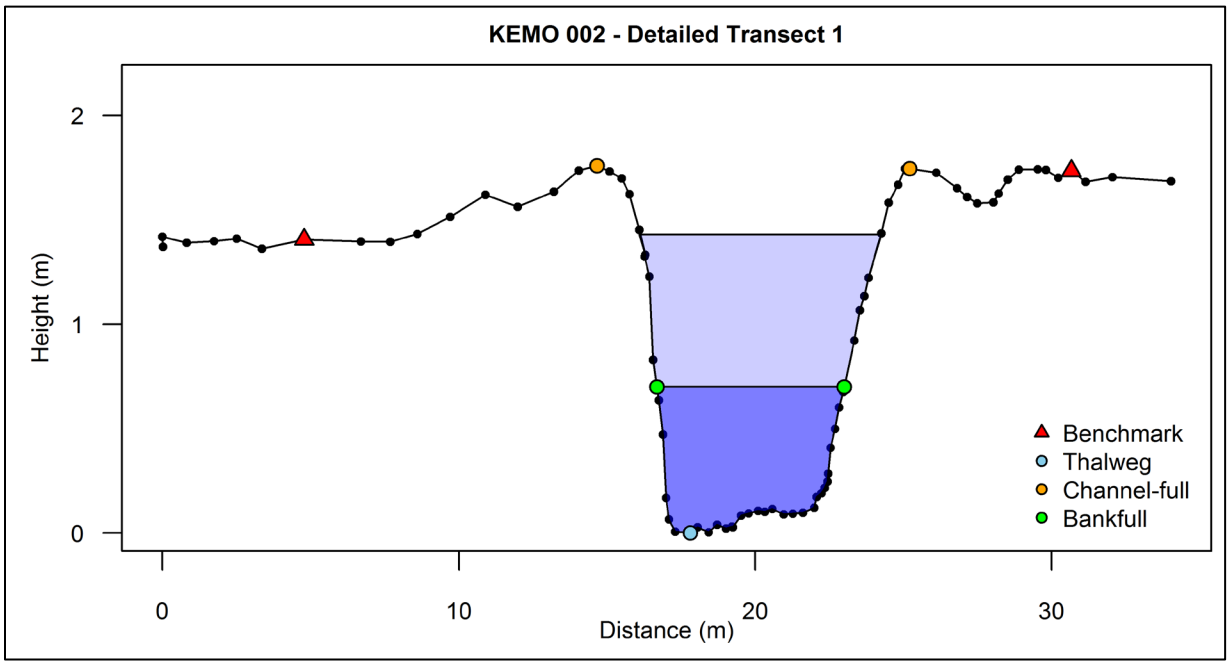


Figure C-14. Detailed transect 1 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Additionally, the channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

Table C-7. Cross-sectional characteristics for detailed transect 2 at KEMO002 [m-meters.

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.06	8.63	0.47	8.08	0.70	11.54
Channel-full	5.76	9.62	0.60	8.96	0.90	9.93
Ratio*	1.42	1.12	1.27	1.11	1.29	0.86

* Bankfull to channel-full ratio [m—meters].

