National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Wadeable Stream Habitat Monitoring at Kennesaw Mountain National Battlefield Park

2019 Change Report

Natural Resource Report NPS/SECN/NRR—2020/2199



The production of this document cost $11,452.55, including costs associated with data collection, processing, analysis, and subsequent authoring, editing, and publication

ON THE COVER
Picture looking downstream from Transect 11 at the stream habitat monitoring site on Noses Creek (KEMO001) at Kennesaw Mountain National Battlefield Park. Photograph taken by SECN staff on May 1, 2019.

Wadeable Stream Habitat Monitoring at Kennesaw Mountain National Battlefield Park

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Natural Resource Report NPS/SECN/NRR—2020/2199

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November 2020

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Bateman McDonald, J.M. 2020. Wadeable stream habitat monitoring at Kennesaw Mountain National Battlefield Park: 2019 change report. Natural Resource Report NPS/SECN/NRR—2020/2199. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2280026.

NPS 352/173866 November 2020

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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—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

NED—National Elevation Dataset

NL—Natural levee

NLCD—National Land Cover Dataset

NPS—National Park Service

OCMU—Ocmulgee Mounds National Historical Park

P—Pool

Ru—Run

SECN—Southeast Coast Network

SOP—Standard operating procedure

T#—Standard transect

Summary and Key Findings

The Southeast Coast Network (SECN) 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 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 [GCUs], and large woody debris [LWD]),
- 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 the analysis of remotely-sensed geographic information system (GIS) data, are presented in a baseline report that describes and compares the watershed-, reach-, and transect-scale characteristics of these two stream reaches to each other and to similar-sized streams at Chattahoochee National Recreation Area (McDonald and Starkey 2019a). On May 1, 2019, KEMO001 and KEMO002 were resurveyed to determine the amount of change that has occurred on each reach. This report compares the results of the 2019 resurveys to the initial 2017 baseline surveys.

Noses Creek's watershed (KEMO001) is steep and forested and Ward Creek's watershed (KEMO002) has low slope and relief and is covered mostly by urban and or 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 and distribution of GCUs within each reach, and the presence or absence of LWD, in-stream habitat within both of the surveyed streams were classified the same as in 2017 ('poor to fair' on KEMO001 and 'poor' on KEMO002). The processes that have a potential impact on these habitat classifications have not changed since the previous survey.

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 KEMO001 may increase habitat diversity and provide more stability to the reach that could upgrade the classification to 'fair.' The addition of LWD to KEMO001 seems likely, as a large LWD dam has developed just upstream of the reach that may fail prior to the next scheduled survey in 2022. 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 delivered to the reach (Allan and Castillo 2007). Currently, much of the existing LWD bridges the channel (does not contact the bed) and has minimal influence on GCUs.

Both of the stream reaches are recovering from a legacy of poor land use practices and are influenced by varying amounts of impervious surface cover and urban and or suburban development in their watersheds. Both reaches are affected by episodic and progressive slumping of their banks. These slump surfaces (from here on elevated entrenched surfaces) had been interpreted as relatively stable bankfull 'floodplain' surfaces. The changes in the heights and sizes of these features have shown that these surfaces are not stable and represent the process by which these streams will continue to widen as they equilibrate to their modern flow and sediment regimes. The loss and movement of bar surfaces along both reaches is evidence agreeing with the interpretation of highly mobile beds within these stream

reaches. The small knickpoint identified in the downstream portion of Noses Creek (KEMO001) in 2017 has not migrated further into the reach. The riffle immediately upstream of the knickpoint continues to provide enough resistance to prevent headward migration of the knickpoint. Similar to 2017, no immediate management concerns were identified along either reach. The biggest concern for visitors is navigating the high banks to access the streams.

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 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 2019b). Streams chosen for monitoring 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 (e.g., gullies) typical of highly disturbed landscapes like the Appalachian Piedmont.

The objectives of this report are to:

- Present the wadeable stream surveys completed at Kennesaw Mountain NBP during late spring 2019,
- Provide a comparison of the 2019 results to the 2017 baseline surveys,
- Describe the processes that are responsible for the differences between the two surveyed stream reaches (KEMO001 and KEMO002), and
- Explain why these streams are changing and their potential trajectories of change.

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 approximately 27°F (-3°C) in December to 92°F (33°C) in August (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 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 and or 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 from unstable banks, and finally stabilization and more natural reworking of in-channel alluvium (Figure 1). The exact stage that a particular stream occupies, at a given moment in time, 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 quite unstable and subject to undercutting and slumping (Ruhlman and Nutter 1999).

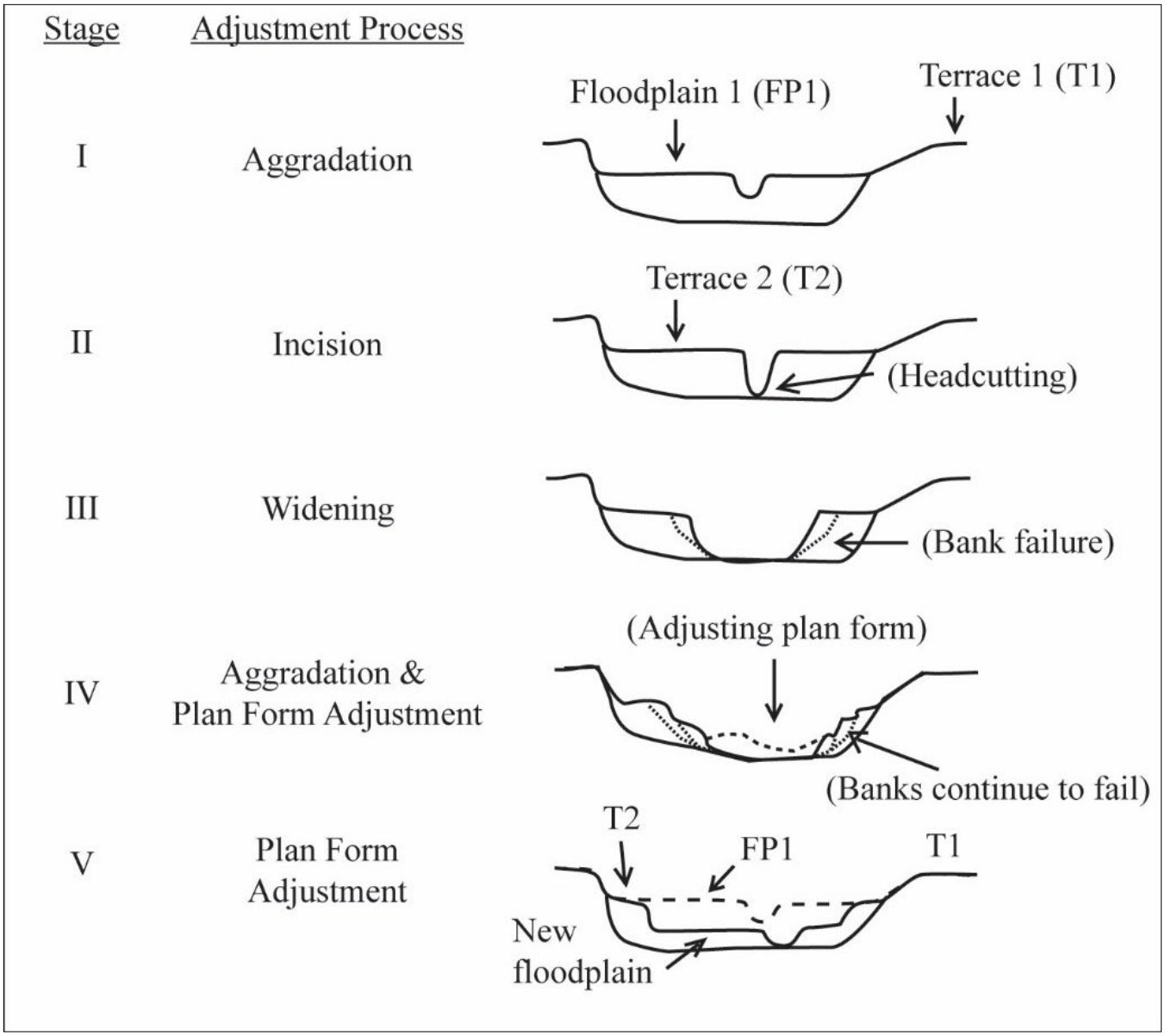


Figure 1. Generalized channel evolution model (modified from Schumm et al. 1984).

Kennesaw Mountain National Battlefield Park

Kennesaw Mountain National Battlefield Park (KEMO) 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 located in 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 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, verbal communication).

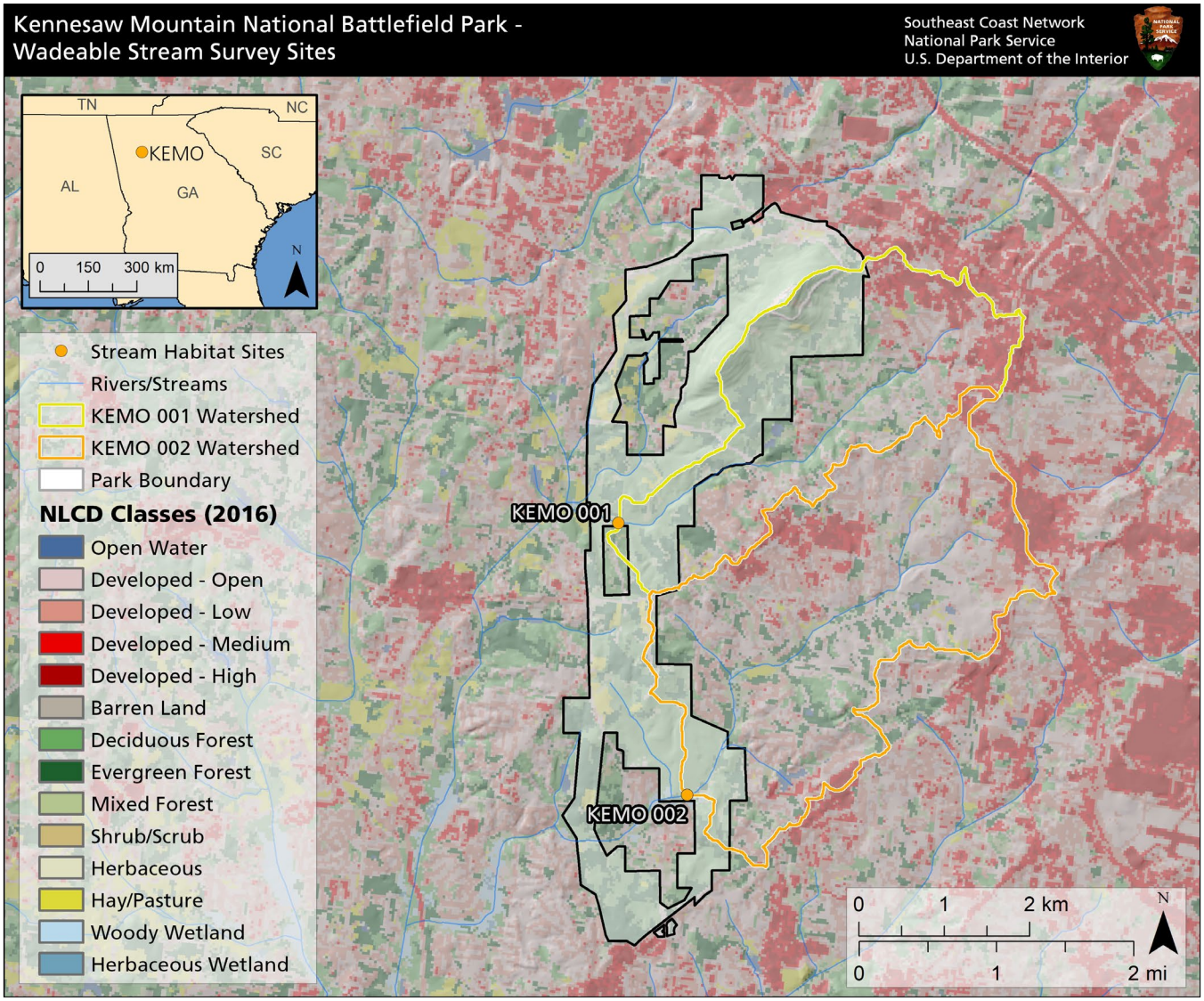


Figure 2. Map showing Kennesaw Mountain National Battlefield Park and its wadeable stream sites (KEMO001 and KEMO002). The watersheds draining to each study reach are shown to provide a context for the data presented in this report. The land use and land cover (NLCD 2016, Homer et al. 2020) and perennial streams (derived from a 10-meter [32.8-foot {ft}] digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

Previous Survey

On May 17, 2017, data were collected at Kennesaw Mountain National Battlefield Park to characterize the in-channel and near-stream habitat on Noses Creek (KEMO001) and John Ward Creek (KEMO002; Figure 2). These data, along with analysis of remotely-sensed geographic information system (GIS) data, are presented in a baseline report that describes and compares the watershed-, reach-, and transect-scale characteristics of these two stream reaches and compares them to two similar-sized streams at Chattahoochee River National Recreation Area (Haw Creek [CHAT001] and Long Island Creek [CHAT013]; McDonald et al. 2019).

The analysis of the GIS data found that Noses Creek's watershed (KEMO001) is steep and forested and Ward Creek's watershed (KEMO002) has low slope and relief and is covered mostly by urban and or suburban development. Based on the pebble counts, the type and distribution of GCUs within each reach, and the presence or absence of LWD, in-stream habitat in the surveyed stream reaches were classified as 'poor to fair' at KEMO001 and 'poor' at KEMO002. Note, 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.

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 or suburban development within their respective watersheds. In addition to urban and or suburban development, Ward Creek is also influenced by a history of upstream disturbance caused by a highly active beaver population and the installation of a sewer line within the past decade. These disturbances have created a multi-channel system upstream with a highly mobile bed and unstable banks.

The surveyed reaches were interpreted as 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 (large increase in slope) that may cause further bed degradation in the middle and upstream portions of the survey reach. 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. Neither of these streams had immediate management concerns. The biggest concern for visitors is high banks that need to be navigated to access the streams.

Methods

The habitat characteristics and geomorphic parameters selected for monitoring are based on those collected by other federal organizations (USFS, Harrelson et al. 1994; USGS, Fitzpatrick et al. 1998; 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 also identifies 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 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).

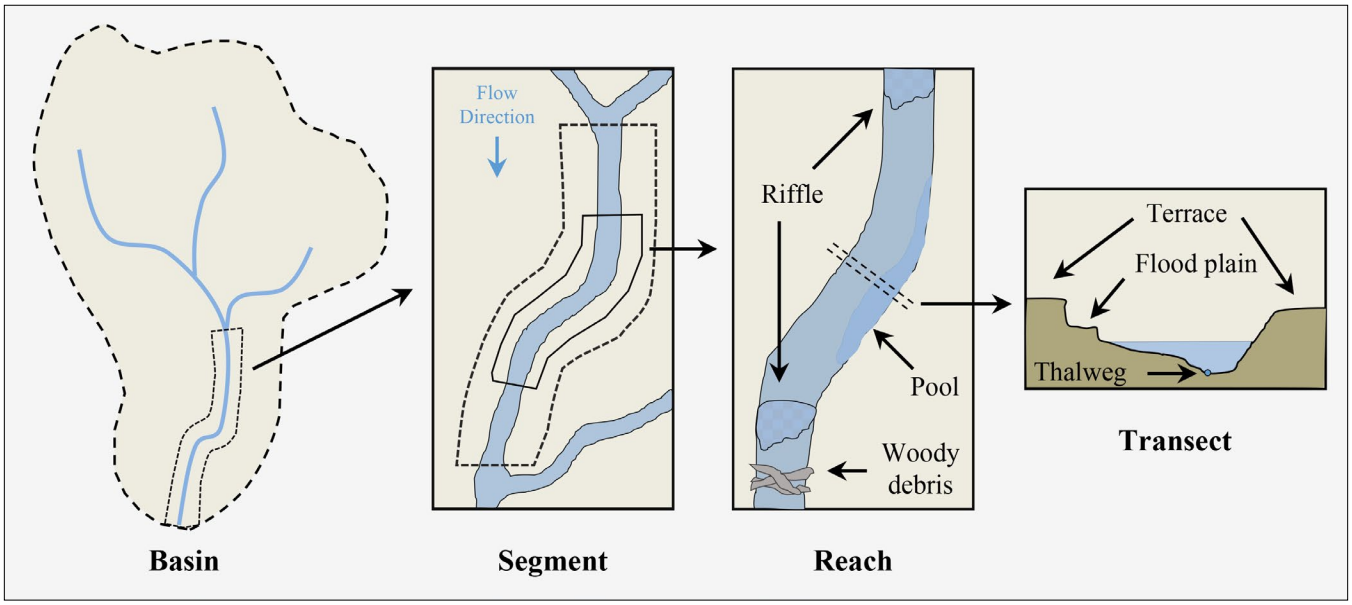


Figure 3. Spatial hierarchy of stream systems and scales of data collection (modified from Fitzpatrick et al. 1998). View in transect diagram is in the downstream direction.

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 *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 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 have bank stability scores of 'at-risk' or 'unstable.' This condition is

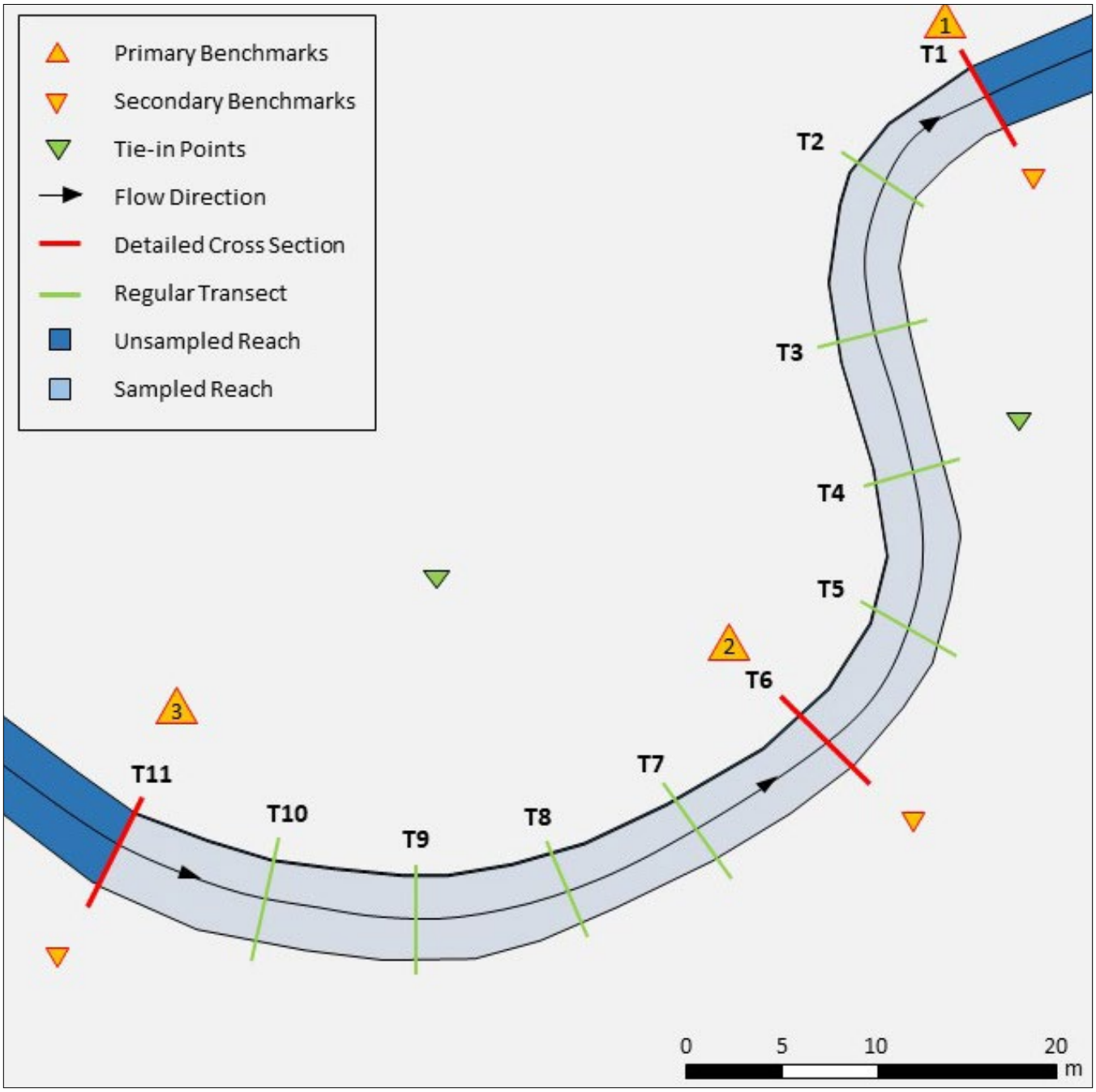


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.

