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Wadeable Stream Habitat Monitoring at Kennesaw Mountain National Battlefield Park

2023 Change Report



Looking downstream from Transect 10 at the stream habitat monitoring site on Ward Creek (KEMO002) at Kennesaw Mountain National Battlefield Park

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Wadeable Stream Habitat Monitoring at Kennesaw Mountain National Battlefield Park: 2023 Change Report

Science Report NPS/SR—2025/329

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Abstract

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. Streams chosen for assessment were specifically targeted for management interest or to provide a context for similar-sized stream(s) within the park. This report documents the 2023 resurvey of wadeable stream habitats in Kennesaw Mountain National Battlefield Park (KEMO), focusing on two third-order streams—Noses Creek (KEMO001) and John Ward Creek (KEMO002). It is the third monitoring event, following baseline data collection in 2017 and a resurvey in 2019. The Southeast Coast Network (SECN) stream habitat monitoring protocol was employed to assess geomorphic, sedimentary, and habitat characteristics, and to track changes over time at multiple spatial scales (basin, reach, and transect).

Findings indicate that while both streams continue to exhibit signs of recovery from historical land-use impacts, they remain in degraded conditions. KEMO001 is classified as “poor to fair” and KEMO002 as “poor” based on habitat metrics including pebble counts, large woody debris (LWD), and the distribution of geomorphic channel units (GCUs). Both watersheds are affected by varying levels of urbanization, with KEMO002 experiencing higher impervious surface cover and upstream disturbances (e.g., beaver activity and sewer installation).

Despite minor improvements in LWD volume and habitat diversity, both streams remain unstable, showing evidence of episodic bank slumping and bar mobility. Notably, KEMO001’s previously identified knickpoint has remained stable, suggesting some channel resistance. Overall, the 2023 surveys reaffirm that both stream systems are in a widening phase (Stage 3 of channel evolution) and continue to be shaped by legacy sediment, altered hydrology, and urban runoff. No urgent management interventions were identified, although access-related hazards persist due to steep banks.

Continued monitoring and potential management interventions, such as LWD placement, bank stabilization, and sediment source control, may be necessary to mitigate these issues and maintain the ecological integrity of these valuable stream ecosystems. Further research on flow regime and macroinvertebrate community structure is necessary to better understand how these streams and associated habitat are changing through time.

List of Acronyms

ANOVA: Analysis of variance

B: Sand/gravel bar

Be: Bench

Bf: Bankfull

BM: Benchmark

BSi: Bank stability index

CHAT: Chattahoochee River National Recreation Area

CONG: Congaree National Park

C: Cobble bar

CV: Coefficient of variation

DEM: Digital elevation model

FP: Floodplain

FPM: Floodplain margin

GCU: Geomorphic channel unit

GIS: Geographic information system

Gl: Glide

HOBE: Horseshoe Bend National Military Park

KEMO: Kennesaw Mountain National Battlefield Park

LWD: Large woody debris

LT: Low terrace

NED: National Elevation Dataset

NL: Natural levee

NLCD: National Land Cover Dataset

NPS: National Park Service

OCMU: Ocmulgee Mounds National Historical Park

P: Pool

R: Riffle

Ru: Run

SECN: Southeast Coast Inventory and Monitoring Network

SOP: Standard operating procedure

T#: Standard transect

Un: Undercut

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 implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park, Kennesaw Mountain National Battlefield Park, 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 River National Recreation Area (McDonald and Starkey 2019a). On May 1, 2019, KEMO001 and KEMO002 were resurveyed to determine the amount of change that occurred on each reach (Bateman McDonald 2020). A second resurvey took place in 2023 on May 24 (KEMO001) and 25 (KEMO002). This report compares the results of the most recent survey to the 2019 resurveys and 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 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 bed sediment (from pebble counts), the type and distribution of GCUs (geomorphic channel units; e.g., riffle, run, and pool) within each reach, and the presence or absence of LWD (large woody debris), in-stream habitat within both of the surveyed streams were classified the same in 2023 as they were in 2017 and 2019 ("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.” 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).

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. The stream reaches are affected by episodic and progressive slumping of their banks. These slump surfaces (henceforth referred to as elevated entrenched surfaces) had been interpreted as relatively stable bankfull “floodplain” surfaces. The changes in the heights and sizes of these features have shown 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. Additionally, it is hypothesized that groundwater is one of the main contributors to the development of these elevated entrenched surfaces, by increasing pore water pressure in the bank simultaneously destabilizing the bank (facilitating undercutting) and lubricating failure planes in the bank (leading to slumping) and understanding how groundwater influences these streams could help predict where additional elevated entrenched surfaces develop. The loss and movement of bar surfaces within both reaches is evidence of highly mobile beds and a lack of long-term storage of sediment. The small knickpoint in the downstream portion of Noses Creek (KEMO001), first identified 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. No immediate management concerns were identified along either reach. The primary concern for visitors is the high banks that need to be navigated 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 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 National Military Park, Kennesaw Mountain National Battlefield Park, and Chattahoochee River National Recreation Area 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 2019; McDonald and Starkey 2018a; and McDonald and Starkey 2018b). The streams at Congaree National Park are typical low gradient, blackwater, Coastal Plain streams (McDonald and Starkey 2018c) while the streams at Ocmulgee Mounds National Historical Park are a mixture of Appalachian Piedmont and Coastal Plain type streams (McDonald and Starkey 2019a). Streams chosen for monitoring were specifically targeted due to management interest (e.g., 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 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 intermittent or ephemeral stream channels nor 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 National Battlefield Park during late spring 2023,
- Provide a comparison of the 2023 results to the 2019 initial resurvey and the 2017 "baseline" survey,
- 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 an average annual rainfall of around 50 inches (in) per year (127 centimeters [cm] per year; Wright et al. 2011). Snowfall is negligible, and winters are mild; summers are hot and humid. Average monthly temperatures range from approximately 35°F (1.9°C) to 82°F (27.7°C) (Wright et al. 2011). Monthly rainfall totals are distributed rather evenly from October through May due to the influence of frontal systems; convective thunderstorms influence the region from late spring through early fall (Lecce 2000). 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. is 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 (Bartram 1996) 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 pre-contact or near pre-contact levels, though their morphology (width, depth, entrenchment) is quite different from pre-contact channel morphology (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 the park) 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 (Schumm et al. 1984; James 2018). These stages include aggradation (receiving more sediment than the flow regime can transport), incision and narrowing (from a reduction in sediment and or increased runoff), further degradation and widening from unstable banks, a period of aggradation and adjustment, 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, the unique history of that stream, and current land use/land cover conditions of the stream's watershed. In general, streams in the Appalachian Piedmont are at the third stage of channel development (further degradation and widening) and their banks are quite unstable and subject to undercutting and slumping (Ruhlman and Nutter 1999).

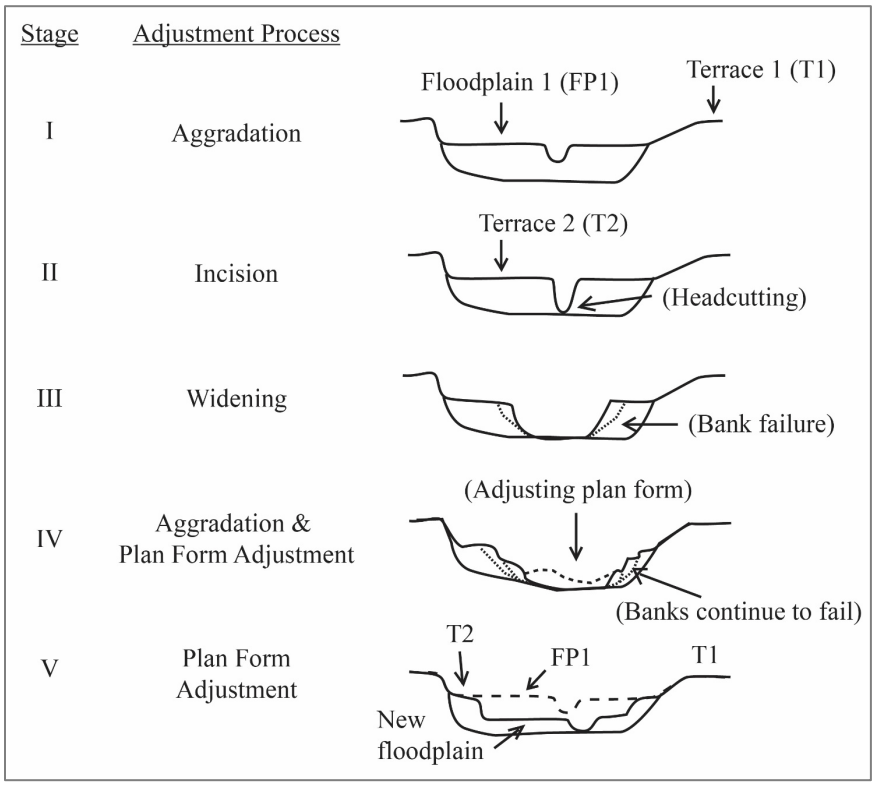


Figure 1. Generalized channel evolution model.
MODIFIED FROM SCHUMM ET AL. 1984

Kennesaw Mountain National Battlefield Park

Kennesaw Mountain National Battlefield Park consists of approximately 3,000 acres (1,214 hectares [ha]) of mixed hardwood pine forest and open fields. The park is located within the Atlanta metropolitan area in the Allatoona Mountain range (Figure 2). Kennesaw Mountain itself is 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 the intense urban and suburban development outside the park, the hydrology of these streams has been substantially altered, and they exhibit flashy flows typical of streams in an urban setting (Gregory and Calhoun 2007; Gregory et al. 2012; and 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).

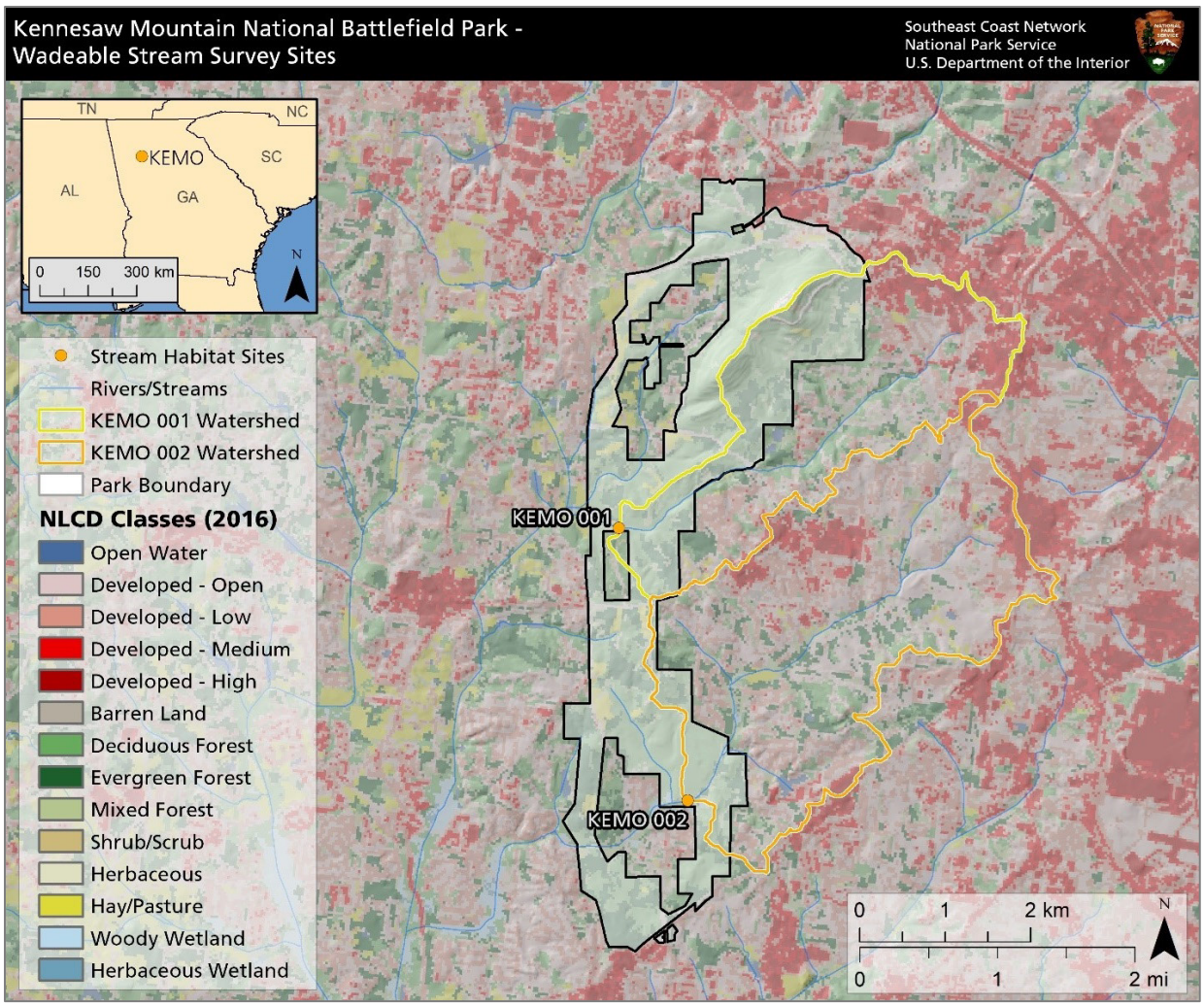


Figure 2. Map showing Kennesaw Mountain National Battlefield Park and its wadeable stream sites (KEMO001 and KEMO002). The watersheds draining to each study reach are shown to provide a context for the data presented in this report. The land use/land cover (NLCD 2016; Homer et al. 2020) and perennial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

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, 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 the park.