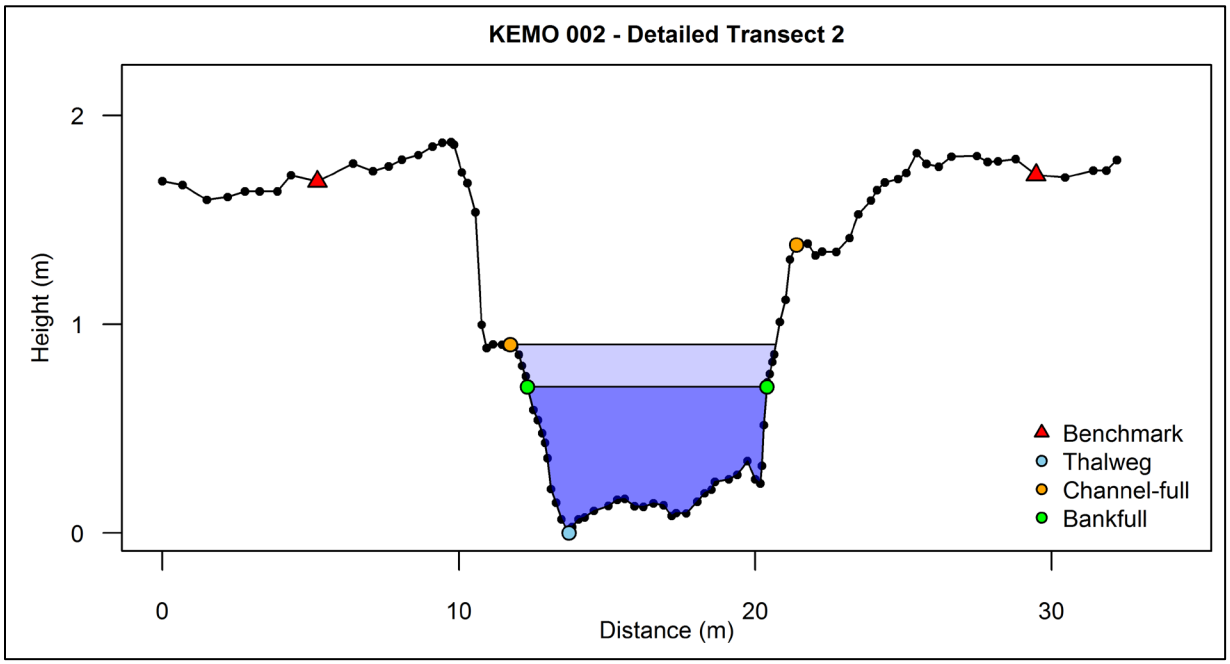


Figure C-15. Detailed transect 2 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

Table C-8. Cross-sectional characteristics for detailed transect 3 at KEMO002 [m-meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.81	6.09	0.30	5.65	0.69	8.14
Channel-full	8.05	9.96	0.81	8.89	1.51	5.90
Ratio*	4.46	1.63	2.73	1.57	2.17	0.73

* Bankfull to channel-full ratio [m—meters].

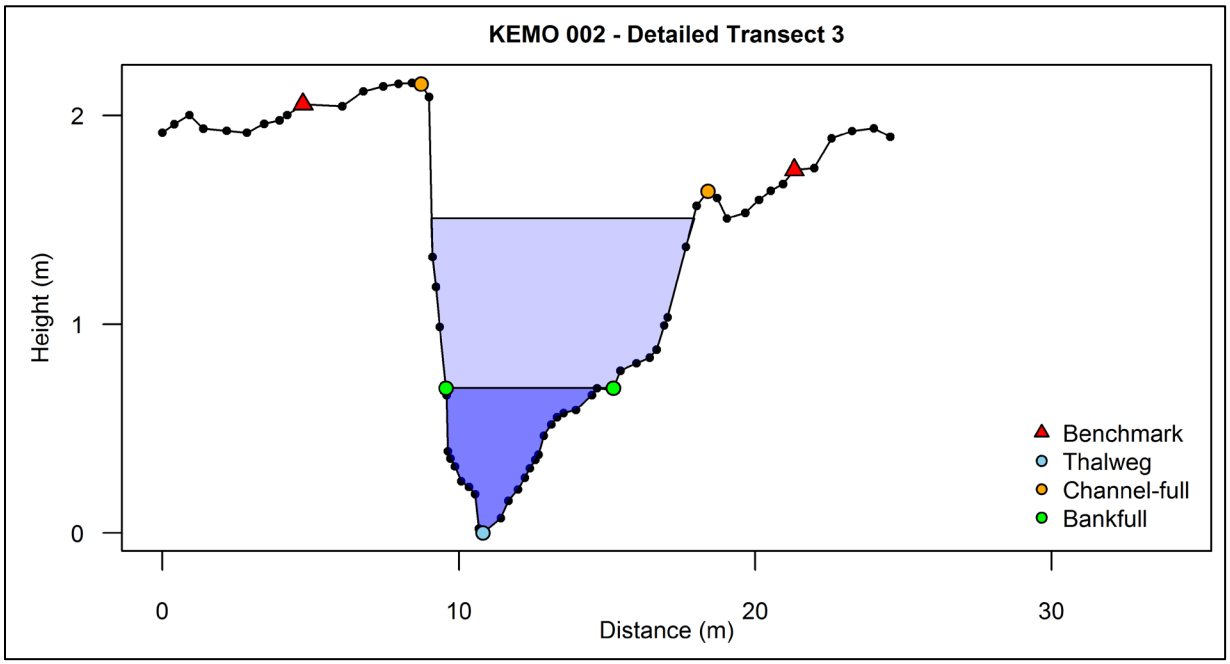


Figure C-16. Detailed transect 3 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue).

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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525