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 geomorphic channel units (GCUs) or in-stream habitat (e.g., high-energy riffles vs. low-energy pools), an inventory of large woody debris (LWD; defined as greater than 1 meter [3.28 ft] in length and greater than 10 centimeters [3.9 in] in diameter, as defined in McDonald et al. 2018a) within the reach, 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 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 influence future classification and lead to habitat improvement or degradation.

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] Park and site water-quality index ratings are adapted from ratings established by the EPA (2012).

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.

Statistical Analysis

The statistical significance of the difference of means between surveys (2017 and 2019) and between the stream reaches (KEMO001 and KEMO002) for nine variables was tested using two-sample t-tests.

1. pebble count data (millimeters [mm]);
2. thalweg depth (meters [m]);
3. thalweg position (% distance from left bank);
4. wetted width (m);
5. active channel width (m);
6. channel-full width (m);
7. channel-full height (m);
8. bank angle (°); and
9. vegetative cover of the banks (%).

Bankfull width and height are 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 and between surveys was not always equal.

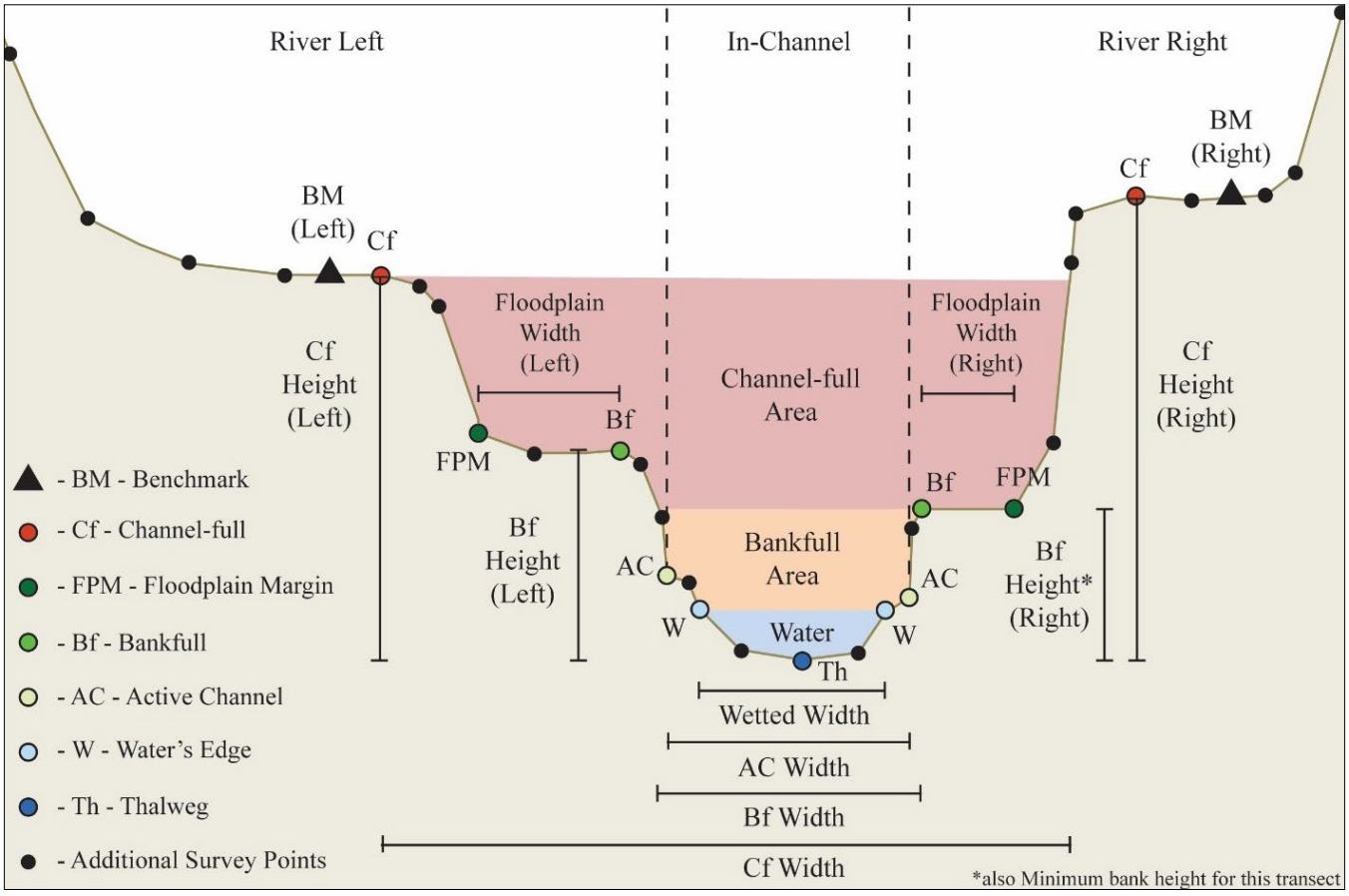


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes light blue (baseflow) and orange portions of the cross-section. Channel-full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

Results

On May 1, 2019, two streams (Noses Creek [KEMO001] and John Ward Creek [KEMO002]) 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). Both surveyed reaches are on a third-order segment within their respective stream networks. Field surveys, in-office analyses, and statistical comparisons between monitoring years (2017 and 2019) between the monitored reaches are presented in the following sections. Results and data summary tables for each reach are provided in Appendices B (KEMO001) and C (KEMO002).

Weather 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). Slightly more rain fell in the months prior to the 2019 survey compared to 2017 (Table 2), though a small storm did affect the area around Kennesaw Mountain NBP the week before the 2017 survey. Another difference between the survey periods was that there were a few more large events (greater than 1 inch [2.5 cm]) in the months leading up to the 2019 survey.

Basin Characteristics

The section provides a brief summary of the basin characteristics of the study watersheds. For a more in-depth look at the basin characteristics and how they compare to the third-order watersheds at Chattahoochee River NRA, see McDonald and Starkey (2019a). The watersheds drain 8.30 square kilometers (3.2 square miles [mi^2]; KEMO001) and 12.66 square kilometers (4.89 mi^2; 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 higher slope than KEMO002's watershed. KEMO002 has a high drainage density but a low segment slope. The land use and 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 much more suburban land cover (Open and low-intensity development) than KEMO001 (Table 4). KEMO001 has more forest cover than KEMO002. The higher percent forest cover for KEMO001 is attributable to the higher percent of the watershed managed by the NPS, 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 on-site observations indicate Ward Creek is heavily influenced by beavers just upstream of the park.

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 the 2017 and 2019 wadeable stream surveys at Kennesaw Mountain NBP. Data from weather co-op station Marietta 3.3 NNE [in—inches].

Time Frame	Length of Period	Total Precipitation (Inches)	Number of Events Greater than 1 Inch
5/10/2017–5/17/2017	One Week	0.45	0
4/17/2017–5/17/2017	One Month	3.91	2
2/17/2017–5/17/2017	Three Months	13.44	3
4/24/2019–5/1/2019	One week	0.01	0
4/1/2019–5/1/2019	One Month	5.28	2
2/1/2019–5/1/2019	Three Months	14.30	5

Table 3. Watershed characteristics for KEMO001 and KEMO002 are calculated using the National Elevation Dataset (NED) 10-meter (32.8-ft) digital elevation model. Please refer to McDonald et al. (2018a) for definitions of the variables [km—kilometers; m—meters].

Basin Charactieristic	KEMO001	KEMO002
Drainage Area (km^2)	8.30	12.66
NPS Managed Area (km^2)	2.80	1.00
NPS Managed Area (%)	34%	8%
Total Stream Length (km)	12.68	20.82
Drainage Density	1.53	1.94
Strahler Order	3	3
Bifurcation Ratio	1.60	1.77
Entire Stream Gradient[a]	0.011	0.008
Segment Gradient[b]	0.005	0.001
Slope—Average	6.69	4.50
Slope—Standard deviation	5.75	3.06
Slope—Coefficient of variation (CV)	0.86	0.68
Basin Length (km)	6.35	7.14
Basin Shape[c]	0.21	0.25
Basin Relief (m)	261	88
Basin Relief Ratio	0.041	0.012
Elevation —Standard deviation (m)	33	15

[a] Entire stream gradient 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.

Table 4. Land use and land cover characteristics in 2011 and 2016 for KEMO001 and KEMO002. The data included in this table are from the National Land Cover Dataset (Homer et al. 2015; Homer et al. 2020).

Variable	KEMO001 in 2011	KEMO001 in 2016	KEMO002 in 2011	KEMO002 in 2016
Developed Open & Low (%)	34	33	60	58
Developed Med. & High (%)	12	12	9	10
Forested (%)	50	53	29	29
Grassland (%)	3	1	1	1
Wetland (%)	0	0	0	0

KEMO001—Noses Creek

Reach Description

KEMO001 is located on Noses Creek approximately 450 meters (1,476 ft) downstream of the pedestrian bridge on Noses Creek Trail (Figure B-1). 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). A very large LWD dam has developed (since 2017) just upstream of the reach. This LWD dam had a large impact on the area immediately downstream (just upstream of T11), causing a deep (greater than 1.5 meters [4.9 ft]) pool to form (through excavation of the bed). A groundwater seep enters the channel on river left between T8 and T9 (Figure 6). KEMO001's channel continues to be fairly entrenched. A few areas interpreted as floodplain in 2017 have developed in the reach (e.g., on river left between T2 and T4 and on river right between T4 and T6; Figure 6). In 2019, these bankfull 'floodplain' surfaces were reclassified as 'elevated entrenched surfaces' because of their apparent instability (e.g., reduction in heights and areas). These elevated entrenched surfaces are likely slump-cored surfaces due to their morphology (arcuate shape cut into banks) and their locations within the reach (found on both the inside and outside of meander bends). The surveyed reach was 80 meters (262 ft) long, with 8 meters (26.2 ft) between transects. The following sections describe the differences in the 2017 and 2019 reach-scale habitat characteristics and channel morphology along KEMO001, as well as the changes observed on the detailed transects. Transect-scale survey results for KEMO001 can be found in Appendix B.

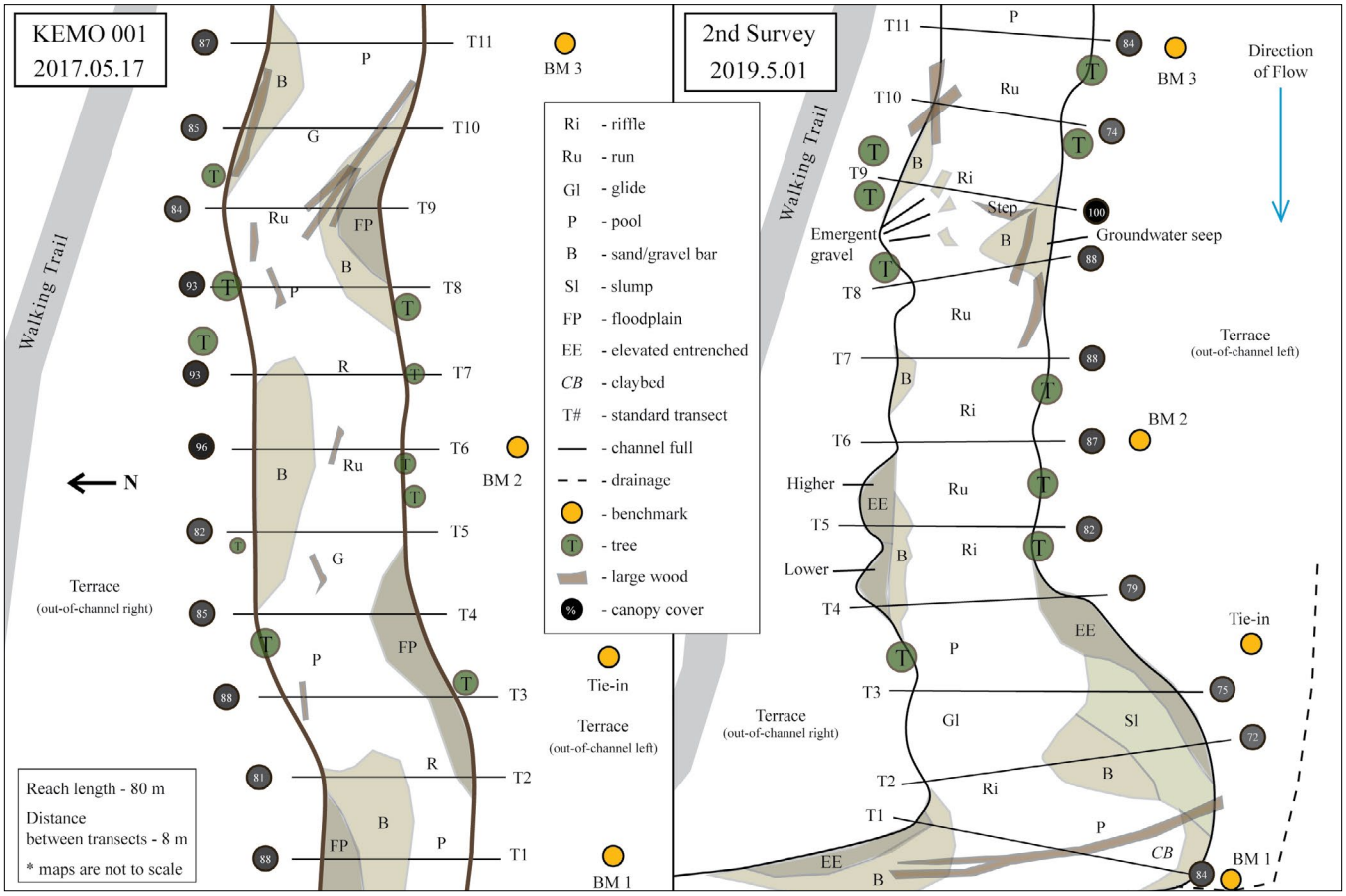


Figure 6. Reach-scale map of KEMO001. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each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

Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) observed at KEMO001 during the 2017 and 2019 surveys were quite different (Table 5). During 2017, the GCUs covering Noses Creek were a mixture of riffle (49%) and pool (33%) with some run (13%) and glide (5%) habitats mixed in. During 2019, the majority of the habitat was run (69%) followed by riffle (23%), glide (7%), and then pool (2%). The results of the pebble counts from the 2017 and 2019 surveys were similar (Table 6). Though the minimum pebble size was coarser in 2019 (3 millimeters [0.1 in] versus less than 0.06 millimeters [.002 in]), the difference in the means (17.77 millimeters [0.70 in; 2017] and 20.57 millimeters [0.81 in; 2019]) was not statistically significant (Table 7). Six pieces of LWD were observed within KEMO001's channel during the 2019 survey (Table 8). This decrease in the number of pieces of LWD led to a reduction of total volume of LWD per channel area (from 0.0005 m^3/m^2 to 0.0002 m^3/m^2). Canopy cover in 2019 (83%) was slightly lower than 2017 (87%; Table 9). Mean thalweg depth (0.22 meters and 0.25 meters [0.72 ft and 0.82 ft]) and mean thalweg position (41% and 44%) were very similar from 2017 to 2019 (Table 10) and these slight differences were not statistically significant (Table 7). In 2019, thalweg depths were slightly less variable (CV = 0.42 versus 0.52 in 2017) and thalweg position was slightly more variable (CV = 0.81 versus 0.68 in 2017).

Table 5. Geomorphic channel units (GCUs) observed in the area between transects during the 2017 and 2019 surveys at KEMO001 and KEMO002.

GCU Type	Site	Year	Frequency	Maximum (%)	Mean (%)	Standard Deviation (%)
Rifle	KEMO001	2017	8	90	49	33
	KEMO001	2019	7	75	23	26
	KEMO002	2017	2	25	5	11
	KEMO002	2019	4	20	4	7
Run	KEMO001	2017	6	40	13	14
	KEMO001	2019	10	100	69	32
	KEMO002	2017	5	80	26	33
	KEMO002	2019	10	100	63	32
Glide	KEMO001	2017	1	50	5	16
	KEMO001	2019	1	70	7	22
	KEMO002	2017	1	20	2	6
	KEMO002	2019	0	0	0	0
Pool	KEMO001	2017	9	80	33	27
	KEMO001	2019	2	10	2	4
	KEMO002	2017	10	100	65	32
	KEMO002	2019	7	80	31	31
Step	KEMO001	2017	0	0	0	0
	KEMO001	2019	0	0	0	0
	KEMO002	2017	1	25	3	8
	KEMO002	2019	1	20	2	6

Table 6. Particle size distributions of bed sediment (in millimeters [mm]) from the pebble counts conducted in 2017 and in 2019 at KEMO001 and KEMO002. The subscripts indicate the percent of the sample that is smaller than the reported diameter [Min—Minimum; Max—Maximum; n—Number of measurements taken].

Statistic	KEMO001 (n=100) in 2017	KEMO001 (n=100) in 2019	KEMO002 (n=100) in 2017	KEMO002 (n=100) in 2019
Min	< 0.06	3.00	< 0.06	< 0.06
D_5	3.00	5.00	1.00	< 0.06
D_{16}	7.00	8.16	1.00	2.00
D_{50}	16.00	20.00	12.00	7.00
Mean	17.77	20.57	12.56	9.28
D_{84}	27.00	32.00	20.84	17.00
D_{95}	37.90	41.00	29.95	22.00
Max	50.00	49.00	57.00	34.00

Table 7. Difference in means t-test results comparing the 2017 and 2019 surveys of KEMO001. 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].

Measurement	n[a]	KEMO001 in 2017	KEMO001 in 2019	P-value	Significance
Pebble Count (mm)	100	17.76	20.57	0.068	–
Thalweg Depth (m)	11	0.22	0.25	0.509	–
Thalweg Position (%)	11	41	44	0.818	–
Wetted Width (m)	11	3.04	4.59	0.013	*
Active Channel Width (m)	11	5.61	5.08	0.307	–
Channel-full Width (m)	11	8.51	9.79	0.005	**
Minimum Bank Height (m)	22	1.31	1.36	0.447	–
Channel-full Height (m)	22	1.44	1.53	0.035	*
Bank Angle (°)	22	40.14	46.37	0.311	–
Vegetative Cover (%)	22	40.45	44.32	0.628	–

[a] Number of measurements taken

Table 8. Summary statistics for the large woody debris measured in 2017 and 2019 at KEMO001 and KEMO002 [m—meters].