The 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 civil 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 (that runs parallel to the stream on river right) within the past decade. These disturbances have created a multi-channel system with a highly mobile bed and unstable banks in the areas upstream of the surveyed reach.

The surveyed reaches were interpreted to be beginning to develop an incipient meandering planform inset within the entrenched channel-full surface. In addition to lateral migration, the stream reaches are affected by episodic and progressive slumping of their banks. The slumping produced elevated entrenched surfaces that were interpreted as relatively stable bankfull "floodplain" surfaces in 2017 (McDonald et al. 2019). These surfaces were reinterpreted in 2019 as likely being slump-cored and highly mutable (Bateman McDonald 2020). 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 (Stage 3, Figure 1) as they equilibrate to their modern flow and sediment regimes. Additionally, the loss and movement of bar surfaces along both reaches is evidence of a highly mobile bed. Finally, the small knickpoint identified in the downstream portion of Noses Creek (KEMO001) in 2017 had not migrated further headward into the reach during the 2019 survey. The riffle immediately upstream of the knickpoint appears to provide enough resistance to prevent headward migration of the knickpoint.

Methods

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

The data collected as part of the SECN wadeable stream monitoring protocol are divided into three scales of analysis (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).

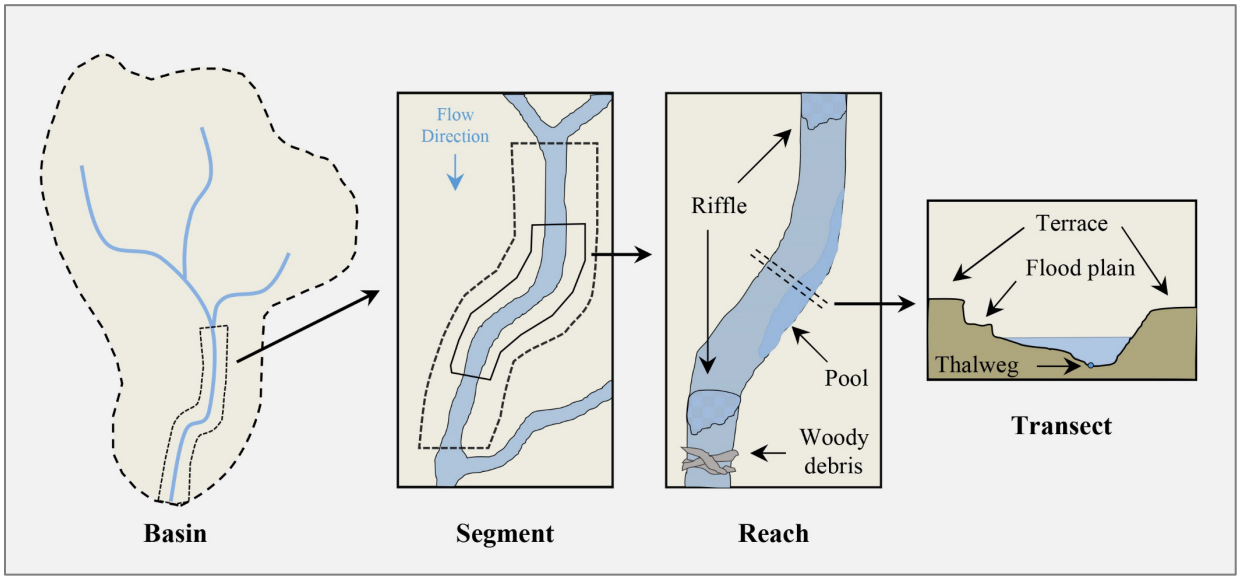


Figure 3. Spatial hierarchy of stream systems and scales of data collection. View in transect diagram is in the downstream direction.

MODIFIED FROM FITZPATRICK ET AL. 1998

Basin Characteristics

Understanding the physical characteristics of a drainage basin, as well as the land use/land cover (LULC) 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). Land use/land cover is from the National Land Cover Database (NLCD) which uses a modified Anderson classification to characterize LULC (Anderson et al. 1976). A detailed description of these basin characteristics can be found in McDonald et al. (2018a).

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

Reach-Scale Measurements

The reach-scale characteristics of each monitored reach are measured at and between 11 equidistant transects (distance between transects is two times average wetted width, Figure 4). Reach length is 20 times average wetted width (as determined during the initial survey of the reach). Data collected at each transect includes 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. Channel-full refers to the entire channel inset within the highest valley bottom surface (T2 in Figure 1). Traditionally, a bankfull surface is at the height of a stream's active floodplain (Fitzpatrick et al. 1998). In this report, a bankfull or elevated entrenched (EE) surface refers to the within channel-full channel's lowest longitudinally continuous surface on each bank on each transect that is lower than channel-full height. This modified interpretation of bankfull was used because the common indicators of a bankfull surface (i.e., longitudinally continuous flat surface with evidence of out of channel flow) are present at multiple heights throughout the study reaches. These surfaces have been interpreted as semi-stable slump-cored (EE) surfaces. To account for the fact that a bankfull surface may not be present on either or both sides of a transect, in addition to bankfull and channel-full bank heights, minimum bank height is also reported. Values of minimum bank height closer to channel-full indicate a lower proportion of banks with bankfull (EE) surfaces; while the opposite is true if minimum bank height greatly diverge from channel-full height. In addition to being a semi-quantitative measure of the presence of EE surfaces within a reach, the statistical significance of changes in minimum bank height can be tested using the tests described in the "Statistical Analysis" section below because the same number of observations are recorded each year. A quantitative measure of bed sediment is obtained by conducting a Wolman pebble count on a representative riffle within the reach (Wolman 1954). The location of the representative riffle each survey cycle may change as the bed is reworked and sediment passes through each reach.

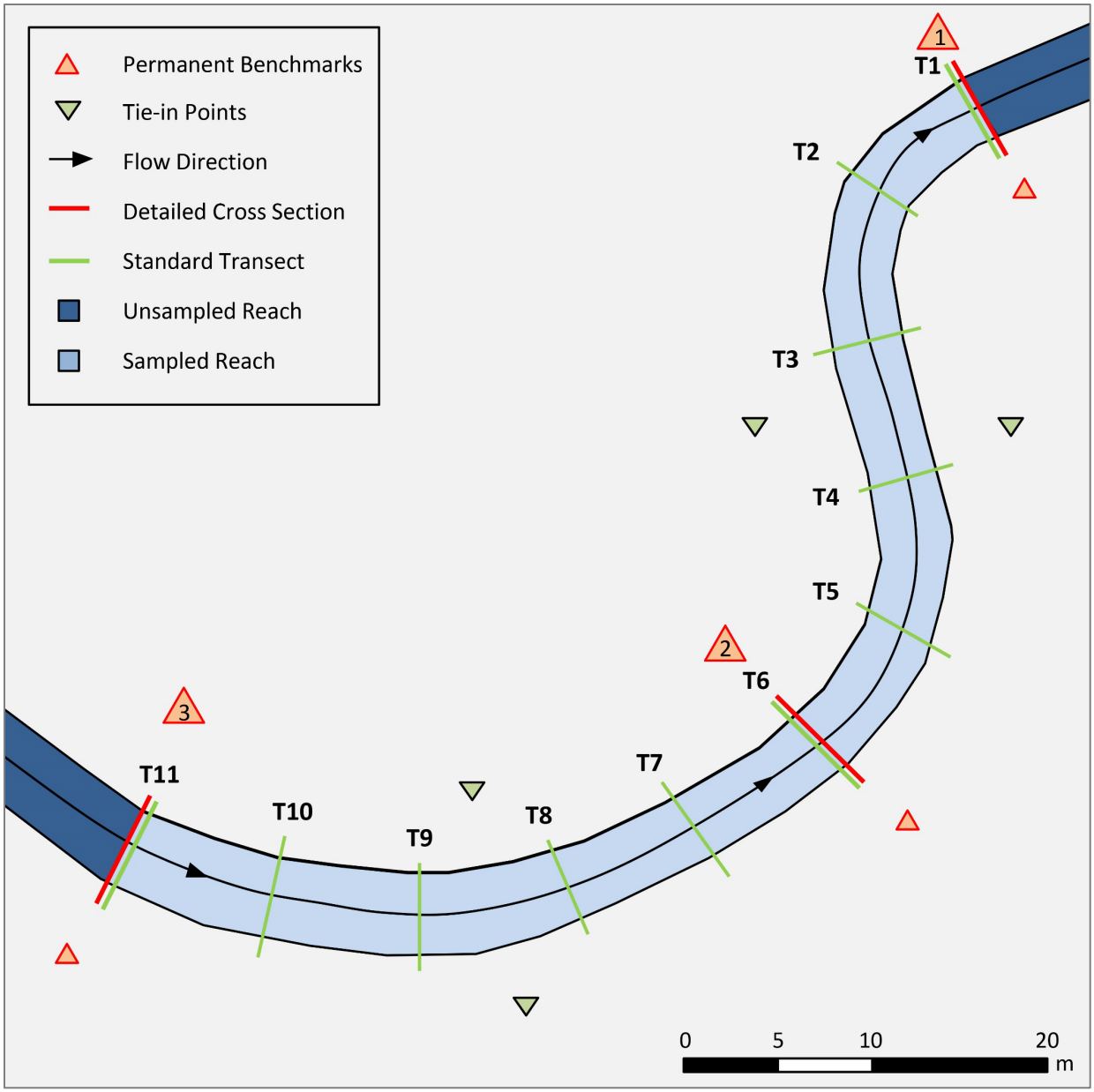


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.
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These data provide an understanding of the geomorphic and physical characteristics of the survey reach and are used to derive a bank stability score for the reach (Table 1). Many stream banks in the Appalachian Piedmont have bank stability scores of "at-risk" or "unstable." This condition is consistent with expectations, given that many comparable streams in the region are currently reestablishing functional floodplains within their highly entrenched channel systems.

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) [m=meters]. [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 (m)	<1	1
	1–2	2
	2–3	3
	3–4	4
	> 4	5
Type of Bank Sediment	Bedrock, artificial	1
	Boulder, cobble	3
	Clay	4
	Silt	5
	Sand	8
	Gravel/Sand	10

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

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 > 1 meter [3.3ft] in length and > 10 centimeters [3.9 inches {in}] in diameter, as defined in McDonald et al. 2018a) within the reach, and a description of in-channel features (e.g., sand 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.

Detailed Transect Cross-Sections

Three of the 11 standard transects (optimally T1, T6, and T11) are surveyed using a survey grade (sub-centimeter accuracy) total station. These surveys allow lateral variability along each transect to be quantified and in- and out-of-channel changes to be monitored through time (Figure 5).