Statistic	Site	Year	n[a]	Length (m)	Diameter (m)	Volume (m^3)
Minimum	KEMO001	2017	11	0.56	0.10	0.01
	KEMO001	2019	6	1.00	0.10	0.01
	KEMO002	2017	25	0.94	0.10	0.01
	KEMO002	2019	38	1.02	0.10	0.02
Mean	KEMO001	2017	11	2.91	0.12	0.03
	KEMO001	2019	6	2.14	0.13	0.03
	KEMO002	2017	25	3.89	0.19	0.13
	KEMO002	2019	38	3.73	0.18	0.14
Maximum	KEMO001	2017	11	10.00	0.16	0.10
	KEMO001	2019	6	6.28	0.19	0.08
	KEMO002	2017	25	9.59	0.47	0.48
	KEMO002	2019	38	13.27	0.41	1.23
Standard Deviation	KEMO001	2017	11	3.02	0.02	0.03
	KEMO001	2019	6	2.06	0.03	0.03
	KEMO002	2017	25	2.66	0.10	0.13
	KEMO002	2019	38	3.14	0.08	0.25
Sum	KEMO001	2017	11	–	–	0.34
	KEMO001	2019	6	–	–	0.19
	KEMO002	2017	25	–	–	3.31
	KEMO002	2019	38	–	–	5.31
Per Channel Area (m^3/m^2)	KEMO001	2017	–	–	–	0.0005
	KEMO001	2019	–	–	–	0.0002
	KEMO002	2017	–	–	–	0.0054
	KEMO002	2019	–	–	–	0.0060

[a] Number of measurements taken

Table 9. Descriptive statistics for reach-scale canopy cover in 2017 and 2019 at KEMO001 and KEMO002.

Site	Year	n[a]	Minimum (%)	Mean (%)	Maximum (%)	Standard Deviation (%)	Coefficient of Variance (%)
KEMO001	2017	11	81	87	96	5	0.05
KEMO001	2019	11	72	83	100	8	0.10
KEMO002	2017	11	76	89	96	6	0.07
KEMO002	2019	11	62	84	99	14	0.16

[a] Number of measurements taken

Table 10. Reach-scale averaged thalweg conditions in 2017 and 2019 at KEMO001 and KEMO002 [m—meters].

Thalweg	Site	Year	n[a]	Minimum	Mean	Maximum	Standard Deviation	Coefficient of Variance
Depth (m)	KEMO001	2017	11	0.09	0.22	0.44	0.12	0.52
	KEMO001	2019	11	0.12	0.25	0.44	0.11	0.42
	KEMO002	2017	11	0.09	0.32	0.49	0.13	0.42
	KEMO002	2019	11	0.17	0.40	0.68	0.14	0.35
Position[b] (%)	KEMO001	2017	11	10	41	90	28	0.68
	KEMO001	2019	11	5	44	95	36	0.81
	KEMO002	2017	11	5	43	90	36	0.84
	KEMO002	2019	11	10	61	90	33	0.54

[a] Number of measurements taken for depth and position

[b] Percent distance from left active channel bank

Channel Morphology

Wetted widths were wider on average during the 2019 survey. Mean wetted width increased to 4.59 meters (15.06 ft) from 3.04 meters (9.97 ft) in 2017 (Table 11). This difference in mean wetted width between survey years was statistically significant (Table 7). Additionally, the maximum (7.86 meters [25.79 ft]) and minimum (2.27 meters [7.45 ft]) wetted widths in 2019 were also wider than in 2017 (4.44 meters and 1.71 meters [14.57 ft and 5.61 ft], respectively). Mean active channel widths, on the other hand, were narrower in 2019 (5.08 meters [16.67 ft]) than in 2017 (5.61 meters [18.41 ft]; Table 11), but this difference was not significant (Table 7). A relatively large difference between survey years was that variability in active channel width was more than two times more variable in 2019 (CV = 0.29) than in 2017 (CV = 0.13; Table 11). The same number of bankfull widths were measured in 2019 as 2017 (n = 5; Table 11). Bankfull widths were slightly wider in 2019 (6.90 meters [22.64 ft] versus 6.37 meters [20.90 ft]). Differences in mean bankfull width were not statistically tested because of the relatively small number of bankfull widths available to measure. Channel-full widths were on average wider in 2019 (9.79 meters [32.12 ft]) compared to 2017 (8.51 meters [27.92 ft]; Table 11), and this difference was statistically significant (Table 7).

Mean minimum bank height (lowest bank height on a transect) in 2019 (1.36 meters [4.46 ft]) was similar to the mean in 2017 (1.31 meters [4.30 ft]; Table 12). Bankfull heights were slightly higher in 2019 (0.88 meters [2.89 ft]) and less variable (CV = 0.17) than in 2017 (0.73 meters [2.40 ft]; CV = 0.26). Additionally, the minimum bankfull height in 2019 (0.73 meters [2.40 ft]) was approximately 0.20 meters [0.66 ft] higher than in 2017 (0.51 meters [1.67]). Channel-full heights were also higher in 2019 (1.53 meters [5.02 ft] compared to 1.44 meters [4.72 ft]; Table 12). The difference in mean channel-full height between the survey years was statistically significant (P-value = 0.005; Table 7). Similar to 2017, variability in channel-full heights was low (CV = 0.10 [2017] and 0.08 [2019]; Table 12). The banks have become more undercut from 2017 to 2019 (n = 1 to n = 4; Table 12). The mean depth of undercut during 2017 (0.14 meters [0.46 ft]) was slightly less than the minimum undercut depth measured in 2019 (0.15 meters [0.49 ft]). Bank angles were on average slightly steeper during 2019 (46°) compared to 2017 (40°; Table 12). The slight difference in mean bank angle between survey years was not statistically significant (Table 7). Bank vegetation cover was similar in 2019 (44%) compared to 2017 (40%; Table 12), and the difference was not statistically significant (Table 7). Bank stability scores were lower (more stable) in 2019 compared to 2017 (Table 12).

Table 11. Reach-scale width characteristics in 2017 and 2019 at KEMO001 and KEMO002.

Widths	Site	Year	n[a]	Minimum	Mean	Maximum	Standard Deviation	Coefficient of Variance
Wetted	KEMO001	2017	11	1.71	3.04	4.44	0.96	0.31
	KEMO001	2019	11	2.27	4.59	7.86	1.58	0.34
	KEMO002	2017	11	2.48	4.37	6.11	1.20	0.27
	KEMO002	2019	11	2.11	5.13	7.10	1.69	0.33
Active Channel	KEMO001	2017	11	4.65	5.61	7.16	0.70	0.13
	KEMO001	2019	11	2.78	5.08	7.75	1.48	0.29
	KEMO002	2017	11	3.33	5.40	7.36	1.52	0.28
	KEMO002	2019	11	3.28	5.55	7.18	1.36	0.24
Bankfull	KEMO001	2017	5	4.80	6.37	7.70	1.06	0.17
	KEMO001	2019	5	5.48	6.90	8.30	1.14	0.16
	KEMO002	2017	7	4.86	6.00	7.49	0.97	0.16
	KEMO002	2019	6	7.94	8.71	10.60	1.06	0.12
Channel-Full	KEMO001	2017	11	7.55	8.51	9.65	0.76	0.09
	KEMO001	2019	11	8.39	9.79	12.20	1.08	0.11
	KEMO002	2017	11	7.36	8.75	9.55	0.81	0.09
	KEMO002	2019	11	8.36	12.54	15.94	2.67	0.21

[a] Number of measurements taken

Table 12. Reach-scale averaged bank characteristics in 2017 and 2019 at KEMO001 and KEMO002 [m—meters].

Bank Characteristics	Site	Year	n[a]	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variance
Minimum Bank Height[b,c] (m)	KEMO001	2017	22	0.51	1.31	1.74	0.32	0.24
	KEMO001	2019	22	0.73	1.36	1.75	0.33	0.24
	KEMO002	2017	22	0.34	1.49	2.20	0.54	0.36
	KEMO002	2019	22	1.11	1.86	2.30	0.36	0.19
Bankfull Height[b,d] (m)	KEMO001	2017	5	0.51	0.73	1.01	0.19	0.26
	KEMO001	2019	6	0.73	0.88	1.06	0.15	0.17
	KEMO002	2017	7	0.34	0.75	1.02	0.23	0.31
	KEMO002	2019	6	1.11	1.36	1.63	0.23	0.17
Channel-full Height[b] (m)	KEMO001	2017	22	1.18	1.44	1.74	0.14	0.10
	KEMO001	2019	22	1.37	1.53	1.75	0.12	0.08
	KEMO002	2017	22	0.96	1.72	2.20	0.36	0.21
	KEMO002	2019	22	1.81	2.06	2.35	0.15	0.07
Bank Undercut[d] (m)	KEMO001	2017	1	–	0.14	–	–	–
	KEMO001	2019	4	0.15	0.45	0.80	0.31	0.69
	KEMO002	2017	2	0.37	0.44	0.51	0.10	0.22
	KEMO002	2019	4	0.12	0.27	0.40	0.12	0.43
Bank Angle (°)	KEMO001	2017	22	3	40	72	20	0.50
	KEMO001	2019	22	11	46	83	20	0.43
	KEMO002	2017	22	9	56	90	27	0.48
	KEMO002	2019	22	3	47	91	24	0.50
Vegetation Cover (%)	KEMO001	2017	22	0	40	85	28	0.69
	KEMO001	2019	22	10	44	90	24	0.55
	KEMO002	2017	22	0	18	50	18	0.99
	KEMO002	2019	22	10	38	70	21	0.57
Bank Stability[e]	KEMO001	2017	22	11.50	13.50	16.00	1.28	0.09
	KEMO001	2019	22	9.50	12.02	14.50	1.22	0.10
	KEMO002	2017	22	11.50	14.43	15.75	1.30	0.09
	KEMO002	2019	22	10.50	12.95	14.50	1.06	0.08

[a] Number of measurements taken

[b] Above thalweg

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

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

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

Detailed Transects

The detailed transects on KEMO001 were surveyed on T1 (BM1; Figure 7), T6 (BM2; Figure 8), and T11 (BM3; Figure 9). On the detailed transects, bankfull cross-sectional area was on average 0.44 square meters [4.74 square feet {ft^2}] larger in 2019 (3.74 square meters [40.26 ft^2]) than in 2017 (3.31 square meters [35.63 ft^2]; Table 13). On average, channel-full area was also larger (increase of 0.43 square meters [4.63 ft^2]) in 2019 (9.10 square meters [97.95 ft^2]) compared to 2017 (8.67 square meters [93.32 ft^2]; Table 13). Water surface slope (longitudinal profile) for this section of Noses Creek was 0.0042 m/m in 2019 and 0.0015 m/m in 2017 (Figure 10; Table 13). In 2017, channel gradient was relatively consistent except for a large increase in slope between T1 and T2. During 2019, two relatively large increases in slope were identified (between T1 and T2 as well as between T9 and T10) relating to the well-developed riffles in these areas. The reach is straight and has very low sinuosity (1.03; Table 13).

Bankfull cross-sectional area on detailed transect 1 (T1) increased by 0.70 square meters [7.53 ft^2] (Table 14). Bankfull width increased by 1.00 meter [3.28 ft], and bankfull height decreased by 0.08 meters [0.26 ft]. The 2017 interpreted point bar and floodplain sequence along river right on detailed transect 1 (T1) has eroded back towards the right bank. The flat elevated entrenched surface (2017 floodplain) was much smaller during the 2019 survey (Figure 7). Detailed transect 1 (T1) continues to erode into a clayey deposit along river left and an ephemeral channel is still affecting the creek just downstream of T1. Channel-full area on detailed transect 1 also increased (by 0.93 square meters [10.01 ft^2]) from 2017 (7.48 square meters [80.51 ft^2]) to 2019 (8.41 square meters [90.52 ft^2]; Table 14). There was a slight increase in channel-full width (0.32 meters [1.05 ft) and a slight decrease in channel-full height (-0.08 meters [-0.26 ft]) on detailed transect 1.

Detailed transect 2 (T6) is entrenched and no elevated entrenched surfaces (bankfull) were present. In order for changes in the bed and bank to be quantified, bankfull cross-sectional area and width were estimated using the reach-scale average bankfull height from the 2017 survey (0.73 meters [2.40 ft]; Table 12). Bankfull cross-sectional area on detailed transect 2 (T6) increased by 0.36 square meters [3.88 ft^2], while bankfull width decreased by 0.15 meters (0.49 ft; Table 15). The sand and gravel bar that was observed on river right on detailed transect 2 (T6) was not observed during the 2019 survey (Figure 8). Though bankfull width decreased in 2019, the loss of the bar along river right led to a net increase in bankfull area between 2017 and 2019. There was a slight increase in channel-full area on detailed transect 2 (0.20 square meters [2.15 ft^2]) from 2017 (8.38 square meters [90.20 ft^2]) to 2019 (8.58 square meters [92.35 ft^2]; Table 15). Channel-full width increased by 0.49 meters (1.61 ft), and there was a slight decrease in channel-full height (-0.01 meters [-0.03 ft]) on detailed transect 2.

Detailed transect 3 (T11) is entrenched and no elevated entrenched surfaces (bankfull) were present. Similar to detailed transect 2, in order for changes in the bed and bank to be quantified, bankfull cross-sectional area and width were estimated using the reach-scale average bankfull height from the 2017 survey (0.73 meters [2.40 ft]; Table 12). Bankfull cross-sectional area on detailed transect 3 (T11) increased by 0.24 square meters (2.58 ft^2) and bankfull width increased by 0.22 meters (0.72 ft; Table 16). Similar to detailed transect 2, the sand and gravel bar that was observed along river right on detailed transect 3 (T11) in 2017 was not observed during the 2019 survey (Figure 9). Instead, a shallowly submerged incipient mid-channel bar was observed on detailed transect 3. There was a slight increase in channel-full area on detailed transect 3 (0.15 square meters [1.61 ft^2]) from 2017 (10.15 square meters [109.25 ft^2]) to 2019 (10.30 square meters [110.87 ft^2]; Table 16). Channel-full width increased by 0.71 meters (2.33 ft) and channel-full height decreased by 0.02 meters (0.07 ft). The main difference in the cross-sections from 2017 to 2019 is the restructuring of the bed and the migration of the thalweg from the middle of the channel to river left (Figure 9).

Table 13. Comparison of 2017 and 2019 reach scale and average detailed transect characteristics at KEMO001 and KEMO002 [m—meters].

Site	Year	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)
KEMO001	2017	14	0.0015	1.02	3	3.31	6.34	0.74	8.67	8.76	1.45
	2019	16	0.0042	1.03	3	3.74	6.70	0.71	9.10	9.27	1.41
Difference	2017–2019	–	0.0027	0.01	–	0.44	0.36	-0.03	0.43	0.51	-0.04
KEMO002	2017	11	0.0019	1.09	3	3.15	6.68	0.70	7.53	8.67	1.28
	2019	12	0.0020	1.06	3	4.09	6.92	0.84	11.90	9.94	1.77
Difference	2017–2019	–	0.0001	-0.03	–	0.94	0.23	0.14	4.37	1.27	0.49

[a] Number of slope measurements taken

[b] Number of bankfull and channel-full measurements taken

Table 14. Changes to cross-sectional characteristics on detailed transect 1 at KEMO001 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	1.47	4.77	0.68
	2019	2.17	5.77	0.60
Change	2017–2019	0.70	1.00	-0.08
Channel-Full	2017	7.48	7.91	1.54
	2019	8.41	8.23	1.46
Change	2017–2019	0.93	0.32	-0.08

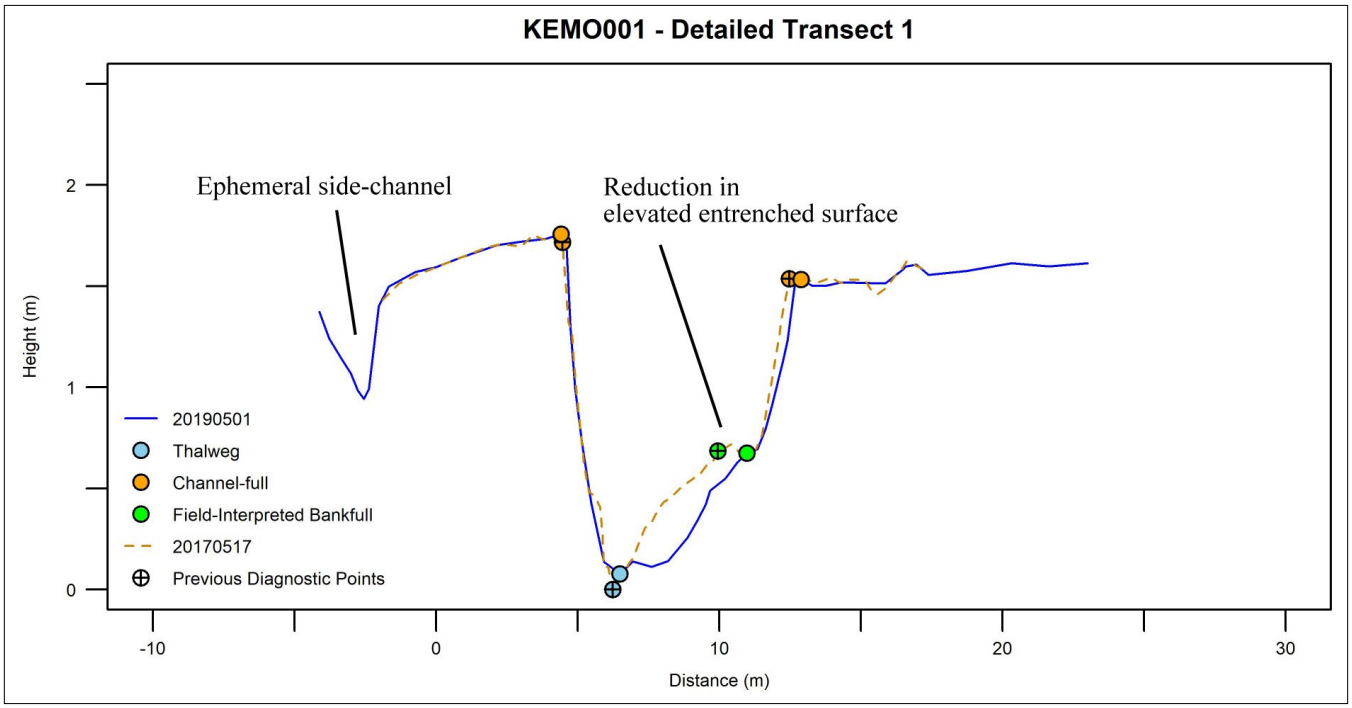


Figure 7. Differences between 2017 and 2019 surveys of detailed transect 1 at KEMO001. View is in the downstream direction (river left is on the left).