Additionally, repeated surveying of channel cross-sections allows changes in streambed elevation and bank profiles to be quantitatively assessed in relation to a known point (benchmark). These data are used to calculate bankfull and channel-full areas. They are also employed, along with the bank stability index values, to assess the condition and stability of the reach.

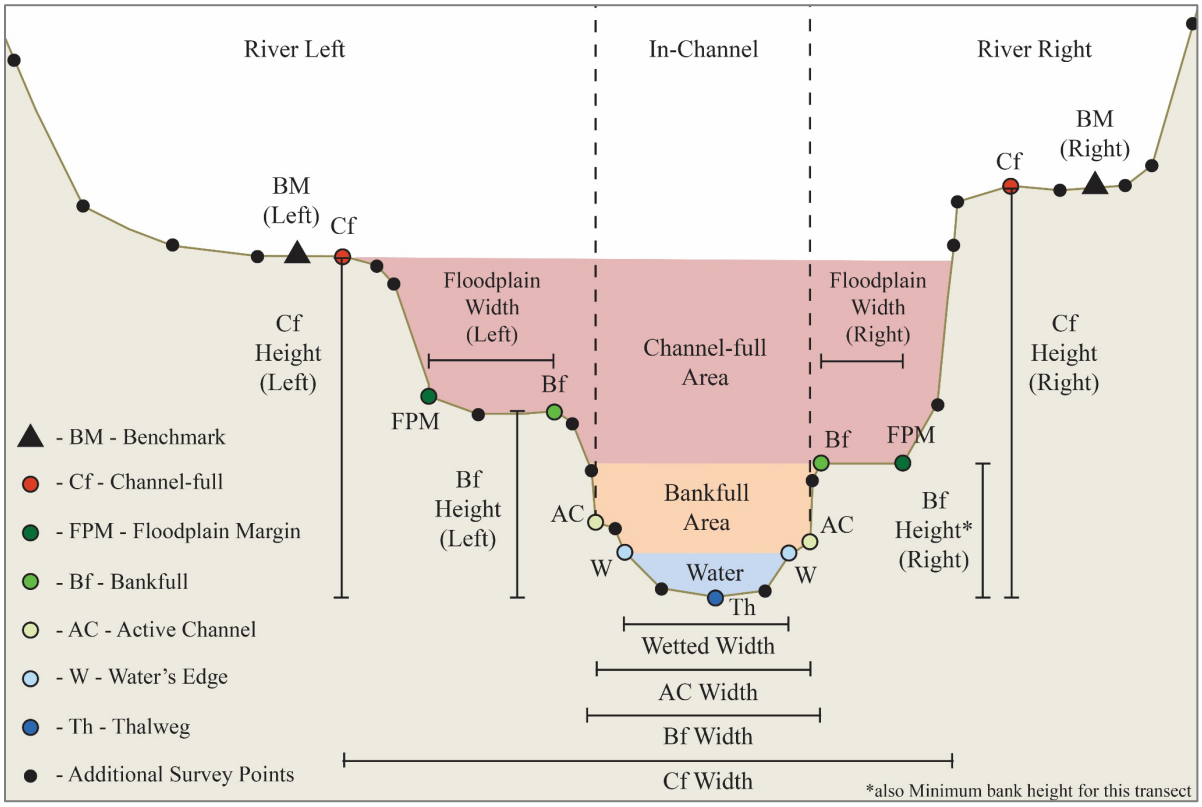


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces surveyed and the descriptive characteristics derived from the data. Bankfull area includes baseflow area (light blue) and bankfull area (orange). Channel full area includes baseflow, bankfull, and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

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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. These nine variables included: (1) pebble count data (millimeters [mm]); (2) thalweg depth (meters [m]); (3) thalweg position (% distance from left bank); (4) wetted width (meters); (5) active channel width (meters); (6) channel-full width (meters); (7) channel-full height (meters); (8) bank angle (°); and (9) vegetative cover of the banks (%). Bankfull width 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. An ANOVA was used to determine if observed changes at each reach were statistically significant. The results of the ANOVA were run through a post-hoc Tukey test to determine which of the nine variables mentioned above changed in statistically significant way.

Results

On May 24 and 25, 2023, two streams (Noses Creek [KEMO001, 5/24] and John Ward Creek [KEMO002, 5/25]) were surveyed following the methods outlined in SOP 1.2.16 *Wadeable Stream Reach-Scale Field Data Collection–Version 1.1* (McDonald et al. 2018c) and SOP 1.2.18 *Using a Total Station to Conduct a Stream Survey–Version 1.1* (McDonald et al. 2018d). The surveyed reaches are on a third order segment within their respective stream networks. Field surveys, GIS analyses, and statistical comparisons between monitoring years (2017, 2019, and 2023) and 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).

Basin Characteristics

This section provides a 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 CHAT see McDonald and Starkey (2019a). The watersheds drain 8.30 square kilometers (km^2 [3.2 square miles {mi^2}]; KEMO001) and 12.66 km^2 (4.9 mi^2; KEMO002; Table 2). The park manages 34% of KEMO001's watershed and 8% of KEMO002's watershed. The main geomorphic difference between the two watersheds is their relief and slope. KEMO001's watershed, which drains the southeastern side of Kennesaw Mountain, has more relief and has higher slope than KEMO002's watershed. KEMO002 has a high drainage density but a low segment slope. The land use/land cover for the watersheds draining to the two sites is also quite different. While both watersheds have similar amounts of medium- and high-intensity development, KEMO002 has much more suburban land cover (open and low-intensity development) than KEMO001 (Table 3). Alternatively, KEMO001 has more forest cover than KEMO002. The higher percent forest cover for KEMO001 is attributable to the higher percent of the watershed that is managed by the NPS, which includes forested hillslopes along the southeastern side of Kennesaw Mountain (Figure 2). Another distinguishing characteristic between the two KEMO watersheds is that on-site observations found substantial beaver activity in the upstream portions of Ward Creek.

Table 2. 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 Characteristic	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

[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 2 (continued). 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 Characteristic	KEMO001	KEMO002
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 - Std. Dev.	5.75	3.06
Slope - 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 - Std. Dev. (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 3. Land use/land cover characteristics in 2016 and 2021 for KEMO001 and KEMO002. The data included in this table are from the National Land Cover Database (USGS 2021).

NLCD Classes	KEMO001	KEMO001	KEMO002	KEMO002
Year	2016	2021	2016	2021
Developed Open & Low (%)	34	33	59	59
Developed Med. & High (%)	14	15	12	13
Forested (%)	50	50	26	26
Grassland (%)	1	2	1	1
Cultivated (%)	0	0	0	0

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). While only slightly more rain fell in the months prior to the 2023 surveys than both the 2019 and 2017 surveys, the week prior to the 2023 surveys had a substantial amount of rain compared to the previous surveys (Table 4). This large difference in precipitation in the week prior to the 2023 surveys is important context to consider when interpreting any potential changes that have occurred since 2019.

Table 4. Amount of precipitation and number of precipitation events greater than 1 inch in the week and month(s) prior to the 2017, 2019, and 2023 wadeable stream surveys at Kennesaw Mountain NBP. Data from Remote Automated Weather Stations (RAWS) Dallas, GA, weather station (https://raws.dri.edu/cgi-bin/rawMAIN.pl?laGDAL).

Time Frame	Length of Period	Total Precipitation (inches)	Number of Events > 1 Inch
5/11/2017–5/17/2017	One Week	0.2	0
4/17/2017–5/17/2017	One Month	2.75	0
2/17/2017–5/17/2017	Three Months	11.55	1
4/25/2019–5/1/2019	One Week	0.19	0
4/1/2019–5/1/2019	One Month	5.25	2
2/1/2019–5/1/2019	Three Months	13.77	5
5/19/2023–5/25/2023	One Week	1.48	1
4/25/2023–5/25/2023	One Month	5.56	3
2/24/2023–5/25/2023	Three Months	14.86	6

KEMO001—Noses Creek

Reach Description

KEMO001 is located on Noses Creek approximately 450 meters (1476.4 ft) downstream of the pedestrian bridge on Noses Creek Trail. A social trail passes within a meter 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). In 2019, a very large LWD dam was observed just upstream of the reach (Bateman McDonald 2020). Loss of this LWD dam has had a large impact on the area upstream of T11 as the deep (> 1.5 meters [4.9 ft]) pool observed in 2019 has been infilled. As observed during previous surveys, a groundwater seep enters the channel on river left between T8 and T9 (Figure 6). KEMO001's channel continues to be fairly entrenched. All of the likely slump-cored "elevated entrenched surfaces" identified in 2019 have been reduced in size, with the surface(s) between T4 and T6 on river right having almost been completely eroded away. The surveyed reach was 80 meters (262.5 ft) long, with 8 meters (26.2 ft) between transects. The following sections describe the differences in the 2017, 2019, and 2023 reach-scale habitat characteristics and channel morphology along KEMO001, as well as the changes that were observed on the detailed transects. Transect-scale survey results for KEMO001 can be found in Appendix B.

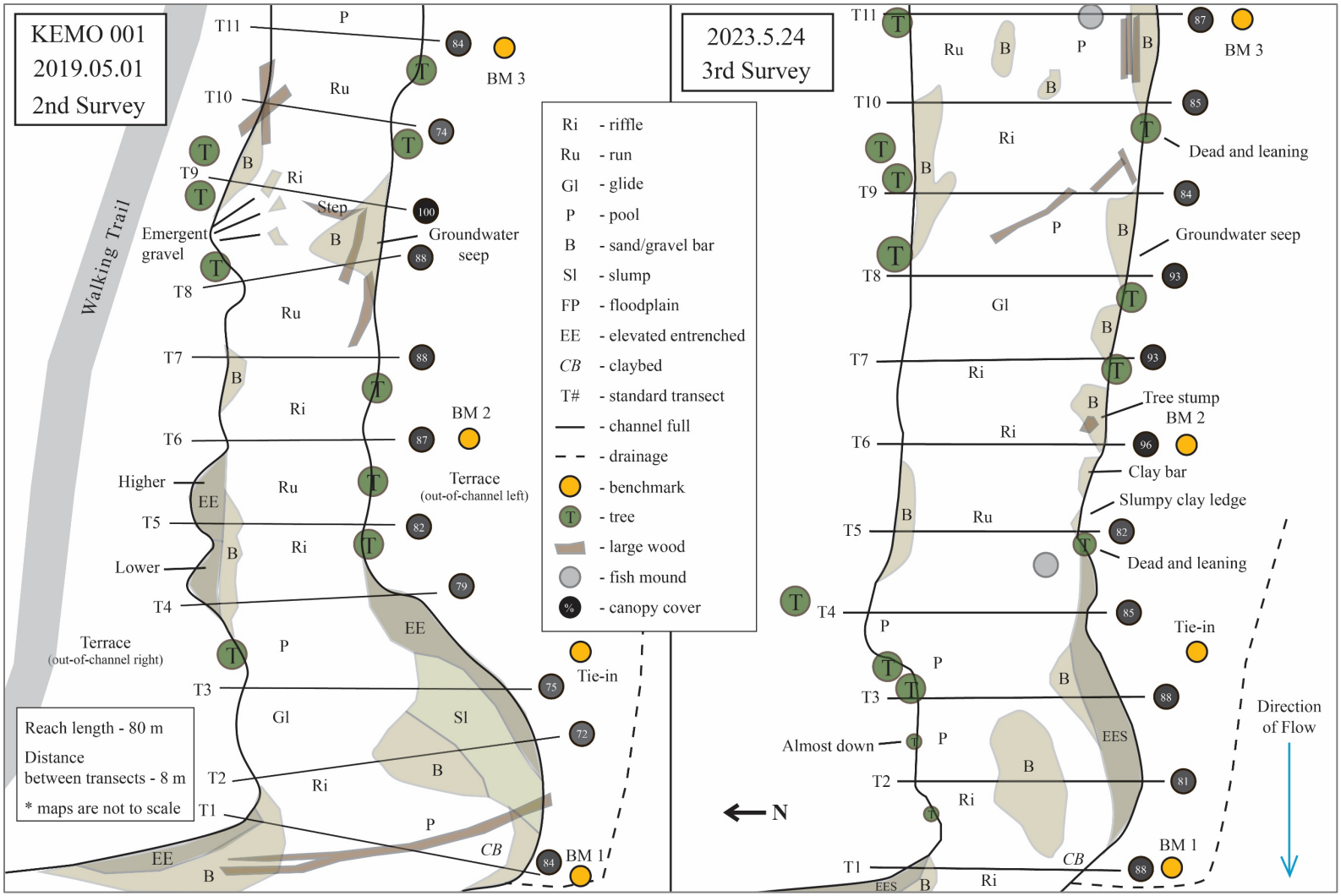


Figure 6. Reach-scale map of KEMO001 comparing the second (2019) and third surveys (2023). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of 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 and width are due to artistic differences (unless noted in the text).