Table 15. Changes to cross-sectional characteristics on detailed transect 2 at KEMO001 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	3.79	6.59	0.77
	2019	4.15	6.43	0.77
Change	2017–2019	0.36	-0.15	0.00
Channel-Full	2017	8.38	9.07	1.38
	2019	8.58	9.56	1.37
Change	2017–2019	0.20	0.49	-0.01

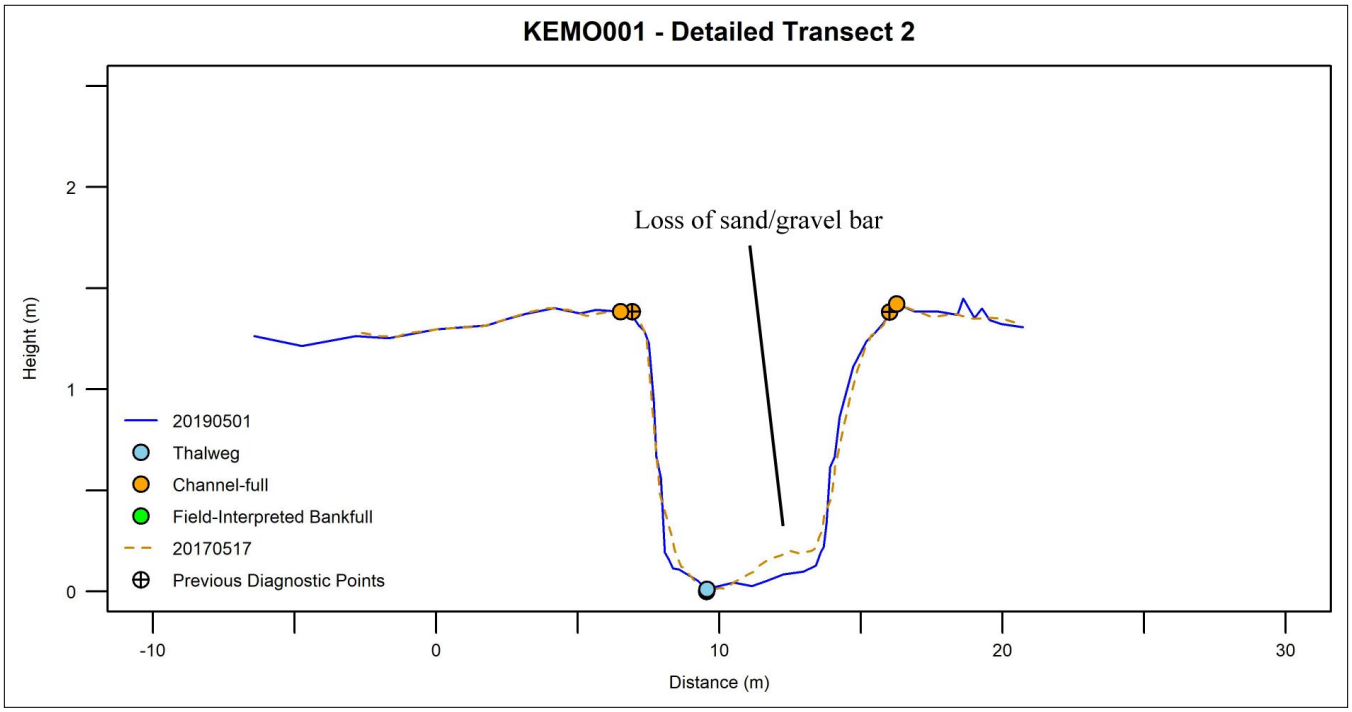


Figure 8. Differences between 2017 and 2019 surveys of detailed transect 2 at KEMO001. View is in the downstream direction (river left is on the left).

Table 16. Changes to cross-sectional characteristics on detailed transect 3 at KEMO001 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	4.66	7.66	0.77
	2019	4.90	7.88	0.77
Change	2017–2019	0.24	0.22	0.00
Channel-Full	2017	10.15	9.30	1.43
	2019	10.30	10.00	1.41
Change	2017–2019	0.15	0.71	-0.02

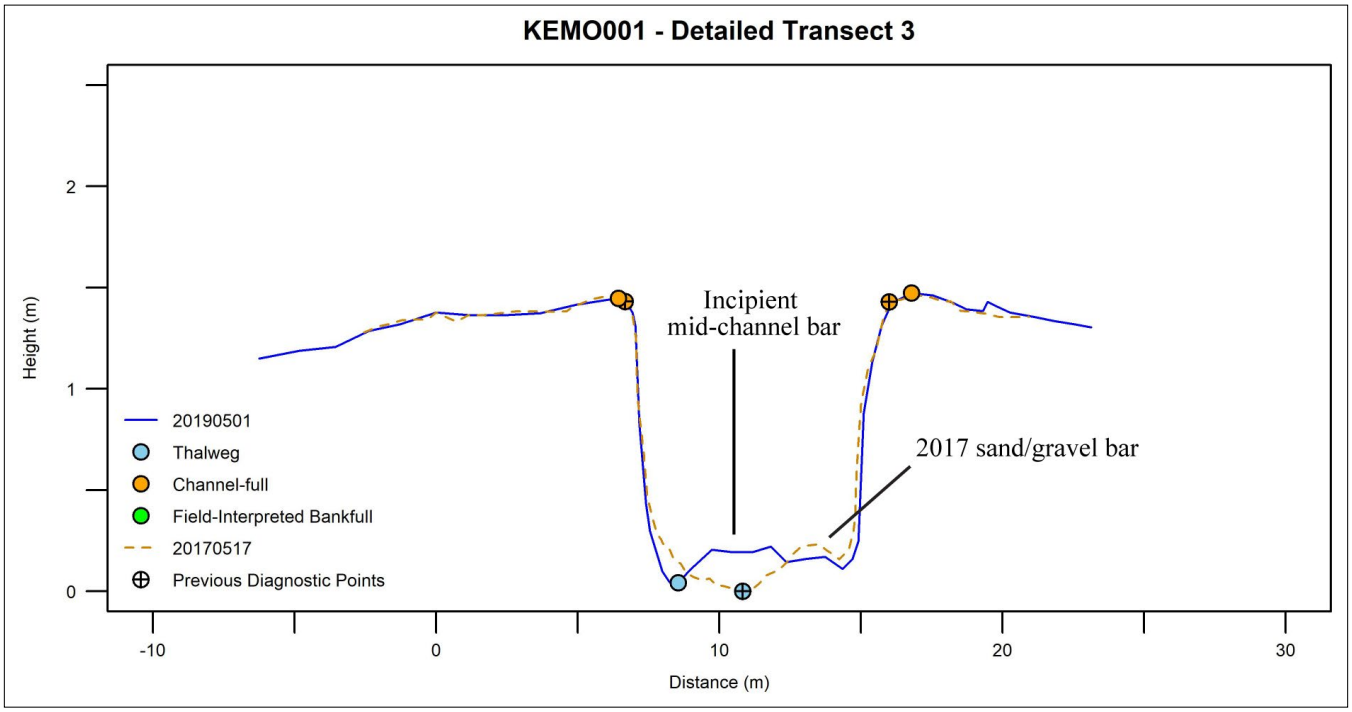


Figure 9. Differences between 2017 and 2019 surveys of detailed transect 3 at KEMO001. View is in the downstream direction (river left is on the left).

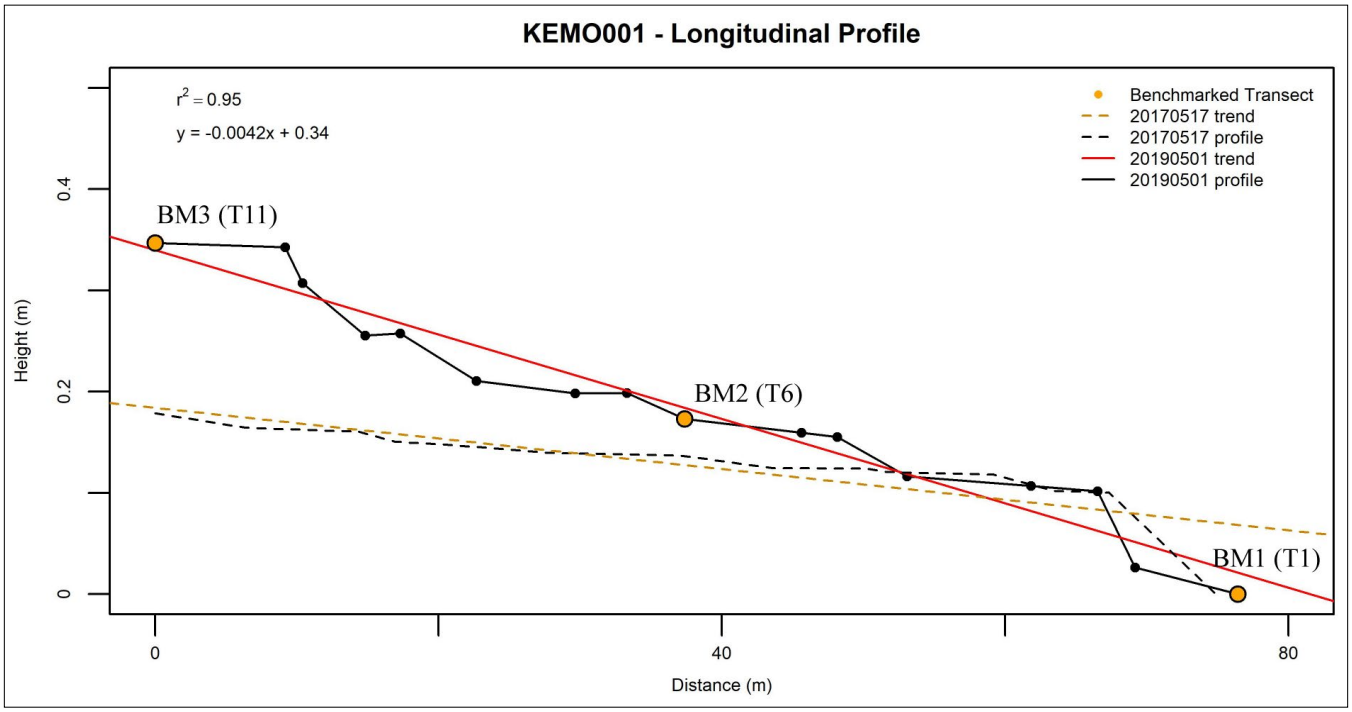


Figure 10. Longitudinal profile for KEMO001. The red line on the graph corresponds to the interpreted slope of the reach (0.0042 m/m). The r^2 value describes the strength of the 2019 trend line (interpreted slope). The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

KEMO002—Ward Creek

Reach Description

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 (Figure C-1). A small ephemeral drainage enters KEMO002 between T10 and T11 on river right (Figure 11). 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 elevated entrenched surfaces (on river left on T3, between T6 and T9, and between T10 and T11; Figure 11). A low terrace, initially observed in 2017, is still present within the reach between T6 and T9. The reach that was surveyed was 70 meters (229.7 ft) long, with 7 meters (23 ft) between transects. The following sections describe the differences in the 2017 and 2019 reach-scale habitat characteristics and channel morphology along KEMO002, as well as the changes that were observed along the detailed transects. Transect-scale survey results for KEMO002 are in Appendix C.

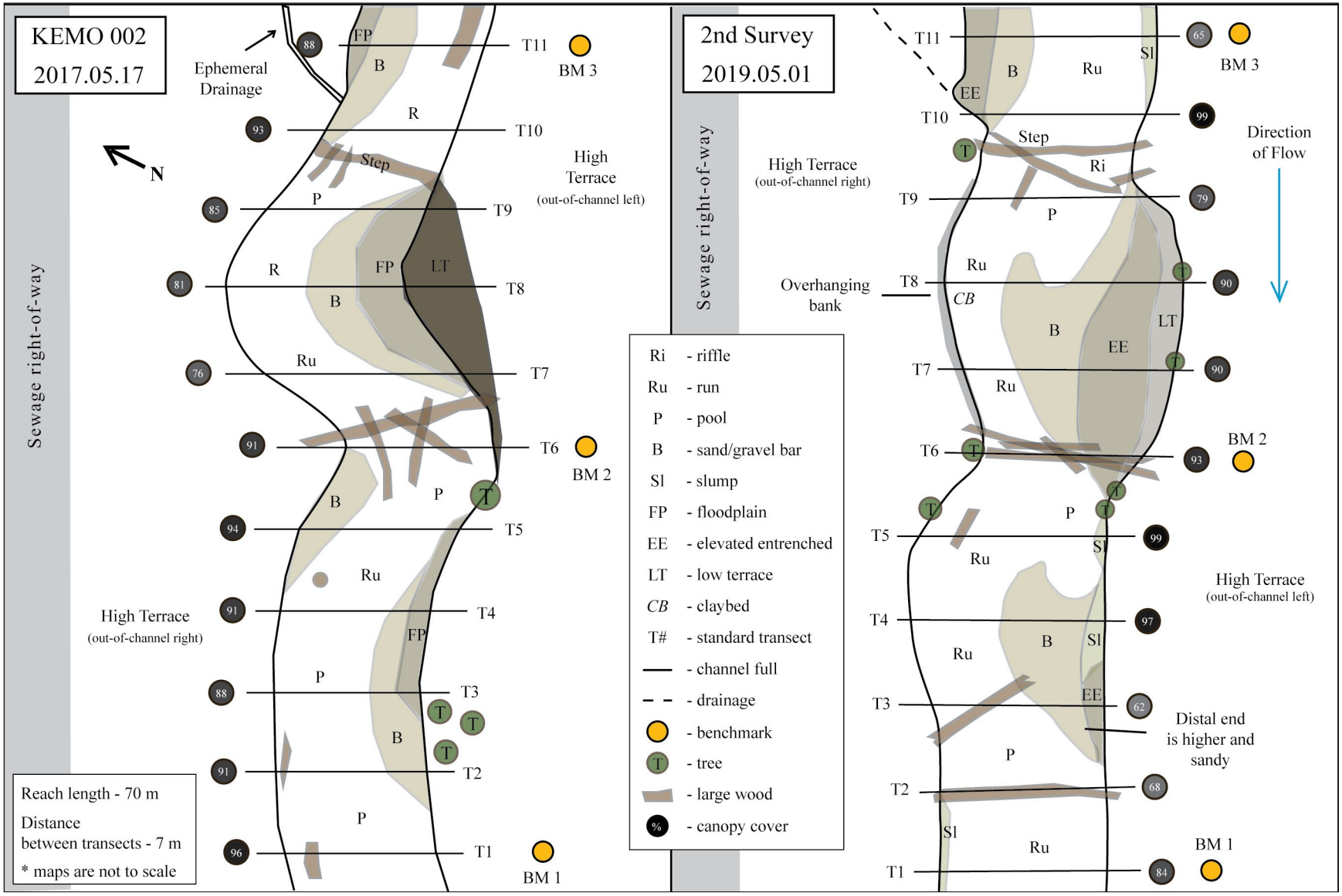


Figure 11. Reach-scale map of KEMO002. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Only the dominant GCUs are labeled on the map. Differences in planform are due to artistic differences and not due to actual changes (unless noted in the text).

Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) at KEMO002 changed substantially between 2017 and 2019 (Table 5). During 2017, the GCUs covering Ward Creek were mostly pool habitat (65%) with some run (26%), riffle (5%), and step (3%) habitat mixed in. During 2019, the majority of the habitat that was observed was run (63%) followed by pool (31%), riffle (4%), and then step (2%). Bed sediment in the representative riffle (near T9) was finer in 2019 compared to 2017 (Table 6), and the difference in the means (12.56 millimeters and 9.28 millimeters [0.49 in and 0.37 in]) was statistically significant (p-value = 0.016; Table 17). Thirteen more pieces of LWD (n = 38) were observed within KEMO002's channel during 2019 (Table 8). This increase in the number of pieces of LWD led to a concomitant increase in the total volume of LWD per channel area (from 0.0054 m^3/m^2 to 0.0060 m^3/m^2). Mean canopy cover was slightly lower in 2019 (84%) compared to 2017 (89%; Table 8). Mean thalweg depth (0.32 meters and 0.40 meters [1.05 ft and 1.31 ft]) and mean thalweg position (43% and 68%) were slightly different from 2017 to 2019 (Table 10), though these differences were not statistically significant (Table 17). Thalweg depth was less variable in 2019 (CV = 0.35 compared to 0.42 in 2017; Table 10). Thalweg position was also less variable in 2019 (CV = 0.54 versus 0.84 in 2017).

Table 17. Difference in means t-test results comparing the 2017 and 2019 surveys of KEMO002. 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].

Measurement	n[a]	KEMO002 in 2017	KEMO002 in 2019	P-value	Significance
Pebble Count (mm)	100	12.39	9.28	0.016	*
Thalweg Depth (m)	11	0.32	0.40	0.156	–
Thalweg Position (%)	11	43	61	0.228	–
Wetted Width (m)	11	4.37	5.13	0.238	–
Active Channel Width (m)	11	5.40	5.55	0.817	–
Channel-full Width (m)	11	8.75	12.54	< 0.001	***
Minimum Bank Height (m)	22	1.44	1.86	0.006	**
Channel-full Height (m)	22	1.72	2.06	< 0.001	***
Bank Angle (°)	22	55.98	47.47	0.274	–
Vegetative Cover (%)	22	18.18	37.50	0.002	**

[a] Number of measurements taken

Channel Morphology

Wetted widths were on average wider during 2019 (5.13 meters [16.83 ft]) compared to 2017 (4.37 meters [14.34 ft]; Table 11). This difference in mean wetted width between survey years was not statistically significant (Table 17). Active channel widths were similar in 2019 (5.55 meters [18.21 ft]) and 2017 (5.40 meters [17.72 ft]) at KEMO002 (Table 11). Similar to wetted width, the difference in mean active channel width from 2017 to 2019 was not statistically significant (Table 17). One less bankfull width (n = 6) was measured in 2019 (Table 11). Bankfull widths were much wider (8.71 meters [28.58 ft] versus 6.00 meters [19.69 ft]) in 2019. Differences in mean bankfull width were not statistically tested because of the relatively small number of bankfull widths available to measure. Channel-full widths were on average much wider during 2019 (12.54 meters [41.14 ft]) than in 2017 (8.75 meters [28.71 ft]; Table 11), and this difference in mean channel-full width between survey years was significant at a p-value of less than 0.001 (Table 17).

Mean minimum bank height (lowest bank height on a transect) in 2019 (1.86 meters [6.10 ft]) was higher and less variable (CV = 0.19) than the mean minimum bank height in 2017 (1.49 meters [4.89 ft] and CV = 0.36; Table 12). The difference in mean minimum bank heights was statistically significant (p-value = 0.006; Table 17). Bankfull heights in 2019 (1.36 meters [4.46 ft]) were also higher and less variable (CV = 0.17) than in 2017 (0.75 meters [2.46 ft] and CV = 0.31; Table 12). Additionally, the minimum bankfull height in 2019 (1.11 meters [3.64 ft]) was approximately 0.77 meters (2.53 ft) higher than in 2017 (0.34 meters [1.12 ft]). Similar to the other bank heights, channel-full heights in 2019 (1.53 meters [5.20 ft]) were higher and less variable (CV = 0.07)

than in 2017 (1.72 meters [5.64 ft] and CV = 0.21; Table 12). The difference in mean channel-full height between the survey years was significant at a p-value of < 0.001 (Table 17).

Two more undercuts were measured in 2019 (n = 4) than in 2017 (Table 12). Though more undercuts were measured, the depths of the undercuts in 2019 were much smaller, and the minimum depth of undercut during 2017 (0.37 meters [1.21 ft]) was nearly as deep as the maximum undercut depth measured in 2019 (0.40 meters [1.31 ft]). Bank angles were on average less steep during 2019 (47°) compared to 2017 (56°; Table 12). The slight difference in mean bank angle between survey years was not statistically significant (Table 17). Bank vegetation cover was on average greater in 2019 (38%) compared to 2017 (18%; Table 12), and this difference was statistically significant (p-value of 0.002; Table 17). Bank stability scores were lower (more stable) in 2019 compared to 2017 (Table 12). Though bank stability scores were lower in 2019, similar to 2017, all of the banks were classified as 'unstable.'

Detailed Transects

The detailed transects on KEMO002 were surveyed on T1 (BM1; Figure 12), T6 (BM2; Figure 13), and T11 (BM3; Figure 14). On the detailed transects, bankfull cross-sectional area was on average 0.94 square meters (10.12 ft^2) larger in 2019 (4.09 square meters [44.02 ft^2]) than in 2017 (3.15 square meters [33.91 ft^2]; Table 13). On average, channel-full area on the detailed transects was also larger (increase of 4.37 square meters [47.04 ft^2]) in 2019 (11.90 square meters [128.10 ft^2]) compared to 2017 (7.53 square meters [81.05 ft^2]; Table 13). Water surface slope for this section of Ward Creek was 0.0019 m/m in 2017 and 0.0020 m/m in 2019 (Figure 15; Table 13). 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 but is slightly more sinuous than KEMO001 (1.06 vs. 1.03; Table 13).

Detailed transect 1 (T1) is entrenched and no elevated entrenched surfaces (bankfull) were present (Figure 12). In order for changes in the bed and bank to be quantified, bankfull cross-sectional area and width were estimated using the reach-average bankfull height from the 2017 survey (0.75 meters [2.46 ft]; Table 12). Bankfull cross-sectional area on detailed transect 1 (T1) increased by 0.29 square meters (3.12 ft^2), while bankfull width increased by 0.72 meters (2.36 ft; Table 18). Channel-full area on detailed transect 1 increased (by 4.00 square meters [43.06 ft^2]) from 2017 (8.78 square meters [94.51 ft^2]) to 2019 (12.79 square meters [137.67 ft^2]). Both channel-full width (9.90 meters [32.48 ft]) and height (1.82 meters [5.97 ft]) increased from 2017 (8.17 meters [26.80 ft] and 1.43 meters [4.69 ft]) to 2019. The main difference along detailed transect 1 from 2017 to 2019 is that the bed of the stream has incised along rivers left and right and a mid-channel bar has begun to form (Figure 12).

Detailed transect 2 (T6) has changed substantially since the 2017 survey (Figure 13). In 2017, no elevated entrenched surface (bankfull surface) was identified and bankfull cross-sectional area was estimated using the reach-scale average bankfull height (McDonald and Starkey 2019a). The 2017 channel-full surface on river left slumped down into the channel and is now an inset bankfull elevated entrenched surface (Figure 13). On river right, the channel-full surface has also slumped lower. Bankfull cross-sectional area on detailed transect 2 (T6) increased by 1.63 square meters (17.55 ft^2; Table 19). Bankfull width was 0.54 meters (1.77 ft) narrower (8.08 meters [26.51 ft] and 7.53 meters [24.70 ft]), while bankfull depth increased by 0.41 meters (1.35 ft; from 0.70 meters [2.30 ft] to 1.11 meters [3.64 ft]). The bed has incised, and a relatively deep pool has formed along the transect. Though bankfull width decreased in 2019, the large increase in bankfull height led to the large net increase in bankfull area between 2017 and 2019 (Figure 13). Channel-full area also increased substantially from 2017 (5.76 square meters [62.00 ft^2]) to 2019 (11.68 square meters [125.72 ft^2]) on detailed transect 2 (Table 19). Increases in both channel-full width (from 8.96 meters [29.40 ft] to 10.50 meters [34.45 ft]) and height (from 0.90 meters [2.95 ft] to 1.75 meters [5.74 ft]) contributed to this increase in channel-full area.

Detailed transect 3 (T11) is entrenched and no elevated entrenched surfaces (bankfull) were present (Figure 14). Similar to detailed transect 1, in order for changes in the bed and bank to be quantified, bankfull cross-sectional area and width were estimated using the average bankfull height from the 2017 survey (0.75 meters [2.46 ft]; Table 12). Bankfull cross-sectional area on detailed transect 3 (T11) increased by 0.92 square meters (9.90 ft^2), and there was no change in bankfull width (Table 20). Channel-full area on detailed transect 3 increased (by 3.19 square meters [34.34 ft^2]) from 2017 (8.05 square meters [86.65 ft^2]) to 2019 (11.24 square meters [120.99 ft^2]; Table 20). Channel-full width and height increased by 0.53 meters (1.74 ft) and 0.23 meters (0.75 ft), respectively. The main difference in the cross-sections from 2017 to 2019 was the loss of a large portion of the sand and gravel bar running along river right (Figure 14).

Table 18. Changes to cross-sectional characteristics on detailed transect 1 at KEMO002 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	3.58	6.32	0.70
	2019	3.86	7.04	0.70
Change	2017–2019	0.29	0.72	0.00
Channel-Full	2017	8.78	8.17	1.43
	2019	12.79	9.90	1.82
Change	2017–2019	4.00	1.73	0.39

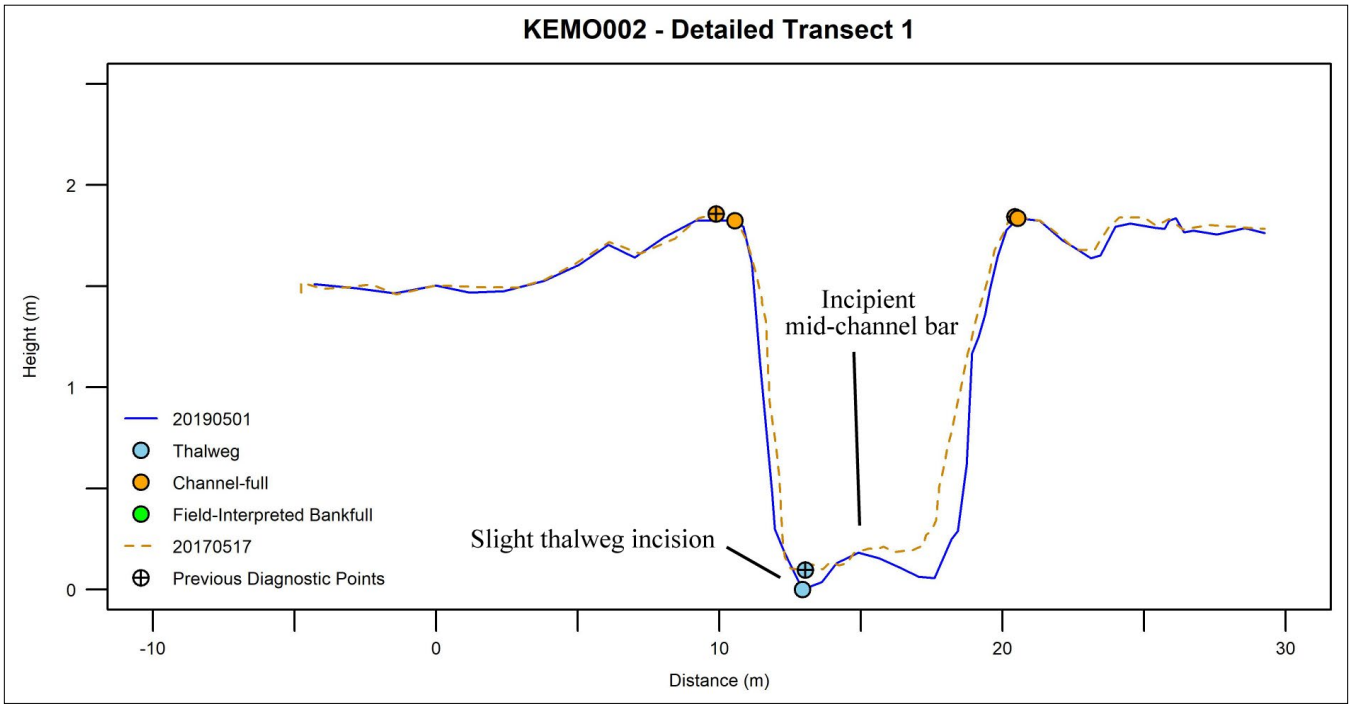


Figure 12. Differences between 2017 and 2019 surveys of detailed transect 1 at KEMO002. View is in the downstream direction (river left is on the left).

Table 19. Changes to cross-sectional characteristics on detailed transect 2 at KEMO002 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	4.06	8.08	0.70
	2019	5.68	7.53	1.11
Change	2017–2019	1.63	-0.54	0.41
Channel-Full	2017	5.76	8.96	0.90
	2019	11.68	10.50	1.75
Change	2017–2019	5.92	1.54	0.85

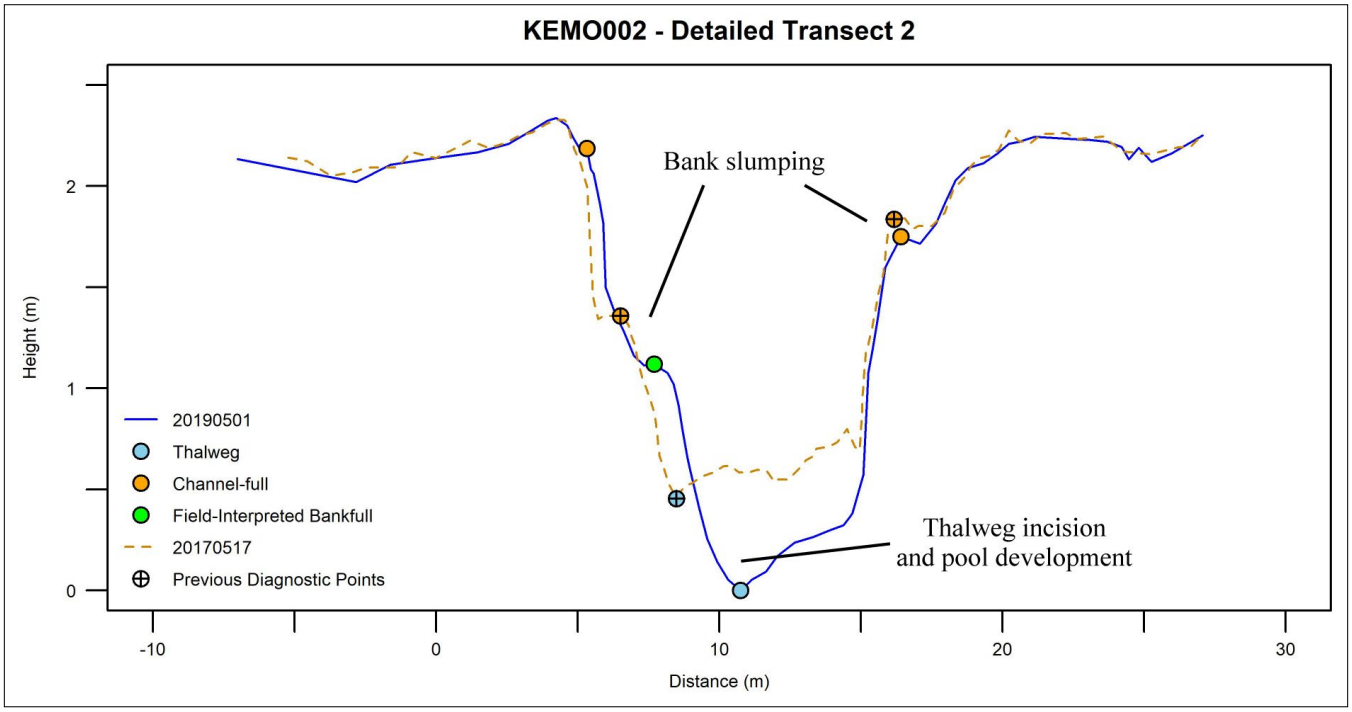


Figure 13. Differences between 2017 and 2019 surveys of detailed transect 1 at KEMO002. View is in the downstream direction (river left is on the left).

Table 20. Changes to cross-sectional characteristics on detailed transect 3 at KEMO002 [m—meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2017	1.81	5.65	0.69
	2019	2.72	5.65	0.69
Change	2017–2019	0.92	0.00	0.00
Channel-Full	2017	8.05	8.89	1.51
	2019	11.24	9.42	1.74
Change	2017–2019	3.19	0.53	0.23

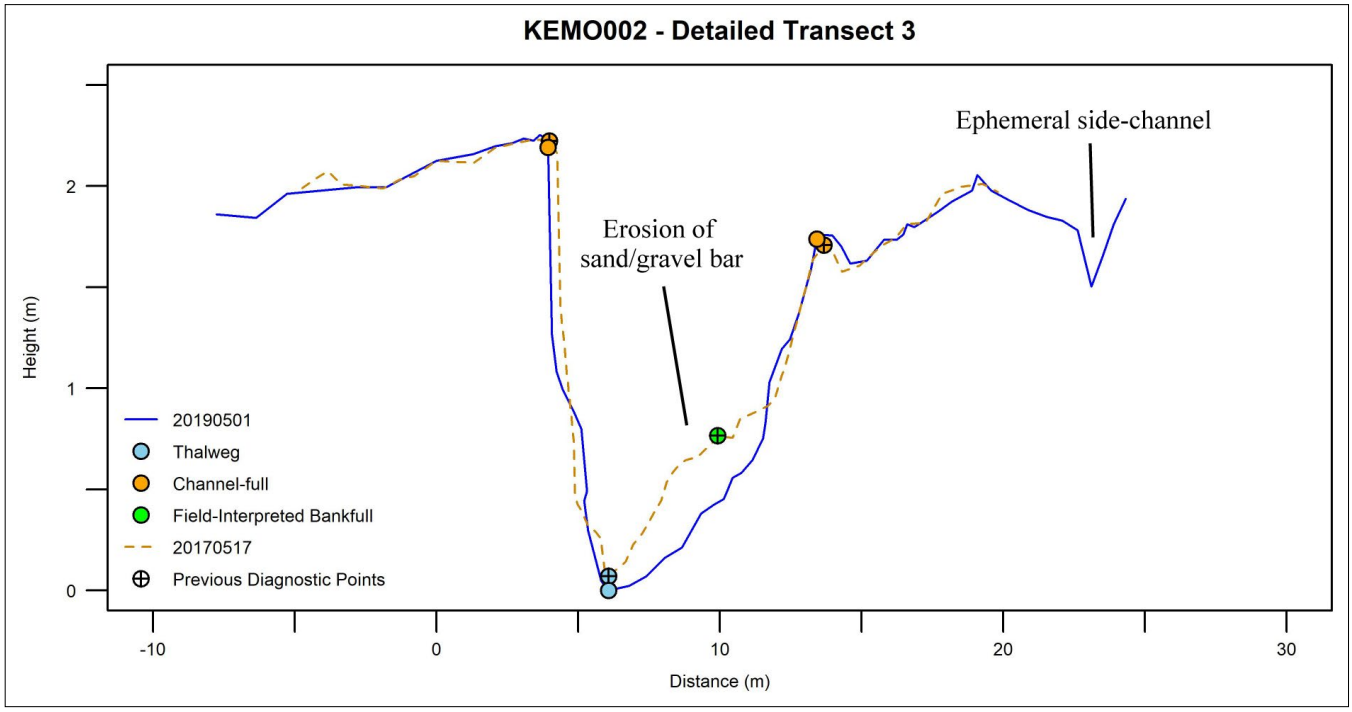


Figure 14. Differences between 2017 and 2019 surveys of detailed transect 3 at KEMO002. View is in the downstream direction (river left is on the left).

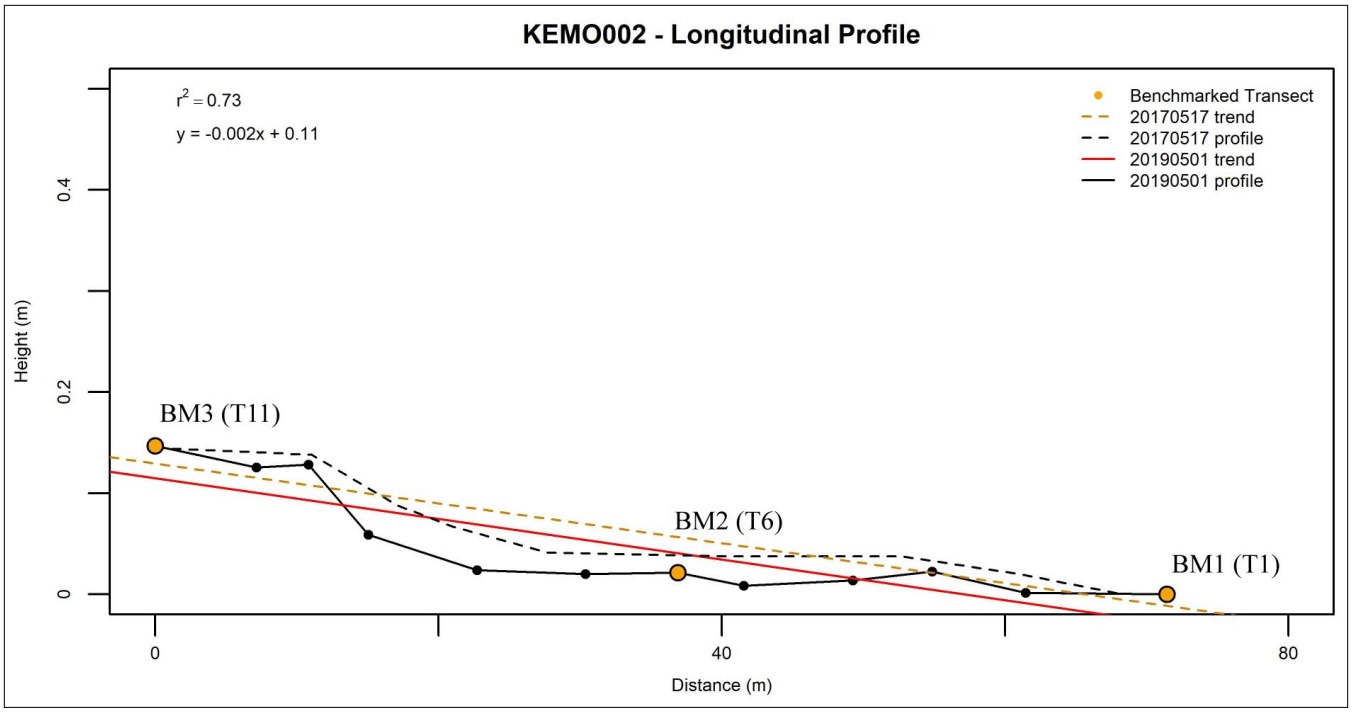


Figure 15. Longitudinal profile for KEMO002. The red line on the graph corresponds to the interpreted slope of the reach (0.0020 m/m). The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

Differences between Sites

The results of the t-tests comparing the bed sediment, thalweg, width, and bank characteristics at KEMO001 and KEMO002 are presented in Table 20. Mean bed sediment size continues to be finer at KEMO002 (9.28 millimeters [0.37 in]) compared to KEMO001 (20.57 millimeters [0.81 in]; p-value < 0.001; Table 21). The development of pools at KEMO002 and a concomitant increase in thalweg depth has made the difference in mean thalweg depth between the sites statistically significant (p-value = 0.012; Table 21). While the difference in mean wetted width between the sites was statistically significantly different in 2017 (p-value = 0.010), the increases in reach-scale wetted width at KEMO001 between 2017 and 2019 has made the difference between the sites no longer significant (p-value = 0.445). Channel-full width and height, as well as minimum bank height, were statistically significantly different in 2019 (p-values = 0.007, <0.001, and <0.001; Table 21). The reason for the rather large increase in channel-full width and height and minimum bank height at KEMO002 during 2019 are related to misinterpretations of the diagnostic surfaces on the reach during 2017 and not to significant geomorphic changes at the reach-scale. The new interpretations are explained in the Implications and Synthesis of Results section.