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Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) observed at KEMO001 in 2023 are similar to those observed in 2019 with some slight improvements in habitat diversity (Table 5). During 2017, the GCUs covering Noses Creek were a mixture of riffle and pool with some run and glide habitats mixed in. During 2019, based on mean percent at each transect, most of the habitat observed was run followed by riffle, glide, and then pool. The percentage of habitat covered by run continued to be high in 2023 (+46% over 2017). The percentage of pool in 2023 increased by 15% relative to 2019, but it was still down 16% from 2017.

Table 5. Geomorphic channel units (GCUs) observed in the area between transects during the 2017, 2019, and 2023 surveys at KEMO001 and KEMO002.

GCU Type	Site	Year	Frequency	Max (%)	Mean (%)	SD (%)
Riffle	KEMO001	2017	8	90	49	33
	KEMO001	2019	7	75	23	26
	KEMO001	2023	7	75	25	30
	KEMO002	2017	2	25	5	11
	KEMO002	2019	4	20	4	7
	KEMO002	2023	2	40	8	17
Run	KEMO001	2017	6	40	13	14
	KEMO001	2019	10	100	69	32
	KEMO001	2023	10	100	59	27
	KEMO002	2017	5	80	26	33
	KEMO002	2019	10	100	63	32
	KEMO002	2023	10	100	69	28
Glide	KEMO001	2017	1	50	5	16
	KEMO001	2019	1	70	7	22
	KEMO001	2023	0	0	0	0
	KEMO002	2017	1	20	2	6
	KEMO002	2019	0	0	0	0
	KEMO002	2023	5	30	8	10
Pool	KEMO001	2017	9	80	33	27
	KEMO001	2019	2	10	2	4
	KEMO001	2023	8	50	17	17
	KEMO002	2017	10	100	65	32
	KEMO002	2019	7	80	31	31
	KEMO002	2023	5	70	13	22

Table 5 (continued). Geomorphic channel units (GCUs) observed in the area between transects during the 2017, 2019, and 2023 surveys at KEMO001 and KEMO002.

GCU Type	Site	Year	Frequency	Max (%)	Mean (%)	SD (%)
Step	KEMO001	2017	0	0	0	0
	KEMO001	2019	0	0	0	0
	KEMO001	2023	0	0	0	0
	KEMO002	2017	1	25	3	8
	KEMO002	2019	1	20	2	6
	KEMO002	2023	1	30	3	9

The pebble counts from all survey years were similar (Table 6). Though the minimum pebble size was coarser in 2019 and 2023 than 2017, the difference in the means was not statistically significant between any of the survey years (Table 7). Ten pieces of LWD were observed within KEMO001's channel during the 2023 survey (Table 8). This increase in the number of pieces of LWD led to an increase in the volume of LWD per channel area. This volume of LWD per channel area was the most observed during any of the surveys on this reach. The mean percentage of canopy cover in 2023 was slightly higher than 2019 and slightly lower than 2017 (Table 9).

Out of the three surveys, mean thalweg depth in 2023 was the lowest observed yet the slight differences between the survey years were not statistically significant (Tables 7 and 10). Mean thalweg position did not change substantially yet continued to migrate away from river left (Table 10). In 2019 and 2023, based on the coefficient of variation (CV) of thalweg depths were slightly less variable than 2017. Variability in thalweg position, again based on CV, in 2023 was similar to 2017 and lower than 2019.

Table 6. Particle size distributions of bed sediment (in mm) from the pebble counts conducted during 2017, 2019, and 2023 at KEMO001 and KEMO002. The subscripts indicate the percent of the sample that is smaller than the reported diameter [Min=minimum; Max=maximum].

Site	Year	n	Min	D5	D16	D50	Mean	D84	D95	Max
KEMO001	2017	100	< 0.06	3.00	7.00	16.00	17.77	27.00	37.90	50.00
	2019	100	3.00	5.00	8.16	20.00	20.57	32.00	41.00	49.00
	2023	100	2.00	2.00	7.00	15.00	17.62	29.00	42.80	54.00
KEMO002	2017	100	< 0.06	1.00	1.00	12.00	12.56	20.84	29.95	57.00
	2019	100	< 0.06	< 0.06	2.00	7.00	9.28	17.00	22.00	34.00
	2023	100	2.00	2.00	2.00	7.00	7.21	12.00	17.95	27.00

Table 7. Significance of the differences between the 2017, 2019, and 2023 surveys of KEMO001 based on a post-hoc Tukey analysis (m=meters; mm=millimeters). The significance (Sig) of the differences is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001.

Measurement	Difference 2023–2019	P-Value	Sig.	Difference 2019–2017	P-Value	Sig.	Difference 2023–2017	P-Value	Sig.
Mean Particle Diameter (mm)	2.81	0.170	–	−0.14	0.996	–	−2.95	0.142	–
Wetted Width (m)	0.15	0.952	–	1.55	0.014	*	1.70	0.006	**
Active Channel Width (m)	0.89	0.123	–	−0.52	0.463	–	0.36	0.689	–
Minimum Bank Width (m)	0.51	0.663	–	0.87	0.313	–	1.38	0.064	–
Channel-full Width (m)	−0.14	0.954	–	1.29	0.035	*	1.14	0.066	–
Thalweg Depth (m)	0.03	0.758	–	−0.01	0.956	–	−0.04	0.584	–
Minimum Bank Height (m)	0.09	0.609	–	0.08	0.675	–	0.16	0.177	–
Channel-full Height (m)	0.01	0.965	–	0.09	0.078	–	0.10	0.043	*
Bank Angle (°)	0.34	0.998	–	6.23	0.490	–	6.57	0.453	–
Veg. Cover (%)	14.55	0.160	–	3.86	0.875	–	18.41	0.056	–
Bank Stability Index	−0.14	0.925	–	−1.55	< 0.001	***	−1.68	< 0.001	***

Table 8. Summary statistics for the large woody debris measured in 2017, 2019, and 2023 at KEMO001 and KEMO002 [m=meters].

Statistic	Site	Year	n	Length (m)	Diameter (m)	Volume (m^3)
Mean	KEMO001	2017	11	2.91	0.12	0.03
	KEMO001	2019	6	2.14	0.13	0.03
	KEMO001	2023	10	2.62	0.19	0.07
	KEMO002	2017	25	3.89	0.19	0.13
	KEMO002	2019	38	3.73	0.18	0.14
	KEMO002	2023	20	3.47	0.19	0.12
Max	KEMO001	2017	11	10.00	0.16	0.10
	KEMO001	2019	6	6.28	0.19	0.08
	KEMO001	2023	10	4.92	0.30	0.14
	KEMO002	2017	25	9.59	0.47	0.48
	KEMO002	2019	38	13.27	0.41	1.23
	KEMO002	2023	20	13.68	0.31	0.73
SD	KEMO001	2017	11	3.02	0.02	0.03
	KEMO001	2019	6	2.06	0.03	0.03
	KEMO001	2023	10	1.32	0.06	0.04
	KEMO002	2017	25	2.66	0.10	0.13
	KEMO002	2019	38	3.14	0.08	0.25
	KEMO002	2023	20	3.33	0.06	0.16
Per Channel Area (m^3/m^2)	KEMO001	2017	–	–	–	0.0005
	KEMO001	2019	–	–	–	0.0002
	KEMO001	2023	–	–	–	0.0009
	KEMO002	2017	–	–	–	0.0054
	KEMO002	2019	–	–	–	0.0060
	KEMO002	2023	–	–	–	0.0026

Table 9. Descriptive statistics for reach-scale canopy cover in 2017, 2019, and 2023 at KEMO001 and KEMO002 [Min=minimum; Max=maximum].

Site	Year	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
KEMO001	2017	11	81	87	96	5	0.05
	2019	11	72	83	100	8	0.10
	2023	11	74	85	94	6	0.07
KEMO002	2017	11	76	89	96	6	0.07
	2019	11	62	84	99	14	0.16
	2023	11	78	87	96	5	0.06

Table 10. Reach-scale averaged thalweg conditions in 2017, 2019, and 2023 at KEMO001 and KEMO002 [Min=minimum; Max=maximum; SD=standard deviation; CV=coefficient of variation].

Thalweg	Site	Year	n	Min	Mean	Max	SD	CV
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
	KEMO001	2023	11	0.08	0.21	0.39	0.09	0.43
	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
	KEMO002	2023	11	0.14	0.21	0.31	0.06	0.26
Position (%) [A]	KEMO001	2017	11	10	41	90	28	0.68
	KEMO001	2019	11	5	44	95	36	0.81
	KEMO001	2023	11	5	53	95	37	0.71
	KEMO002	2017	11	5	43	90	36	0.84
	KEMO002	2019	11	10	61	90	33	0.54
	KEMO002	2023	11	5	56	95	37	0.65

[A] Position is percent distance from left active channel bank.

Channel Morphology

Wetted widths were on average wider during the 2019 and 2023 surveys (2023 was widest) than in 2017 (Table 11). The differences in mean wetted width between 2017 and the other two surveys were statistically significant, while the difference between 2019 and 2023 was not statistically significant (Table 7). Mean active channel widths were on average wider during the 2017 and 2023 surveys (2023 was widest) than in 2019 (Table 11). These differences were not statistically 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 than in both 2017 and 2023 (Table 11). The same number of bankfull widths were measured in 2019 as 2017 (n = 5, Table 11). Two fewer bankfull widths were measured in 2023. While fewer bankfull widths were measured in 2023, bankfull widths were 15% wider than 2019 (which was the widest prior to 2023). Differences in mean bankfull width were not statistically tested because of the relatively small number of bankfull widths available to measure and the difference in the number of measurements. Note, bankfull refers to lowest elevated entrenched (EE) surface present on a transect. See the "Reach-Scale Measurements" section for a detailed explanation of EE surfaces. Channel-full widths were on average wider in 2019 and 2023 compared to 2017 (Table 11). While the difference in channel-full widths was statistically significant when comparing 2017 and 2019, the difference between the 2023 survey and the other two surveys was not statistically significant (Table 7).

Table 11. Reach-scale width characteristics in 2017, 2019, and 2023 at KEMO001 and KEMO002 [Min=minimum; Max=maximum; CV=coefficient of variation; SD=standard deviation; m=meters].

Widths	Site	Year	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
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
	KEMO001	2023	11	3.46	4.74	6.34	0.95	0.20
	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
	KEMO002	2023	11	2.44	3.66	5.97	1.02	0.28
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
	KEMO001	2023	11	4.52	5.97	6.80	0.68	0.11
	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
	KEMO002	2023	11	5.73	7.15	9.23	0.97	0.14
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
	KEMO001	2023	3	6.63	7.95	8.90	1.18	0.15
	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
	KEMO002	2023	6	7.41	9.16	11.16	1.46	0.16
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
	KEMO001	2023	11	7.60	9.65	12.40	1.49	0.15
	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
	KEMO002	2023	11	8.85	12.96	18.21	2.95	0.23

Mean minimum bank height did not change appreciably between the survey years (Table 12). The small differences between mean minimum bank height were not statistically significant when comparing any of the survey years (Table 7). Bankfull heights (minimum, mean, and maximum) in 2023 were the highest measured across all surveys (Table 12). Like bankfull width, bankfull heights were not statistically tested because of the relatively small number of bankfull heights available to measure and the difference in the number of measurements. Channel-full heights were higher in 2019 and 2023 compared to 2017 (Table 12). The difference in mean channel-full height between 2017 and 2023 was statistically significant (Table 7). Variability in channel-full heights was low during all survey years (Table 12).