Table 21. Difference in means t-test results comparing the 2019 surveys of KEMO001 and KEMO002. The significance of the differences is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001 [m—meters; mm—millimeters].

Measurement	n[a]	KEMO001 in 2019	KEMO002 in 2019	P-value	Significance	KEMO001 in 2017	KEMO002 in 2017	P-value	Significance
Pebble Count (mm)	100	20.57	9.28	< 0.001	***	17.77	12.56	< 0.001	***
Thalweg Depth (m)	11	0.25	0.40	0.012	*	0.22	0.32	0.087	–
Thalweg Position (%)	11	44	61	0.261	–	41	43	0.896	–
Wetted Width (m)	11	4.59	5.13	0.445	–	3.04	4.37	0.010	**
Active Channel Width (m)	11	5.08	5.55	0.455	–	5.61	5.4	0.689	–
Channel-full Width (m)	11	9.79	12.54	0.007	**	8.51	8.75	0.485	–
Minimum Bank Height (m)	22	1.36	1.86	< 0.001	***	1.31	1.49	0.290	–
Channel-full Height (m)	22	1.53	2.06	< 0.001	***	1.44	1.72	0.002	**
Bank Angle (°)	22	46	47	0.868	–	40	56	0.034	*
Vegetative Cover (%)	22	44	38	0.328	–	40	18	0.003	**

[a] Number of measurements taken

Implications and Synthesis of Results

This section describes the processes that were observed at each reach and the potential changes that may occur between surveys (next field surveys are tentatively scheduled for spring or summer 2022). 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). The descriptors of watershed-scale variables (e.g., low, average, high) are in comparison to the other watershed in the report (i.e., KEMO001 compared to KEMO002).

KEMO001—Noses Creek

KEMO001's watershed is steep and is covered by forested areas as well as residential and suburban development. Approximately 45% of Noses Creek's watershed is developed and 53% is forested (Table 4). KEMO001's watershed has a high entire stream gradient, a lower segment gradient, and in 2019 developed a relatively high channel gradient (increase in channel gradient from 0.0015 m/m to 0.0042 m/m; Tables 3 and 13). This large increase in channel gradient could be due to the movement of a large slug of sediment into the upper portions of the reach. The hypothesized natural process that produced this large influx of sediment is the excavation of the large pool behind the upstream LWD dam and the deposition of this excavated sediment within the reach. An alternative hypothesis is that surveying errors in 2017 (first official wadeable stream habitat survey conducted by the Southeast Coast Network) could have contributed to this large difference in channel gradient. Although surveying errors may have contributed to the observed differences, this is very unlikely, and the data have been triple-checked and benchmark elevations were consistent between surveys. Additionally, the development of the riffle in the segment between T8 and T9 (which was occupied by a run in 2017; McDonald et al 2019) supports the hypothesis that a large slug of sediment was introduced to the upstream portions of the stream. 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 flashy flow regime, but gage data are needed to confirm this interpretation. Additionally, the development of a much steeper channel gradient has increased the amount of energy available to erode the bed and banks, within and downstream of the reach.

The reach that was 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 changed substantially from 2017 to 2019 (Table 5). While habitat was evenly distributed throughout the reach in 2017, with riffle areas separating the large pools, the habitat in 2019 was mostly run with small areas of riffle, pool, and glide mixed in (Figure 6). This substantial change in geomorphic channel units (GCUs) is interpreted to being directly related to the hypothesized addition of a large slug of sediment into the reach and the large increase in channel gradient in the upstream portion of the reach (Figure 10). KEMO001's bed material was slightly coarser in 2019 compared to 2017 and remained coarser than KEMO002's bed material (Tables 6 and 21). Slight coarsening of the bed material at KEMO001 and the continued difference from KEMO002 is likely due to the increase in channel gradient (Walters et al. 2001), along with the differences in watershed relief and entire stream and segment gradients. Additionally, the slight increase in bank stability at KEMO001 may indicate that a lower quantity of fine sediment is being contributed to the bed from the banks compared to KEMO002 (McDonald et al. 2019).

KEMO001 continues to have a low volume of LWD per channel area (0.0002 m^3/m^2 vs 0.0060 m^3/m^2 at KEMO002; Table 8). The reduction in the already low volume of LWD per channel area (from 0.0005 m^3/m^2) is likely due to the large LWD dam just upstream of the reach capturing all of the LWD that could potentially be added to the reach. When this LWD dam fails, some of the pieces of LWD trapped in the dam may become established in the surveyed reach. Similar to what was identified in the baseline report (McDonald and Starkey 2019a), the lack of LWD coupled with the interpreted influx of sediment into the upper portion of the reach, provides evidence that bed sediment in this reach is highly mobile. This highly mobile bed 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 continues to be classified as 'poor to fair.' Though the GCUs within the reach were mostly run habitat, there were smaller areas of other types of habitat interspersed within the reach. As identified in the baseline report, if the bed material at KEMO001 becomes finer and if the GCUs within the reach become even 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). As mentioned in the Methods section, 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.

The major morphologic changes that occurred on KEMO001 were the loss of many of the sand and gravel bars, the higher variability in thalweg position, and the development of the elevated entrenched surface surfaces. Two processes are hypothesized to have contributed to the loss of the sand and gravel bars within the reach, and both are related to the interpreted movement of sediment into the reach. The large increase in channel gradient has substantially increased the amount of energy available to erode the bed and banks within the reach. It is this increase in slope that could have contributed to the loss (erosion) of the sand and gravel bars (McDonald and Starkey 2019a). Alternatively, some of the sand and gravel bars may not have been eroded from the reach. The addition of extra sediment from upstream (either from below the LWD dam or derived from eroding bars) could have caused aggradation of the bed along some transects. As the stream bed aggraded, water levels would rise causing the previously exposed bar surfaces to become inundated or buried (resulting in a 'loss' of the bar surface; McDonald and Starkey 2019a). Regardless of the process(es) that caused the observed changes, these changes are further evidence that the bed sediment is highly mobile and not optimal habitat for benthic macroinvertebrates.

Though the reach has low sinuosity (1.03) and has lost many of the alternating (side) sand and gravel bars observed in 2017, the increasingly high variability of thalweg position indicates that the interpreted reestablishment of a meandering planform, identified in the baseline report, continues to progress (Simon and Darby 1999; McDonald and Starkey 2019a). Such spatial patterns in thalweg position, coupled with the presence of elevated entrenched surfaces throughout the reach, indicate that the stream is beginning to reestablish a more 'natural' system inset within the higher terrace surface. This reestablishment of a meandering planform is being achieved via lateral erosion, bank undercutting, and episodic yet persistent slumping of the banks.

In 2017, bankfull or floodplain surfaces were identified in the downstream portions of the stream (between T1 and T2 on river right and between T2 and T5 on river left), as well as in the upstream portions of the stream (between T8 and T10; Figure 6; McDonald and Starkey 2019a). In 2019, the downstream surfaces were smaller and appeared to have slumped into the channel, a new set of surfaces have developed between T4 and T6 on river right, and the upstream surface has been reduced and is now low enough to be classified as a bar (Figure 6). The arcuate shape of these surfaces coupled with their continued slumping and development are evidence that these surfaces were misidentified in 2017 and are not actually geomorphic floodplain surfaces (formed through lateral migration of the meander bends). Instead, these elevated entrenched surfaces are likely slump-cored blocks of sediment that have the appearance of being stable, due to their high vegetative cover and the relative uniformity of the heights of these surfaces above the thalweg. These elevated entrenched surfaces appear to be slowly but progressively eroded at their base and slumping lower as their toes are eroded away. The hypothesized development of the inset surfaces in the downstream portion of KEMO001 is presented in Figure 16.

The 2017 survey is represented by row 2 in Figure 16. The downstream elevated entrenched surface was misinterpreted as a floodplain surface due to the consistent height of this surface throughout the reach and its apparent stability due to high vegetative cover. Between the 2017 and 2019 surveys (Figure 16, row 3), the inner portion of the downstream slump is hypothesized to have broken off from the main slump and dropped to the level of the bar. During this time, the upstream slump is also hypothesized to have started slumping. The sediment in the bars along both sections of the stream are hypothesized as being supplied from both upstream and from the banks themselves. These slumps are interpreted to have continued to degrade until the 2019 survey (Figure 16, row 4) and will continue to degrade until the toes of these slump blocks become stabilized or the blocks are completely eroded. If this interpretation is correct, the rate at which this and similar streams widen can be determined by identifying where these slumps are likely to occur and the rate at which they develop.

Due to the highly entrenched nature of the stream, the cohesive banks, and the relatively high frequency of slumping, lateral migration is not appreciably affecting the reach. As the stream begins to reestablish a meandering planform, lateral migration will become a more important contributor to the amount of sediment produced by the reach. No headward migration was detected for the knickpoint (i.e., substantial increase in channel slope)

that exists between T1 and T2 because the riffle that is immediately upstream of it continues to provide enough resistance to prevent its movement. Immediately downstream of KEMO001, visual observations indicate that the large increase in stream power (related to the additional discharge provided by the ephemeral channel just downstream from the reach on river left) continues to cause the stream bed to degrade and its banks to erode.

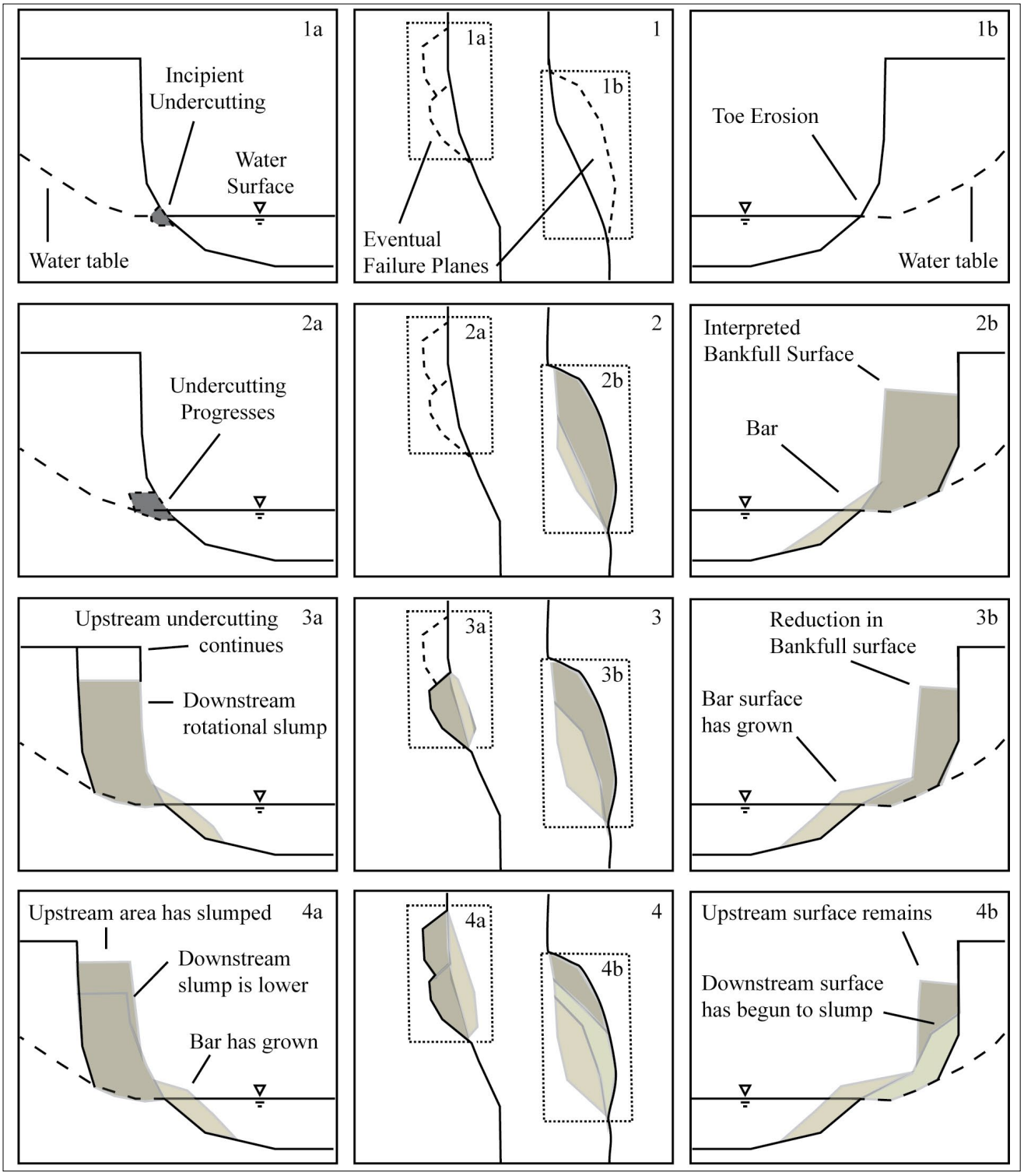


Figure 16. Hypothesized development of the bankfull 'floodplain' surfaces observed at KEMO001 on river right between T4 and T6 (a) and on river left between T1 and T4 (b). Row 1 represents a time before the 2017 survey, row 2 is the 2017 survey, row 3 represents the time between the 2017 and 2019 surveys, and row 4 is a depiction of conditions during the 2019 survey.

KEMO002—Ward Creek

KEMO002's watershed has low slope and relief and has low forest cover. Approximately 68% 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 a low channel gradient (Tables 3 and 13). 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, segment, and channel gradients suggest Ward Creek does not have a flashy flow regime, though gage data are needed to confirm this interpretation.

The reach that was surveyed on Ward Creek (KEMO002) is within 20 meters (65.6 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 horse trail crossing and walking bridge). In-stream habitat changed substantially from 2017 to 2019 (Table 5). In 2017, in-stream habitat was mostly low energy pools with some runs separating the pools (McDonald and Starkey 2019a). In 2019, GCUs were primarily run habitat with a few pools separating the runs (Figure 11). The GCU change appears to be due to the infilling of many of the pools in the lower portion of the reach. The substantial increase in thalweg depth near T6 and the large pool that has developed there may have provided the sediment that contributed to this infilling of pool habitat. Bed material was significantly finer in 2019 compared to 2017 (Table 6 and 17). The fining of the bed material at KEMO002 likely reflects the continuing influence of Ward Creek's low watershed slope and relief; its low entire stream, segment, and channel gradients; and the legacy of disturbance from sewer line installation upstream of the survey reach (McDonald and Starkey 2019a). Additionally, the less stable banks at KEMO002 compared to KEMO001 may indicate that fine sediment inputs from these unstable banks are continuing to contribute to the fining of the bed along this reach.

KEMO002 again had by far the highest volume of LWD per channel area (an order of magnitude more than KEMO001; Table 8). The high volume of LWD in the reach is likely related to a highly active beaver population upstream supplying LWD to the system as well as the highly entrenched and straight stream channel upstream of the reach funneling LWD into the reach. Beaver activity, along with the legacy of the upstream disturbance due to the sewer lines, could also be influencing the sediment supplied to the reach, as well as the characteristics of the discharge that influences the stream. Additional work is needed to determine how the upstream multi-channel system affects sediment yield and discharge in the downstream single thread portion of Ward Creek.

Similar to 2017, the majority of the LWD within the reach was located just upstream of the relatively sharp meander bend between T5 and T7 (Figure 11). 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 continued to contribute to the low energy GCUs that are present and to the fining of the bed, as fines are trapped behind jams and steps. Based on the GCUs, bed sediment, and LWD within the reach, KEMO002's in-stream habitat was again classified as 'poor.' As mentioned in the 2017 baseline report (McDonald and Starkey 2019a), 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 bridges the channel and has minimal influence on GCUs.

The major morphologic changes that occurred on KEMO002 were the large increases in bankfull and channel-full areas on all of the detailed transects, the continued development of the inset surfaces throughout the reach, and the large 'increases' to bankfull and channel-full widths and bank heights. The bar surfaces on all the detailed transects were substantially reduced or completely eroded between 2017 and 2019. Additionally, a deep pool has developed on detailed transect 2 (T6; Figure 18). The changes to the bed and erosion of the bar surfaces may be the natural progression of the bedforms in this stream. Similar to KEMO001, it is hypothesized that Ward Creek is evolving through the episodic and progressive slumping of its banks (e.g., Figure 16). The bars that were observed in 2017 (between T4 and T6 on river right; Figure 11) may have been the last remnants of former slump surfaces. The degradation of the inset surface between T2 and T4 on river left (which is similar to the downstream inset surface at KEMO001; Figure 16-4b) suggests that this surface may not be as stable as was initially thought, and may be completely eroded by

the next survey (tentatively scheduled for 2022). Additionally, the multi-tier inset surface and 'low terrace' between T6 and T9 (Figure 11) is also changing in shape as the toe of the hypothesized slump block continues to be reworked by the stream.

Mean channel-full width was wider and mean channel-full and mean minimum bank heights were higher in 2019 compared to 2017 (Table 17). Additionally, mean bankfull widths and heights also apparently increased from 2017 to 2019 (Tables 11 and 12). These width and height 'changes' were not due to geomorphic processes. These 'changes' were due to different interpretations of the surfaces that define these diagnostic features within the stream. In 2017, the 'low terrace' feature between T6 and T9 was misidentified as the channel-full surface. While in 2019, the highest surface (the surface above the 'low terrace') was correctly identified as the channel-full surface. Future surveys should measure the highest surface, because this surface is the channel-full surface for all of the other transects.

Similar to channel-full, the apparent 'changes' to bankfull width and height were also the result of different interpretations of what constitutes 'bankfull' between T6 and T9. In 2017, bankfull was defined as the top of the point bar surface (the highest inset surface with vegetative cover), whereas, in 2019, the 'low terrace' (the highest inset surface below channel-full) was identified as the bankfull surface. Future surveys should measure bankfull as the top of the lowest inset surface that has vegetative cover and is not an in-channel bar surface. A point bar surface is an acceptable surface (Ritter et al. 2002) as long as it has vegetative cover. At KEMO002, this surface should continue to be monitored because it was used as bankfull during the 2017 baseline survey. Additionally, if there are multiple inset surfaces, on any reach, future surveys should measure channel widths and bank heights associated with each surface to understand the development of these sets of features.

Conclusion

Noses Creek's watershed (KEMO001) is steep and forested, while Ward Creek's watershed (KEMO002) has low slope and relief and is covered mostly by urban and or 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 and distribution of GCUs within each reach, and the presence or absence of LWD, the 2019 in-stream habitat classification for each surveyed stream is the same as in 2017 ('poor to fair' on KEMO001 and 'poor' on KEMO002). The processes that have a potential impact on these habitat classifications have not changed since the previous survey, though the interpretation of geomorphic features and surfaces within the reach has changed substantially.

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 KEMO001 may increase habitat diversity and provide more stability to the reach that could upgrade the classification to 'fair.' The addition of LWD to KEMO001 seems likely, as a large LWD dam has developed, since 2017, just upstream of the reach that may fail prior to the next survey. 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 bridges the channel and has minimal influence on GCUs.

Both of the 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 or suburban development in their watersheds. Both of the stream reaches are affected by episodic and progressive slumping of their banks. These elevated entrenched (likely slump-cored) surfaces were interpreted as relatively stable bankfull 'floodplain' surfaces in 2017. The changes in the heights and sizes of these features have shown that these surfaces are not stable and represent the process by which these streams will continue to widen as they equilibrate to their modern flow and sediment regimes. The loss and movement of bar surfaces along both reaches is evidence agreeing with the interpretation of highly mobile beds within these stream reaches. The small knickpoint that was identified in the downstream portion of Noses Creek (KEMO001) in 2017 has not migrated further headward into the reach. The riffle that is immediately upstream of the knickpoint appears to provide enough resistance to prevent headward migration of the knickpoint. Similar to 2017, no immediate management concerns were identified along either reach. 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.

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 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[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 floodplain (or incipient floodplain) present
Bankfull Height	Transect[a,b]	The height of the channel bank where a floodplain is present
Bankfull Area	Transect[b]	The cross-sectional area of a stream channel at bankfull stage (height) measured perpendicular to flow

[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

Table A-1 (continued). Explanation of Variables.

Variable	Variable Scale	Description
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 floodplain.
Channel-full Height	Transect[a,b]	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[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
Floodplain width	Transect[a]	The width(s) of floodplain(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 B. Survey Results for KEMO001

The following appendix provides transect-scale figures, results, and data summary tables of the 2019 survey of KEMO001. Figures include a watershed map (Figure B-1); photographs taken in the upstream, downstream, left bank, and right bank directions at each detailed transect (T1, T6, and T11; Figures B-2 through B-13); and cross-sectional channel characteristics at each detailed transect (Figures B-14 through B-16). Tables describe watershed land use characteristics (Table B-1), observed geomorphic channel units (Table B-2), characteristics of large woody debris (Table B-3), canopy cover percentages (Table B-4), channel and bank characteristics (Table B-5), and cross-sectional channel characteristics at each detailed transect (Tables B-6 through B-8).

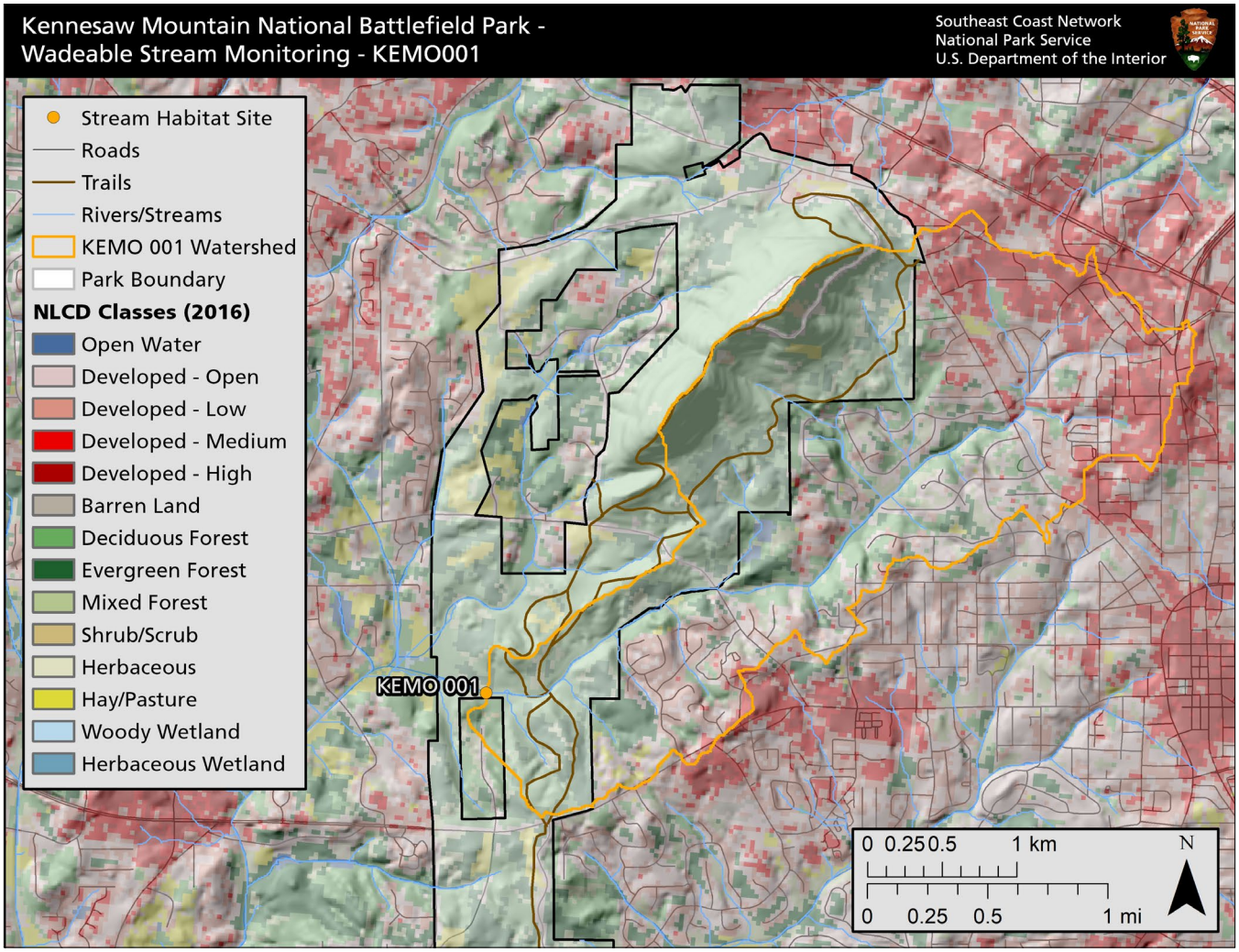


Figure B-1. Map showing the watershed draining to KEMO001 at Kennesaw Mountain National Battlefield. The land use and land cover (NLCD 2016, Homer et al. 2020), road network (Georgia Department of Transportation 2004), and perennial streams (derived from a 10-meter (32.8-foot [ft]) digital elevation 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 and land cover characteristics for 2001, 2006, 2011, and 2016 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; Homer et al. 2020).

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]	18	20	19	18
Developed—Low[a]	14	16	15	15
Developed—Medium[a]	6	7	8	8
Developed—High[a]	3	3	4	4
Barren	0	0	0	0
Deciduous	33	31	31	34
Evergreen	21	19	19	12
Mixed Forest	1	1	1	7
Shrub	0	0	0	0
Grassland	2	1	1	0
Pasture	2	2	2	1
Cultivated	0	0	0	0
Woody Wetland	0	0	0	0
Herbaceous Wetland	0	0	0	0

[a] 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	10	80	0	10	0
2–3	25	75	0	0	0
3–4	0	90	0	10	0
4–5	25	75	0	0	0
5–6	10	90	0	0	0
6–7	60	40	0	0	0
7–8	0	100	0	0	0
8–9	20	10	70	0	0
9–10	75	25	0	0	0
10–11	0	100	0	0	0
Frequency	7	10	1	2	0
Maximum (%)	75	100	70	10	0
Mean (%)	23	69	7	2	0
Median (%)	15	78	0	0	0
Standard Deviation (%)	26	32	22	4	0

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

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	6.28	0.13	0.08	10	Bank Protection	Free
2	2.04	0.19	0.06	10	Bank Protection	Buried
3	1.29	0.10	0.01	9	Bank Protection	Buried
4	1.16	0.15	0.02	9	Sediment Trap	Buried
5	1.06	0.12	0.01	8	Sediment Trap	Buried
6	1.00	0.10	0.01	8	Bank Protection	Buried

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

Transect	Canopy Cover (%)
1	84
2	72
3	75
4	79
5	82
6	87
7	88
8	88
9	100
10	74
11	84
Minimum (%)	72
Maximum (%)	100
Mean (%)	83
Median (%)	84
Standard Deviation (%)	8
Coefficient of Variance	0.10

Table B-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	0.75	0.73	1.75	1.71	1.37	1.35	1.42	1.47	0.32	0.34	0.24	0.25
Bankfull Height[a,b] (m)	3	3	0.75	0.73	1.05	1.06	0.91	0.85	0.92	0.77	0.15	0.18	0.17	0.21
Channel-full Height[a,b] (m)	11	11	1.40	1.37	1.75	1.71	1.54	1.52	1.53	1.50	0.13	0.11	0.08	0.07
Water Depth at Base[c] (m)	11	11	-0.09	-0.11	-0.05	0.09	-0.07	-0.07	-0.07	-0.07	0.02	0.06	–	–
Bank Undercut[b] (m)	2	2	0.15	0.23	0.63	0.80	0.39	0.52	0.39	0.52	0.34	0.40	0.87	0.78
Bank Angle (°)	11	11	15	11	83	71	48	45	46	53	21	20	0.44	0.44
Vegetation Cover (%)	11	11	15	10	50	90	32	56	30	70	10	29	0.30	0.51
Bank Stability[d]	11	11	At-Risk	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.13	1.36	0.09	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 B-6. Cross-sectional characteristics for detailed transect 1 at KEMO001 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	2.17	6.02	0.36	5.77	0.60	9.67
Channel-full	8.41	9.22	0.91	8.23	1.46	5.66
Ratio	3.87	1.53	2.52	1.43	2.44	0.58

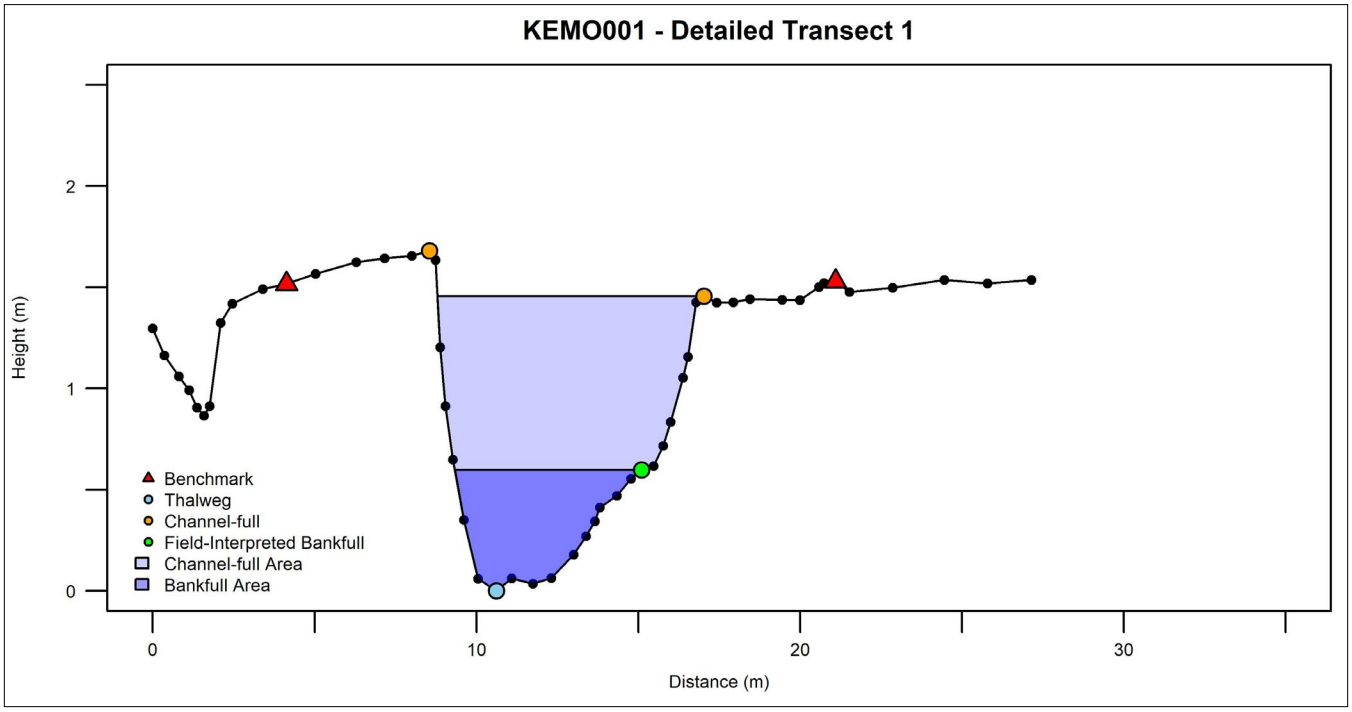


Figure B-14. Detailed transect 1 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional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

Table B-7. Cross-sectional characteristics for detailed transect 2 at KEMO001 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.15	7.12	0.58	6.43	0.77	8.41
Channel-full	8.58	10.68	0.80	9.56	1.37	6.97
Ratio	2.07	1.50	1.38	1.49	1.79	0.83

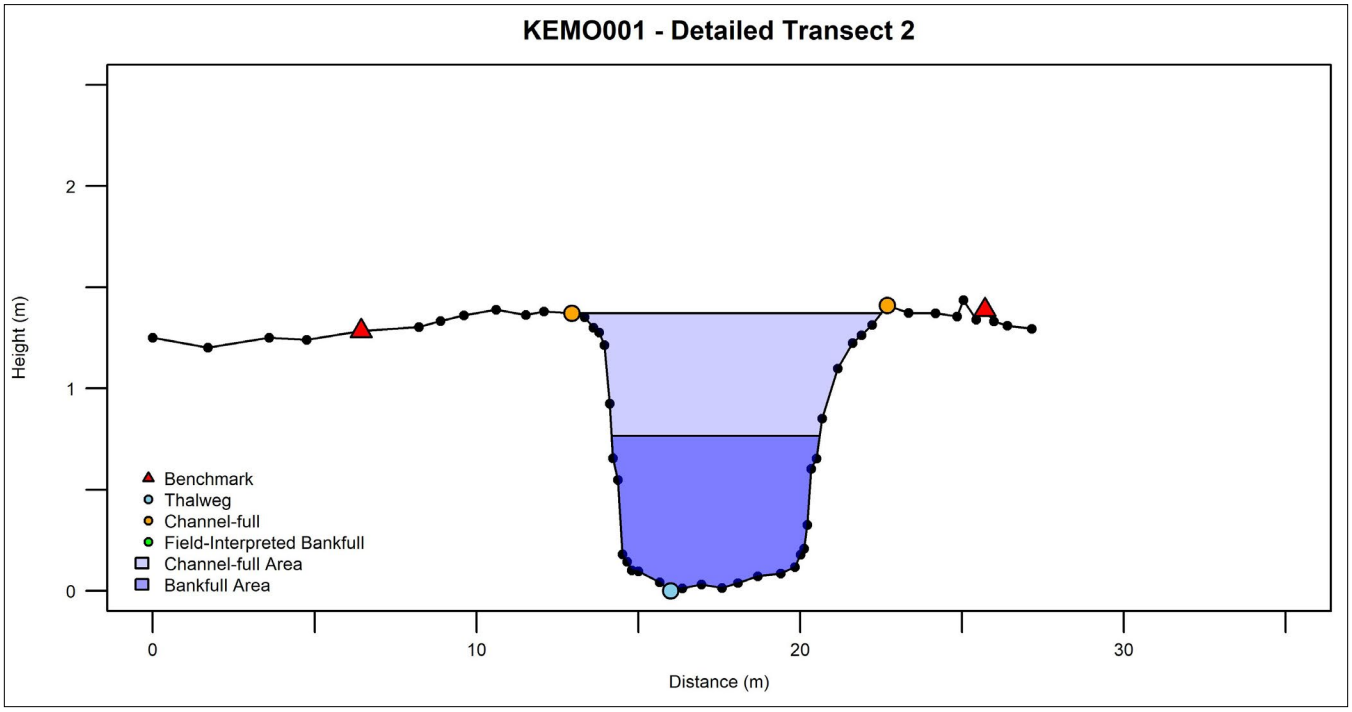


Figure B-15. Detailed transect 2 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area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

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	4.90	8.66	0.57	7.88	0.77	10.30
Channel-full	10.30	11.38	0.90	10.00	1.41	7.11
Ratio	2.10	1.31	1.60	1.27	1.84	0.69

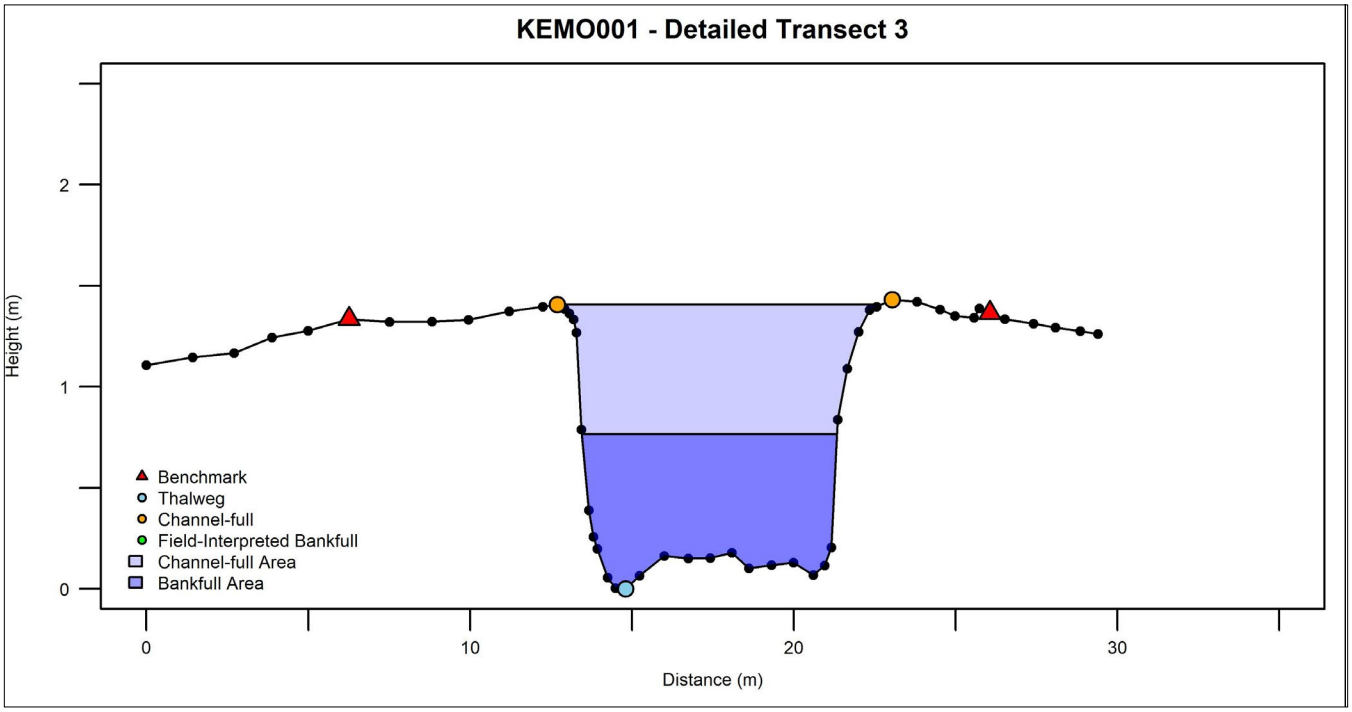


Figure B-16. Detailed transect 3 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional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

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Appendix C. Survey Results for KEMO002

The following appendix provides transect-scale figures, results, and data summary tables of the 2019 survey of KEMO002. Figures include a watershed map (Figure C-1); photographs taken in the upstream, downstream, left bank, and right bank directions at each detailed transect (T1, T6, and T11; Figures C-2 through C-13); and cross-sectional channel characteristics at each detailed transect (Figures C-14 through C-16). Tables describe watershed land use characteristics (Table C-1), observed geomorphic channel units (Table C-2), characteristics of large woody debris (Table C-3), canopy cover percentages (Table C-4), channel and bank characteristics (Table C-5), and cross-sectional channel characteristics at each detailed transect (Tables C-6 through C-8).