Table 12. Reach-scale averaged bank height characteristics in 2017, 2019, and 2023 at KEMO001 and KEMO002 [Min=minimum; Max=maximum; CV=coefficient of variation; SD=standard deviation; m=meters].

Bank Characteristic	Site	Year	n	Min	Mean	Max	SD	CV
Minimum Bank Height (m) [A, B]	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
	KEMO001	2023	22	0.82	1.45	1.77	0.22	0.16
	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
	KEMO002	2023	22	1.07	1.76	2.18	0.28	0.16
Bankfull Height (m) [A, C]	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
	KEMO001	2023	4	0.82	1.09	1.37	0.23	0.21
	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
	KEMO002	2023	7	1.07	1.43	1.87	0.24	0.17
Channel-full Height (m) [A]	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
	KEMO001	2023	22	1.33	1.54	1.77	0.13	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
	KEMO002	2023	22	1.71	1.94	2.18	0.10	0.05

[A] Above thalweg.

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

[C] Statistics are based on the transects where feature is present (reported in “n” field).

The number of bank undercuts was the same in 2019 and 2023 but the mean horizontal depth (distance into bank) and mean vertical height (above thalweg) decreased approximately 40% (Table 13). Bank angles have not changed appreciably across the three surveys (Table 13). The slight differences in mean bank angle between survey years were not statistically significant (Table 7). Bank vegetation cover in 2023 was the highest measured across the survey years (Table 13), but the differences between the years were not statistically significant (Table 7). Bank stability scores were lower (more stable) in 2019 and 2023 compared to 2017 (Table 13). The differences between the 2017 survey and the other two surveys were statistically significant (Table 7).

Table 13. Reach-scale averaged bank characteristics in 2017, 2019, and 2023 at KEMO001 and KEMO002 [Min=minimum; Max=maximum; CV=coefficient of variation; SD=standard deviation; m=meters].

Bank Characteristic	Site	Year	n	Min	Mean	Max	SD	CV
Bank Undercut (horizontal depth) (m) [A]	KEMO001	2017	1	–	0.14	–	–	–
	KEMO001	2019	4	0.15	0.45	0.80	0.31	0.69
	KEMO001	2023	4	0.03	0.27	0.80	0.36	1.34
	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
	KEMO002	2023	4	0.17	0.31	0.65	0.23	0.76
Bank Undercut (vertical height) (m) [A]	KEMO001	2017	1	–	0.45	–	–	–
	KEMO001	2019	4	0.35	0.96	1.38	0.44	0.46
	KEMO001	2023	4	0.35	0.41	0.46	0.05	0.12
	KEMO002	2017	2	0.10	0.91	1.72	1.15	1.26
	KEMO002	2019	4	0.71	1.45	1.99	0.55	0.38
	KEMO002	2023	4	0.90	1.25	1.39	0.23	0.18
Bank Angle (°)	KEMO001	2017	22	3	40	72	20	0.50
	KEMO001	2019	22	11	46	83	20	0.43
	KEMO001	2023	22	23	47	69	13	0.28
	KEMO002	2017	22	9	56	90	27	0.48
	KEMO002	2019	22	3	47	91	24	0.50
	KEMO002	2023	22	14	49	86	19	0.38
Vegetation Cover (%)	KEMO001	2017	22	0	40	85	28	0.69
	KEMO001	2019	22	10	44	90	24	0.55
	KEMO001	2023	22	5	59	90	25	0.43
	KEMO002	2017	22	0	18	50	18	0.99
	KEMO002	2019	22	10	38	70	21	0.57
	KEMO002	2023	22	5	42	80	24	0.59
Bank Stability [B]	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
	KEMO001	2023	22	10.50	11.89	14.50	1.11	0.09
	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
	KEMO002	2023	22	10.50	12.98	15.00	1.22	0.09

[A] Statistics are based on the transects where feature is present (reported in “n” field).

[B] 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 39% larger in 2023 compared to 2019 (Table 14). As mentioned in the "Channel Morphology" section, bankfull refers to the lowest elevated entrenched (EE) surface on a transect. See the "Reach-Scale Measurements" section for a detailed explanation of EE surfaces. On average, channel-full area was also larger in 2023 compared to 2019 (+11%). Water surface slope (longitudinal profile) for this section of Noses Creek was 33% lower in 2023 compared to the 2019 high (Figure 10; Table 14). 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. In 2023, the shape of the channel gradient was similar to 2019 but there was a smaller difference in elevation between the upstream and downstream portions of the reach (Figure 10). The reach is relatively straight and has very low sinuosity (1.03, Table 13).

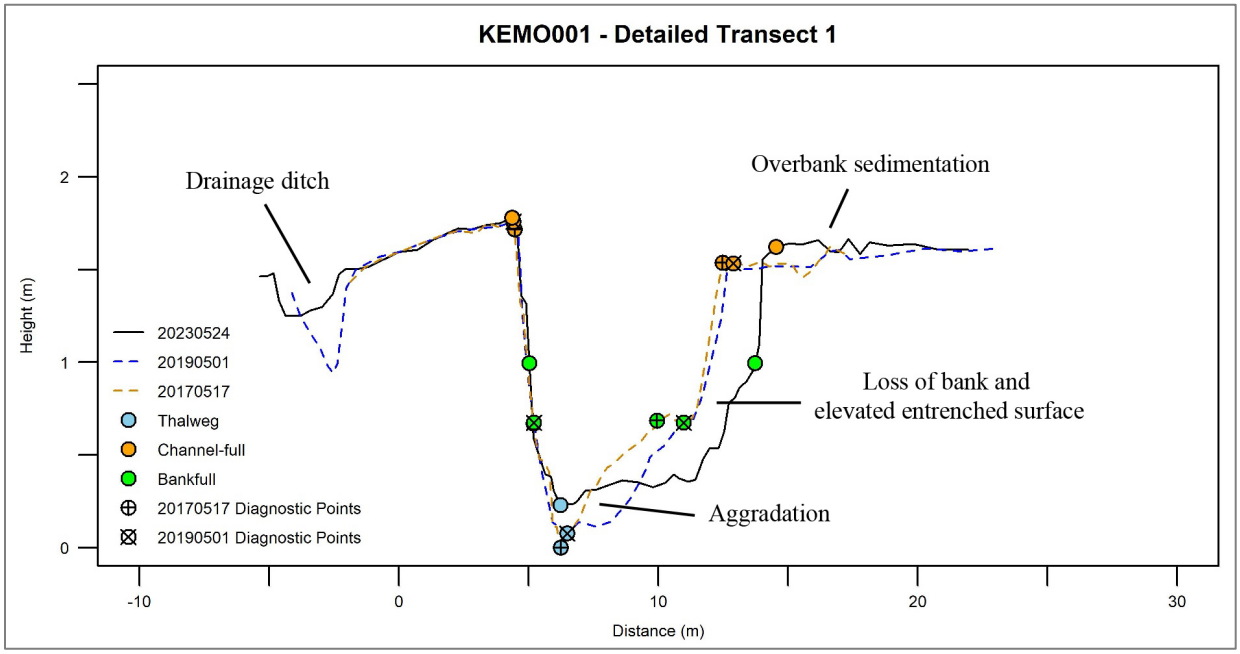


Figure 7. Differences between 2017, 2019, and 2023 surveys of detailed transect 1 at KEMO001. View is in the downstream direction (river left is on the left).

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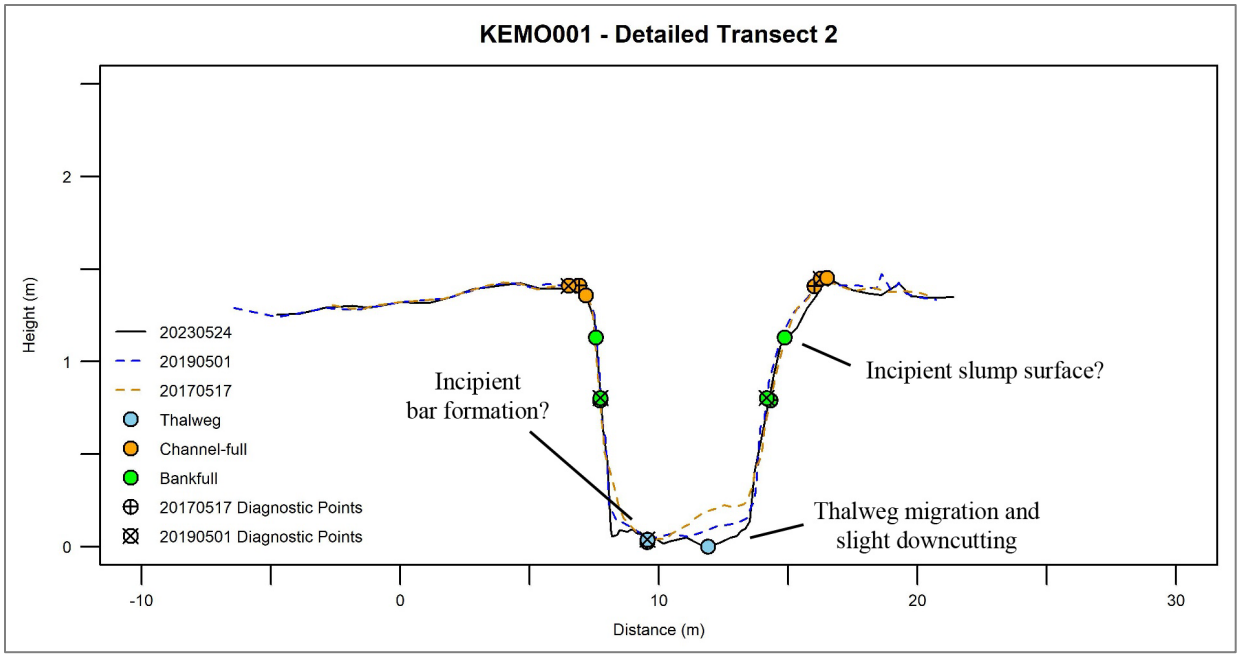


Figure 8. Differences between 2017, 2019, and 2023 surveys of detailed transect 2 at KEMO001. View is in the downstream direction (river left is on the left).

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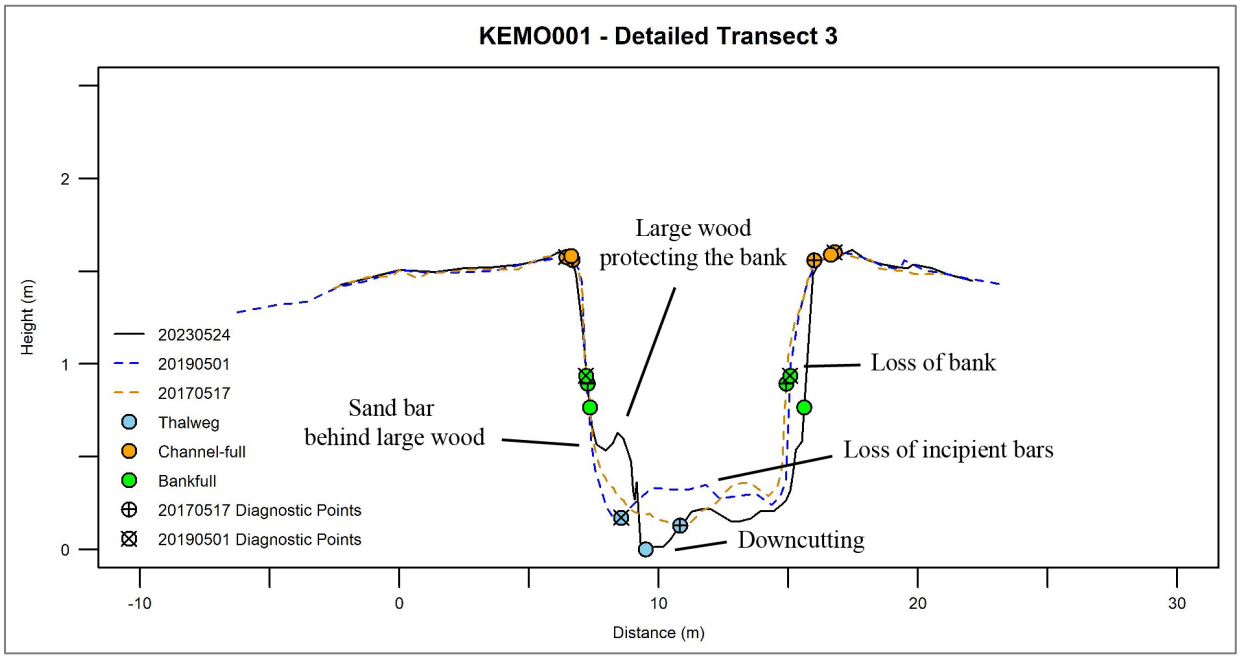


Figure 9. Differences between 2017, 2019, and 2023 surveys of detailed transect 3 at KEMO001. View is in the downstream direction (river left is on the left).

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Table 14. Comparison of reach-scale and average detailed transect characteristics at KEMO001 and KEMO002 [m=meters].

Site	Year	n	Slope	Sinuosity	n	Bankfull Area (m2) [A]	Bankfull Width (m) [A]	Bankfull Height (m) [A]	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
	2023	13	0.0028	1.03	3	5.20	8.09	0.89	10.12	9.60	1.44
Difference	2019–2017	–	0.0027	0.01	–	0.44	0.36	−0.03	0.43	0.51	−0.04
	2023–2019	–	–0.0014	0.00	–	1.46	1.39	0.18	1.02	0.33	0.03
	2023–2017	–	0.0013	0.01	–	1.89	1.75	0.15	1.45	0.84	−0.01
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
	2023	12	0.0026	1.10	3	7.74	9.39	1.20	14.06	13.19	1.82
Difference	2017–2019	–	0.0001	–0.03	–	0.94	0.23	0.14	4.37	1.27	0.49
	2023–2019	–	0.0006	0.04	–	3.65	2.47	0.36	2.16	3.25	0.05
	2023–2017	–	0.0007	0.01	–	4.59	2.71	0.50	6.53	4.52	0.54

[A] Variable recalculated from original survey data to standardize interpretation of surface.

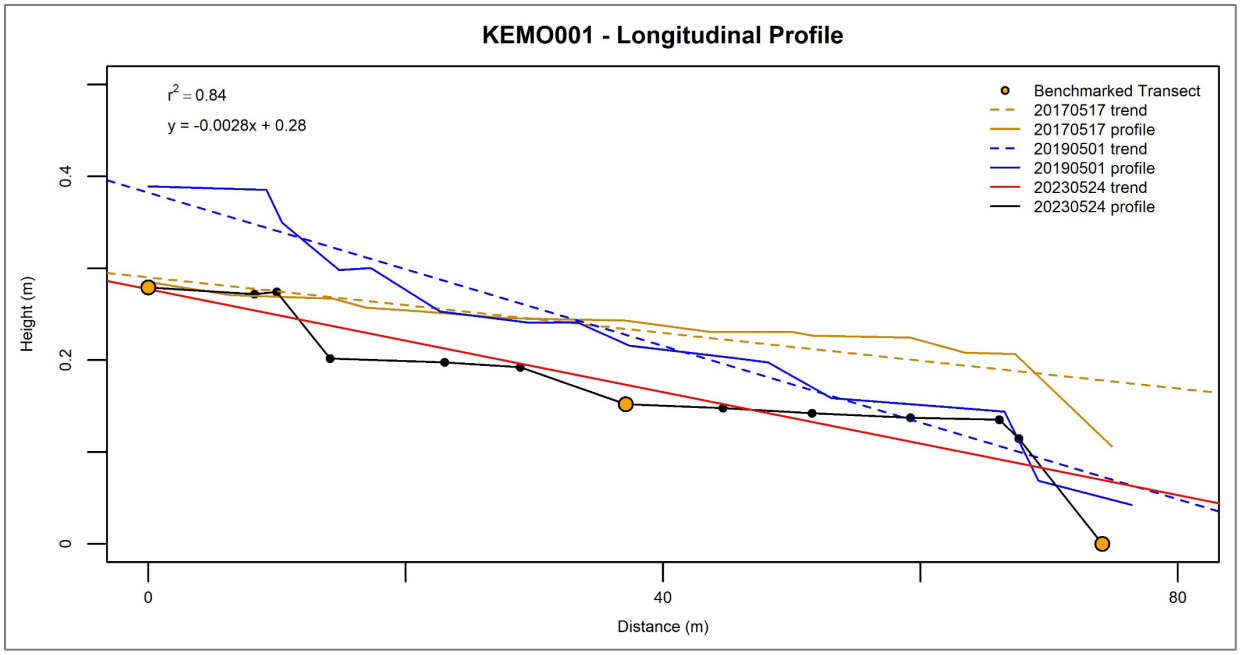


Figure 10. Longitudinal profile for KEMO001. The red line on the graph corresponds to the interpreted slope of the reach (0.0028 m/m). The r^2 value describes the strength of the 2023 trend line (interpreted slope) based on linear regression. The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

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On detailed transect 1 (T1), the flat elevated entrenched surface (interpreted as a floodplain in 2017) on river right has completely eroded and an appreciable portion of the bank was lost (Figure 7). This loss of bank caused bankfull cross-sectional area to increase +122% since 2019, and 229% since 2017 (Table 15). The bed of the channel has aggraded since 2019 and the thalweg is still along river left. The ephemeral (drainage) channel behind the river left benchmark has slightly widened, decreased in depth, and is still affecting the creek just downstream of T1. Channel-full area also increased (+25%) since 2019 (Table 15).

Table 15. Changes to cross-sectional characteristics on detailed transect 1 at KEMO001 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	1.47	4.77	0.68
	2019	2.17	5.77	0.60
	2023	4.83	8.70	0.77
Change	2019–2017	0.70	1.00	−0.08
	2023–2019	2.66	2.93	0.17
	2023–2017	3.36	3.93	0.08

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Table 15 (continued). Changes to cross-sectional characteristics on detailed transect 1 at KEMO001 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Channel-full	2017	7.48	7.91	1.54
	2019	8.41	8.23	1.46
	2023	10.55	9.94	1.39
Change	2019–2017	0.93	0.32	−0.08
	2023–2019	2.15	1.71	−0.06
	2023–2017	3.08	2.03	−0.15

[A] Variables recalculated from original survey data to standardize interpretation of surface.

While detailed transect 2 (T6) continues to be entrenched, an incipient elevated entrenched surface was observed on river right (Figure 8). Using this relatively high surface to calculate bankfull cross-sectional area, bankfull cross-sectional area increased 60% (+75% since 2017, Table 16). A potential incipient bar was observed along river left, and the thalweg down cut and migrated towards river right. There was a slight (2%) reduction in channel-full area as the slight thalweg down cut was cancelled out by a slightly lower channel-full bank top on river left.

Table 16. Changes to cross-sectional characteristics on detailed transect 2 at KEMO001 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	3.79	6.59	0.77
	2019	4.15	6.43	0.77
	2023	6.62	7.30	1.13
Change	2019–2017	0.36	−0.15	0.00
	2023–2019	2.48	0.86	0.37
	2023–2017	2.83	0.71	0.37
Channel-full	2017	8.38	9.07	1.38
	2019	8.58	9.56	1.37
	2023	8.48	8.92	1.36
Change	2019–2017	0.20	0.49	−0.01
	2023–2019	−0.10	−0.64	−0.01
	2023–2017	0.10	−0.15	−0.02

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Detailed transect 3 (T11) continues to be entrenched, though large wood has helped create a higher (bar) surface along river left (Figure 9). For the bankfull characteristics to be calculated and made comparable to the previous surveys, the reach-scale average bankfull height from the 2017 survey was used (0.77 meters [2.5 ft], Table 12). Though there was a slight (5%) increase in bankfull width caused by bank erosion along river right, the addition of the large wood and sediment along river left caused a 16% reduction in bankfull cross-sectional area. Addition of the large wood also caused the

thalweg to migrate towards the middle of the channel and likely contributed to the thalweg cutting down through the incipient mid-channel bar(s) that was (were) present in 2019 (Figure 9). A slight (12%) increase in channel-full height coupled with the loss of bank along river right contributed to a slight (10%) increase in channel-full area (Table 17).

Table 17. Changes to cross-sectional characteristics on detailed transect 3 at KEMO001 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	4.66	7.66	0.77
	2019	4.90	7.88	0.77
	2023	4.14	8.26	0.77
Change	2019–2017	0.24	0.22	0.00
	2023–2019	−0.76	0.38	0.00
	2023–2017	−0.52	0.60	0.00
Channel-full	2017	10.15	9.30	1.43
	2019	10.30	10.00	1.41
	2023	11.32	9.93	1.58
Change	2019–2017	0.15	0.71	−0.02
	2023–2019	1.02	−0.07	0.18
	2023–2017	1.17	0.64	0.15

[A] Variables recalculated from original survey data to standardize interpretation of surface.

KEMO002—Ward Creek

Reach Description

KEMO002 is located on John Ward Creek approximately 300 m downstream of the pedestrian bridge and horse trail crossing on Kolb Farm Trail (see overview map in Appendix C). A small ephemeral drainage enters KEMO002 between T9 and T10 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. The reach surveyed was 70 meters (229.7 ft) long, with 7 meters (23 ft) between transects. KEMO002's channel is fairly entrenched, and a substantial amount of change has occurred within the entrenched channel since 2019 (Figure 11). The low terrace, initially observed in 2017 and present within the reach between T6 and T9 in 2019, could not be differentiated from the lower elevated entrenched surface in 2023. The significance of this "loss" of low terrace is explained in the "Implications of Results" section later in the report. Another substantial change to the reach was the presence of extensive bar surfaces on every transect. The following sections describe the differences in the 2017, 2019, and 2023 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 reported in Appendix C.

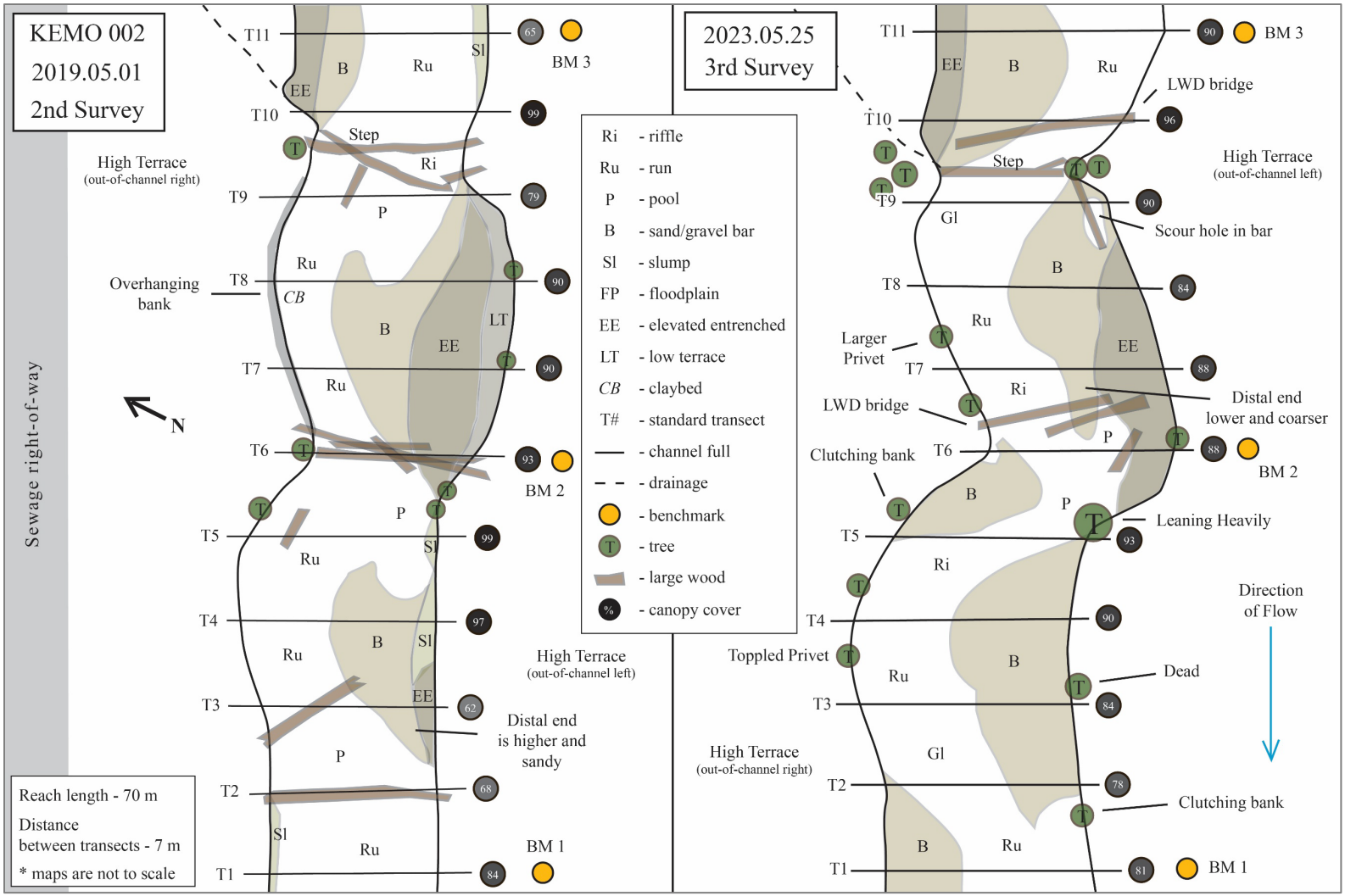


Figure 11. Reach-scale map of KEMO002 comparing the second (2019) and third surveys (2023). Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information presented in this report. The canopy cover circles are varying shades of 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 and width are due to artistic differences (unless noted in the text).