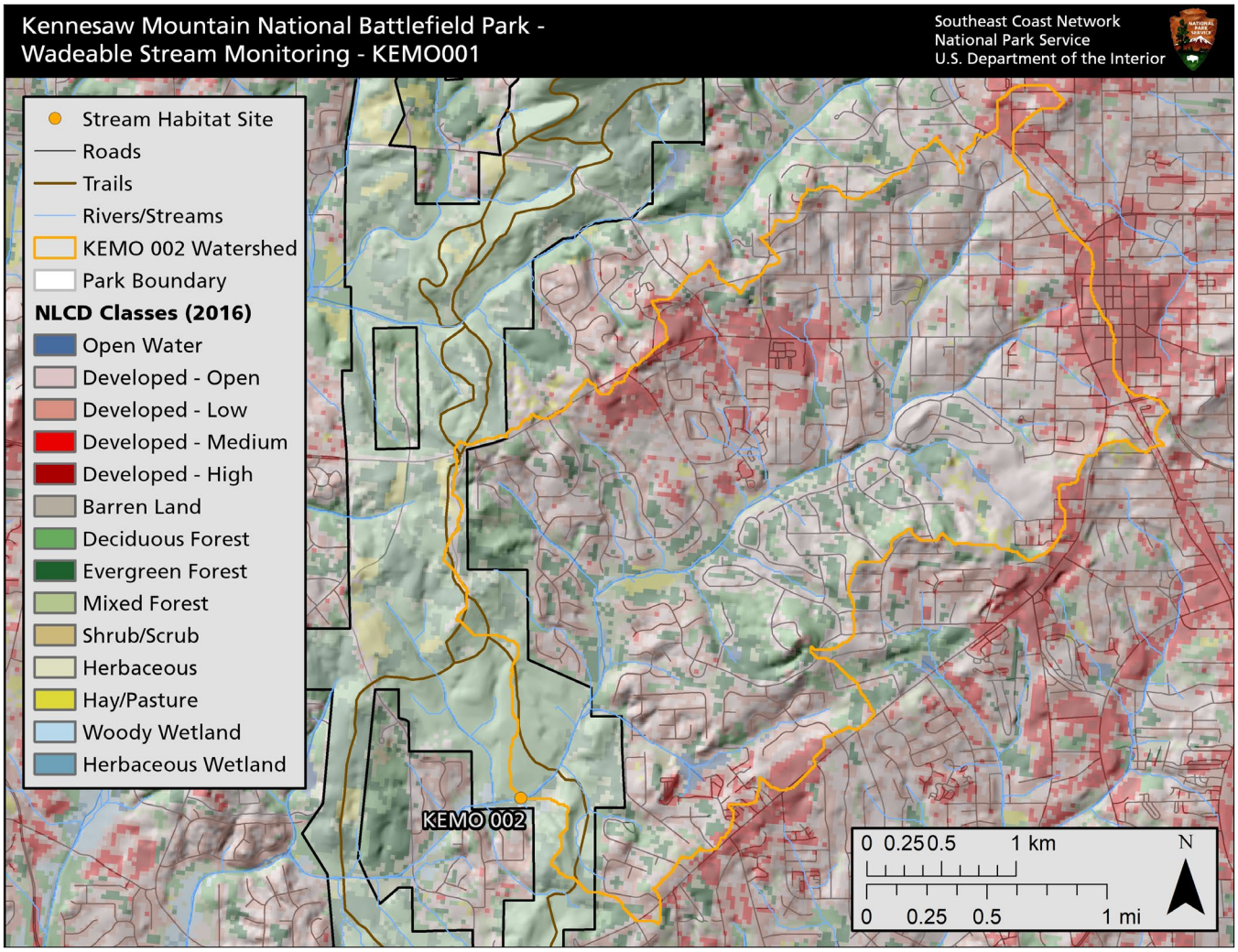


Figure C-1. Map showing the watershed draining to KEMO002 at Kennesaw Mountain National Battlefield. The land use and land cover (NLCD 2016, Homer et al. 2020), road network (Georgia Department of Transportation 2004), and perennial streams (derived from a 10-meter (32.8-foot [ft]) digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



Figure C-2. Photograph taken on 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, 2011, and 2016 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; Homer et al. 2020).

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]	37	38	38	36
Developed—Low[a]	22	22	22	23
Developed—Medium[a]	5	5	6	7
Developed—High[a]	3	3	3	3
Barren	0	0	0	0
Deciduous	12	12	12	11
Evergreen	17	17	17	10
Mixed Forest	1	1	1	7
Shrub	0	0	0	0
Grassland	0	0	0	0
Pasture	2	1	1	1
Cultivated	0	0	0	0
Woody Wetland	0	0	0	0
Herbaceous Wetland	0	0	0	0

[a] 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 GCU.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	70	0	30	0
2–3	0	20	0	80	0
3–4	0	100	0	0	0
4–5	5	80	0	15	0
5–6	0	30	0	70	0
6–7	0	40	0	60	0
7–8	0	100	0	0	0
8–9	2	90	0	8	0
9–10	10	20	0	50	20
10–11	20	80	0	0	0
Frequency	4	10	0	7	1
Max (%)	20	100	0	80	20
Mean (%)	4	63	0	31	2
Median (%)	0	75	0	23	0
Standard Deviation (%)	7	32	0	31	6

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

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	1.02	0.14	0.02	10	Bank Protection	Buried
2	1.24	0.14	0.02	10	Bank Protection	Buried
3	3.10	0.11	0.03	10	Bank Protection	Free
4	1.89	0.14	0.03	10	Sediment Trap	Buried
5	9.65	0.17	0.22	10	None	Bridge
6	5.59	0.12	0.06	10	None	Bridge
7	3.61	0.13	0.05	9	Organic Trap	Ramp
8	1.44	0.14	0.02	9	Bank Protection	Buried
9	5.56	0.15	0.10	9	Jam	Jam
10	2.89	0.13	0.04	9	None	Jam
11	2.39	0.38	0.27	9	Sediment and Organic Trap	Jam
12	1.45	0.15	0.03	9	Sediment and Organic Trap	Jam
13	1.67	0.14	0.03	9	Sediment and Organic Trap	Jam
14	3.73	0.41	0.49	9	Sediment Trap	Buried
15	3.38	0.40	0.42	9	Bank Protection	Ramp
16	2.08	0.13	0.03	9	Sediment Trap	Buried
17	2.64	0.17	0.06	8	None	Ramp
18	9.58	0.13	0.13	6	None	Jam
19	2.30	0.11	0.02	6	None	Jam
20	1.94	0.12	0.02	6	None	Jam
21	9.56	0.21	0.33	6	None	Ramp
22	13.27	0.29	0.88	6	Jam	Bridge
23	3.71	0.12	0.04	6	Bank Protection	Buried
24	3.12	0.12	0.04	6	Bank Protection	Buried
25	3.89	0.19	0.11	6	Bank Protection	Buried
26	1.23	0.15	0.02	6	Bank Protection	Buried
27	5.23	0.20	0.16	6	Jam	Bridge
28	2.11	0.11	0.02	6	Organic Trap	Jam
29	2.48	0.14	0.04	6	None	Jam
30	1.11	0.17	0.03	6	Organic Trap	Jam
31	1.45	0.28	0.09	5	None	Free
32	2.05	0.11	0.02	3	None	Free
33	1.87	0.23	0.08	3	Organic Trap	Free
34	2.27	0.17	0.05	3	Organic Trap	Jam
35	3.49	0.14	0.05	3	Jam	Jam
36	12.79	0.35	1.23	2	None	Bridge
37	2.24	0.10	0.02	2	None	Free
38	2.71	0.11	0.03	1	None	Free

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

Transect	Canopy Cover (%)
1	84
2	68
3	62
4	97
5	99
6	93
7	90
8	90
9	79
10	99
11	65
Min (%)	62
Max (%)	99
Mean (%)	84
Median (%)	90
Standard Deviation (%)	14
Coefficient of Variance	0.16

Table C-5. Average reach-scale bank characteristics at KEMO002. '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	1.11	1.17	2.27	2.30	1.76	1.96	1.93	1.99	0.39	0.30	0.22	0.15
Bankfull Height[a,b] (m)	5	1	1.11	1.17	1.63	1.17	1.39	1.17	1.49	1.17	0.23	-	0.17	-
Channel-full Height[a,b] (m)	11	11	1.93	1.81	2.35	2.30	2.11	2.02	2.12	1.99	0.14	0.16	0.07	0.08
Water Depth at Base[c] (m)	11	11	-0.13	-0.13	-0.06	-0.06	-0.09	-0.09	-0.09	-0.09	0.02	0.02	-	-
Bank Undercut[b] (m)	1	3	0.12	0.26	0.12	0.40	0.12	0.32	0.12	0.30	-	0.07	-	0.23
Bank Angle (°)	11	11	3	33	78	91	34	61	33	63	22	17	0.65	0.28
Vegetation Cover (%)	11	11	10	10	65	70	37	38	40	30	19	24	0.52	0.63
Bank Stability[d]	11	11	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	0.65	1.36	0.05	0.10

[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 KEMO002 [m—meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	3.86	7.57	0.51	7.04	0.70	10.06
Channel-full	12.79	11.47	1.11	9.90	1.82	5.43
Ratio	3.31	1.52	2.18	1.41	2.60	0.54

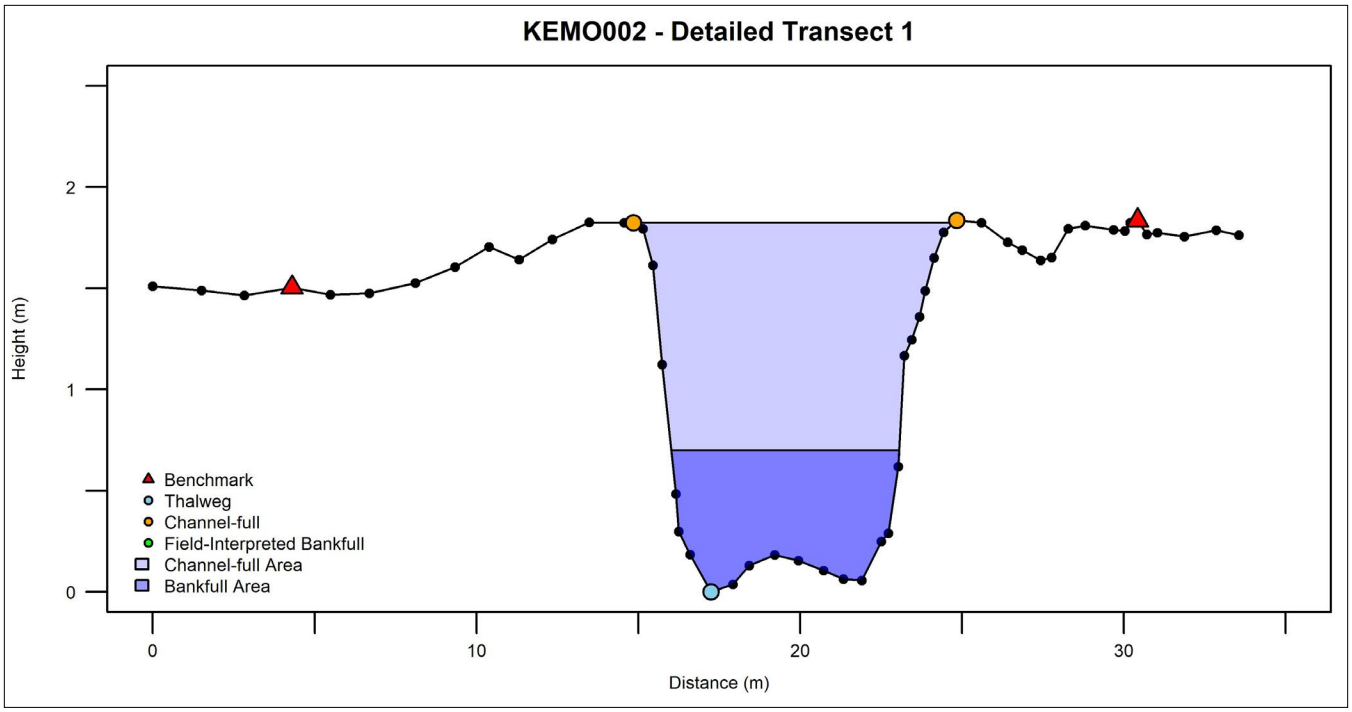


Figure C-14. Detailed transect 1 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional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

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	5.68	8.24	0.69	7.53	1.11	6.77
Channel-full	11.68	11.66	1.00	10.50	1.75	6.00
Ratio	2.06	1.41	1.45	1.39	1.57	0.89

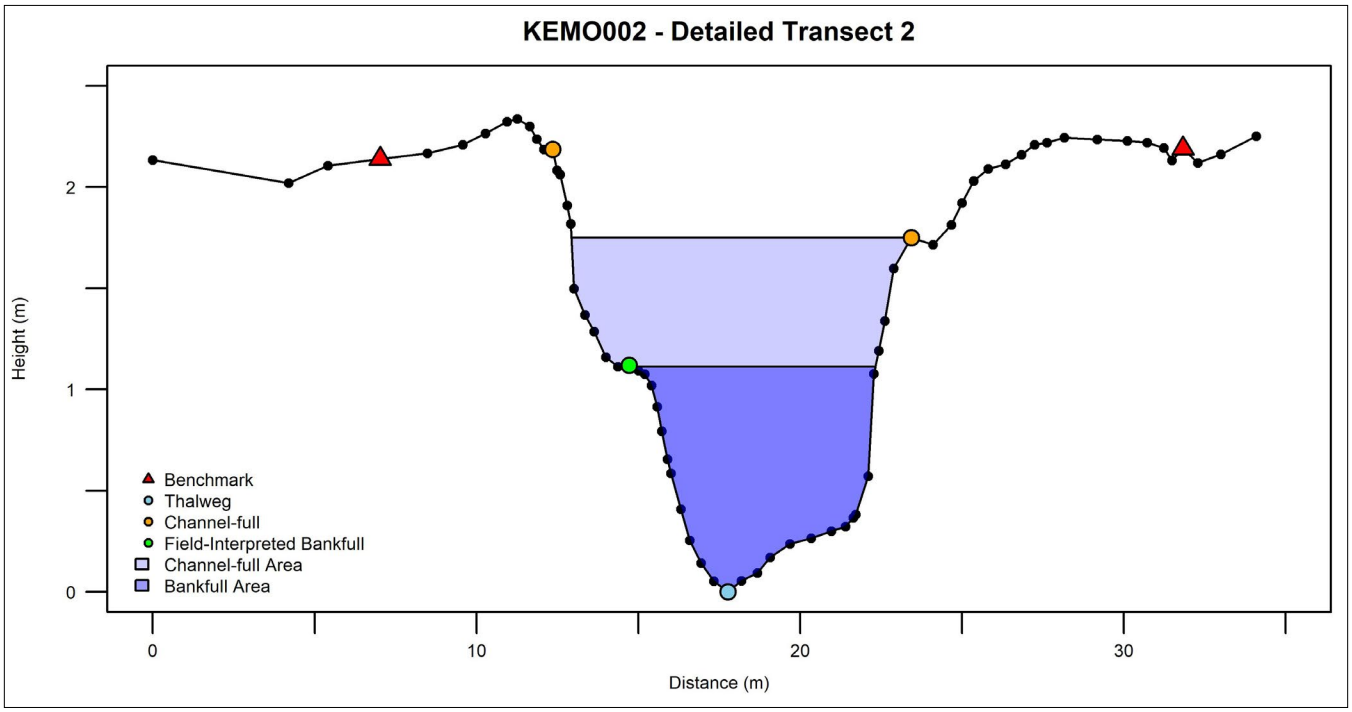


Figure C-15. Detailed transect 2 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area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

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	2.72	6.68	0.41	6.17	0.70	8.81
Channel-full	11.24	10.82	1.04	9.42	1.74	5.42
Ratio	4.13	1.62	2.55	1.53	2.48	0.62

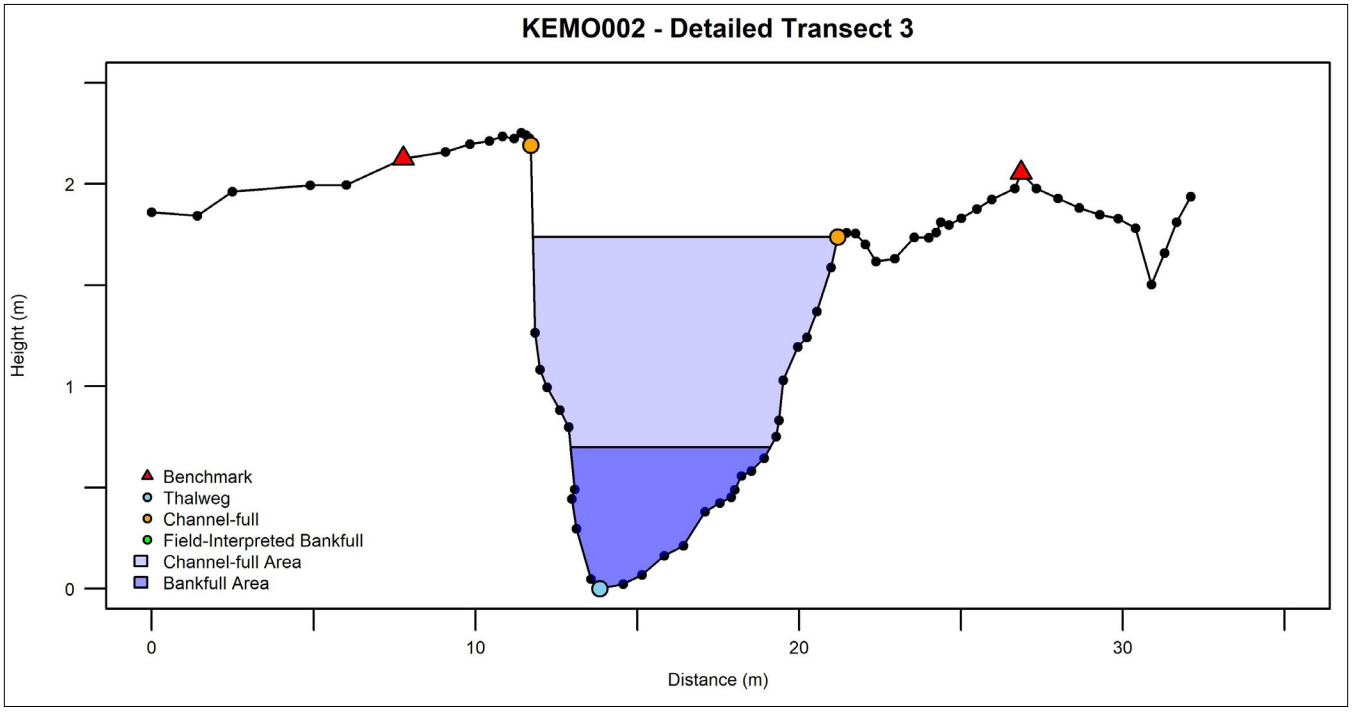


Figure C-16. Detailed transect 3 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional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

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NPS 352/173866, November 2020

National Park Service
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