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Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) at KEMO002 continued the change that began between 2017 and 2019 (Table 5). Between 2019 and 2023, riffle habit increased slightly (+4%), run increased by 6%, glide increased from 0% to 8%, and pool habitat dropped 18% (-52% since 2017). The mean diameter of bed sediment was 22% finer in 2023 compared to 2019 (Table 6), though this difference in the means was not statistically significant (Table 18). Though the mean and larger size classes of sediment decreased, the smallest size classes (min and D5) increased from fines (< 0.06 mm) to very coarse sand (2.0 mm, Table 6).

Eighteen fewer pieces of LWD (n = 20) were observed within KEMO002's channel during the 2023 survey (Table 8). In addition to fewer pieces of LWD being observed, the mean volume of each piece was also slightly lower leading to a 57% decrease in LWD per channel area. Mean canopy cover was slightly higher and less variable in 2023 (Table 9).

The loss of pool habitats contributed to a relatively large (47%) reduction in mean thalweg depth and a 54% reduction in maximum thalweg depth since 2019 (Table 10). This change in mean thalweg depth was statistically significant (p-value = 0.002, Table 18). Mean thalweg position did not change appreciably since 2019. There was a slight increase in the variability (CV) of thalweg position since 2019, but variability was still 23% less than 2017 (Table 10).

Table 18. Differences between the 2017, 2019, and 2023 surveys of KEMO002 based on a post- hoc Tukey analysis (m=meters; mm=millimeters). The significance of the differences (Sig) is indicated by: "–" not significant; "*" p-value <0.05, "**" p-value <0.01, and "***" p-value <0.001.

Measurement	Difference 2023–2019	P-Value	Sig.	Difference 2019–2017	P-Value	Sig.	Difference 2023–2017	P-Value	Sig.
Mean Particle Diameter (mm)	−2.07	0.159	–	–3.11	0.017	*	–5.18	< 0.001	***
Wetted Width (m)	−1.47	0.037	*	0.76	0.385	–	–0.71	0.431	–
Active Channel Width (m)	1.61	0.019	*	0.14	0.964	–	1.75	0.010	*
Minimum Bank Width (m)	0.34	0.888	–	2.79	0.002	**	3.13	< 0.001	***
Channel-full Width (m)	0.42	0.906	–	3.79	0.002	**	4.22	< 0.001	***
Thalweg Depth (m)	−0.19	0.002	**	0.09	0.209	–	–0.11	0.099	–
Minimum Bank Height (m)	−0.10	0.717	–	0.42	0.004	**	0.33	0.034	*
Channel-full Height (m)	−0.13	0.169	–	0.34	< 0.001	***	0.21	0.010	*
Bank Angle (°)	1.36	0.980	–	–8.51	0.455	–	–7.15	0.572	–
Veg. Cover (%)	4.09	0.802	–	19.32	0.011	*	23.41	0.002	**
Bank Stability Index	0.02	0.998	–	–1.48	< 0.001	***	–1.45	< 0.001	***

Channel Morphology

Wetted widths were on average narrower in 2023 compared to the other two survey years (Table 11). The difference in mean wetted width between 2019 and 2023 (-29%) was statistically significant (Table 18). Active channel widths were wider in 2023 compared to the other two survey years (Table 11). The differences in mean active channel width between 2023 and 2017 (+32%) and 2019 (+29%) were statistically significant (Table 18). The same number of bankfull widths (n = 6) were measured in 2023 as 2019 (Table 11). Mean bankfull widths were wider in 2023 compared to 2017 (+53%) and 2019 (+5%). Differences in mean bankfull width were not statistically tested because of the relatively small number of bankfull widths available to measure and the inequal number of measurements across the three survey years. As mentioned previously, bankfull refers to lowest elevated entrenched (EE) surface present on a transect. See the "Reach-Scale Measurements" section for a detailed explanation of EE surfaces. Channel-full widths were on average slightly wider (+3%) in 2023 compared to 2019 (Table 11). The difference in mean channel-full width between 2019 and 2023 compared to 2017 were both statistically significant (Table 18).

Mean minimum bank height (lowest bank height on a transect) in 2023 was slightly lower (-5%) than 2019 (Table 12). This difference was not statistically significant (Table 18). The differences in mean minimum bank height between 2019 and 2023 compared to 2017 were both statistically significant. Bankfull heights in 2023 were slightly higher (+5%) than 2019 (Table 12). Like bankfull width, differences in bankfull heights were not statistically tested because of the relatively small number of bankfull heights measured. Mean channel-full height in 2023 was approximately equal to the 2019 mean (Table 12). Like minimum bank height, the differences in mean channel-full height between 2019 and 2023 compared to 2017 were both statistically significant (Table 18).

The same number of undercuts were measured in 2023 (n = 4) as 2019 (Table 13). Though more undercuts were measured in 2019 and 2023 than 2017, the mean horizontal depth of the undercuts in 2019 and 2023 were less than 2017. The minimum horizontal depth of undercut in 2017 was greater than both the 2019 and 2023 mean horizontal depths. The mean vertical height of the undercuts continued to be greater than 2017 (+37%) but were 14% lower than 2019. Additionally, the variability in the vertical height of the undercuts (CV) in 2023 was substantially smaller than both 2017 and 2019. Bank angles were similar across the survey years and the small differences were not statistically significant (Tables 13 and 18). Bank vegetation cover was on average greater in 2019 and 2023 compared to 2017 (Table 13). The differences between mean bank vegetation cover in 2019 and 2023 were statistically significantly different than 2017 (Table 18). Bank stability scores were lower (more stable) in both 2019 and 2023 compared to 2017 (Table 13). The differences in mean bank stability in 2019 and 2023 were statistically significantly different than 2017 (Table 18). Though bank stability scores were lower in 2019 and 2023 compared to 2017, average scores across all years 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 89% larger in 2023 compared to 2019 (146% larger than 2017, Table 14). As mentioned in the

"Channel Morphology" section, bankfull refers to the lowest elevated entrenched (EE) surface on a transect. See the "Reach-Scale Measurements" section for a detailed explanation of EE surfaces. On average, channel-full area was also larger (+18%) in 2023 compared to 2019 (87% larger than 2017). Water surface slope for this section of Ward Creek was slightly steeper in 2023 compared to 2019 (Figure 15, Table 14). The longitudinal profile highlights the relatively flat downstream and middle portions of the stream and the presence of the step (increase in slope) between T9 and T10. The reach is fairly straight but is slightly more sinuous than KEMO001 (1.10 vs. 1.03, Table 14).

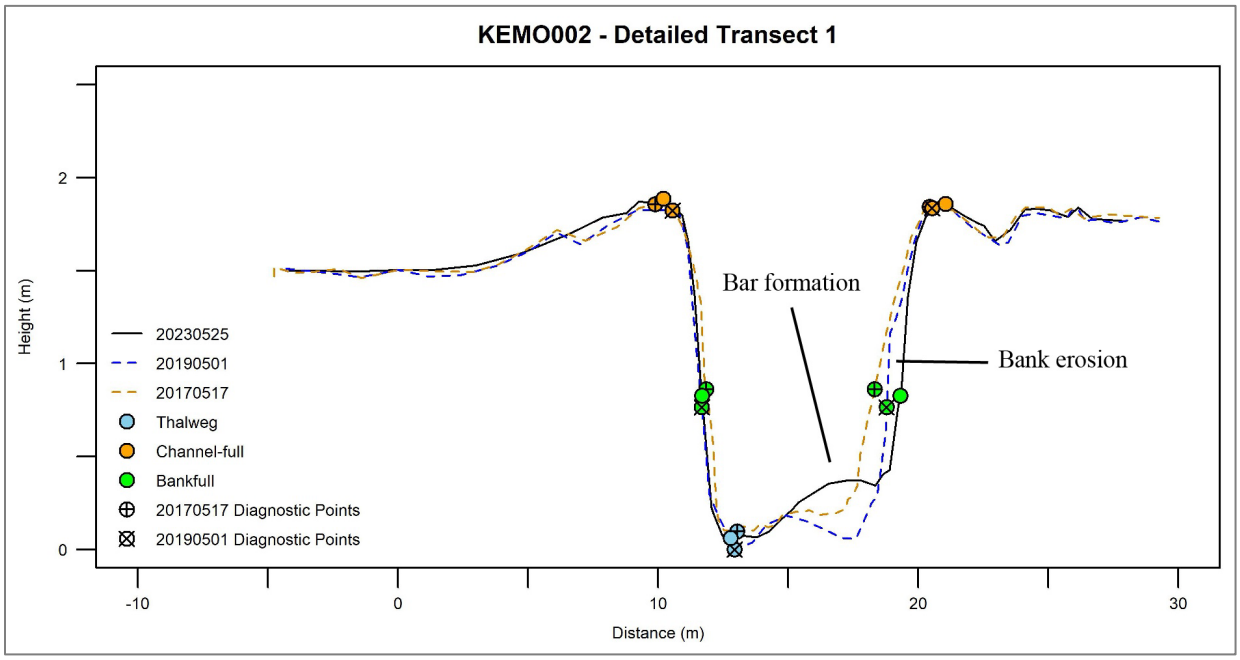


Figure 12. Differences between the 2017, 2019, and 2023 surveys of detailed transect 1 at KEMO002. View is in the downstream direction (river left is on the left).

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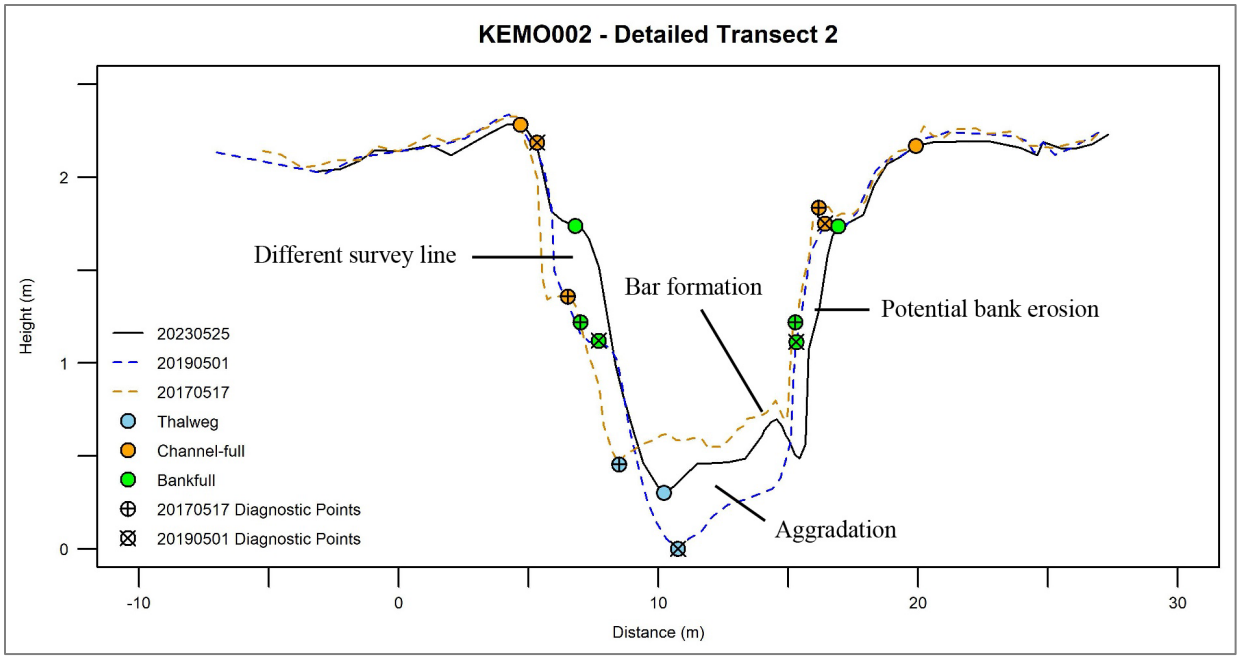


Figure 13. Differences between the 2017, 2019, and 2023 surveys of detailed transect 2 at KEMO002. View is in the downstream direction (river left is on the left).

NPS / SECN

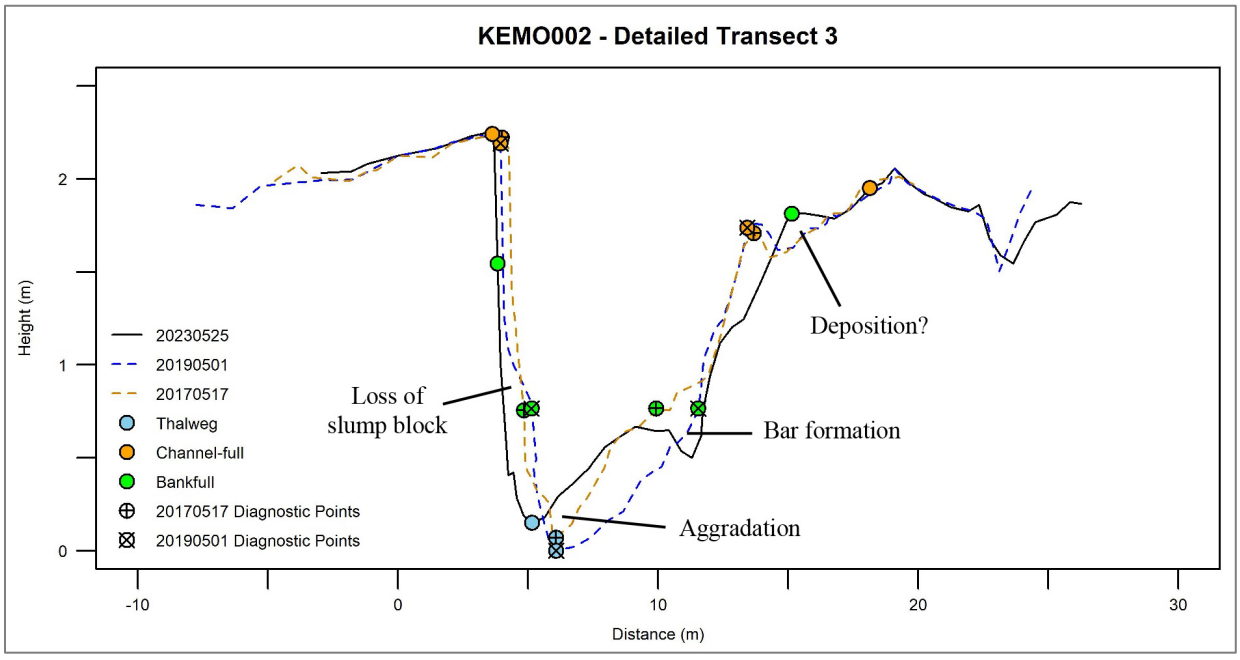


Figure 14. Differences between the 2017, 2019, and 2023 surveys of detailed transect 3 at KEMO002. View is in the downstream direction (river left is on the left).

NPS / SECN

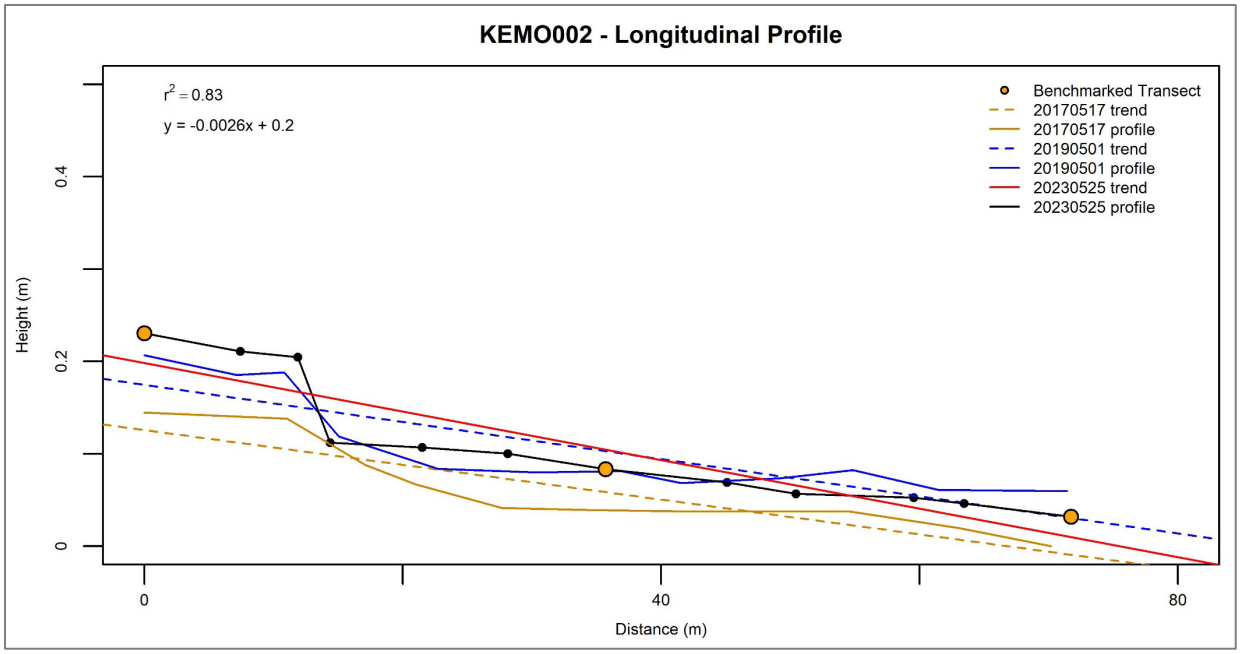


Figure 15. Longitudinal profile for KEMO002. The red line on the graph corresponds to the interpreted slope of the reach (0.0026 m/m). The r^2 value describes the strength of the trend line based on linear regression. The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

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Detailed transect 1 (T1) is entrenched and no elevated entrenched surfaces (bankfull) were present (Figure 12). 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 [2.5 ft], Table 12). Though there was a small (6%) increase in bankfull width from 2019 to 2023 due to loss of bank material along river right, there was a slight (2%) reduction in bankfull cross-sectional area (Table 19). This slight reduction in bankfull cross-sectional area was due to the formation of a bar along river right. The loss of in-channel area caused by the bar did not cause a reduction in channel-full area due to the slightly wider interpretation of channel-full bank tops (Table 19). In addition to the loss of bank on river right and bar formation, there was slight aggradation of the thalweg (Figure 12).

Table 19. Changes to cross-sectional characteristics on detailed transect 1 at KEMO002 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	3.99	6.48	0.77
	2019	4.32	7.11	0.77
	2023	4.25	7.63	0.77
Change	2019–2017	0.33	0.63	0.00
	2023–2019	−0.08	0.52	0.00
	2023–2017	0.25	1.15	0.00

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Table 19 (continued). Changes to cross-sectional characteristics on detailed transect 1 at KEMO002 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Channel-full	2017	11.58	10.32	1.75
	2019	12.79	9.90	1.82
	2023	12.87	10.57	1.80
Change	2019–2017	1.21	−0.42	0.08
	2023–2019	0.08	0.67	−0.03
	2023–2017	1.29	0.25	0.05

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Detailed transect 2 (T6) changed substantially between the 2017 and 2019 surveys and additional changes were observed in 2023 (Figure 13). While the aggradation and bar formation observed in 2023 are interpreted as "real" changes, the addition of the elevated entrenched surface high up on river left is likely a result of a slightly different survey line in 2023 compared to the previous two surveys. Future survey lines will be standardized to the 2023 location. Additionally, starting in 2023, the surface that corresponds to the valley flat, rather than the top of the highest EE surface, was used to define channel-full. This difference in interpretation changed the location of channel-full on river left to the next higher surface, and the previous channel-full surface became a bankfull surface. Though aggradation and bar formation reduced the area of the bankfull channel in the vicinity of the thalweg, this change in interpretation increased bankfull cross-sectional area by 72% and channel-full area by 31% (Table 20).

Table 20. Changes to cross-sectional characteristics on detailed transect 2 at KEMO002 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	4.59	8.27	0.77
	2019	5.68	7.53	1.11
	2023	9.77	10.11	1.44
Change	2019–2017	1.10	−0.74	0.35
	2023–2019	4.09	2.58	0.32
	2023–2017	5.18	1.84	0.67
Channel-full	2017	5.76	8.96	0.90
	2019	11.68	10.50	1.75
	2023	15.25	14.59	1.87
Change	2019–2017	5.92	1.54	0.85
	2023–2019	3.57	4.09	0.12
	2023–2017	9.49	5.63	0.96

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Detailed transect 3 (T11) is entrenched though one high elevated entrenched surface (on river right) was observed (Figure 14). Similar to detailed transect 2, some of the changes that were observed were related to slight positional differences in the surveyed cross-section (e.g., river right bankfull surface morphology), some were related to differences in interpretation (river right channel-full), and some were interpreted as "real" change. The changes that were interpreted as being "real" were the loss of bank (slump block) along river left, the slight aggradation of the bed, the bar formation along river right, and the increased definition of the drainage channel behind the river right benchmark. Also, similar to detailed transect 2, though some of the area near the thalweg of the channel was lost, the other changes caused bankfull cross-sectional area to increase by 192% (Table 21). Channel-full area also increased but the effects of the changes were more muted (+25%).

Table 21. Changes to cross-sectional characteristics on detailed transect 3 at KEMO002 [m=meters].

Type	Year	Area (m^2)	Width (m)	Depth (m)
Bankfull [A]	2017	1.75	5.03	0.68
	2019	3.15	6.41	0.77
	2023	9.21	10.43	1.39
Change	2019–2017	1.40	1.38	0.08
	2023–2019	6.06	4.02	0.63
	2023–2017	7.46	5.40	0.71
Channel-full	2017	9.23	9.34	1.64
	2019	11.24	9.42	1.74
	2023	14.07	14.40	1.80
Change	2019–2017	2.02	0.07	0.10
	2023–2019	2.82	4.99	0.06
	2023–2017	4.84	5.06	0.16

[A] Variables recalculated from original survey data to standardize interpretation of surface.

Differences Between Sites

The results of the t-tests comparing the bed sediment, thalweg, width, and bank characteristics at KEMO001 and KEMO002 during each survey year are presented in Table 22. In 2023, mean bed sediment size continued to be finer at KEMO002 compared to KEMO001. Unlike 2019, in 2023, thalweg depth was no longer statistically significantly different between the two reaches. Like 2017, in 2023, wetted width was statistically significantly different though unlike 2017, wetted width was wider at KEMO001. Unlike the other two surveys, in 2023, active channel width was statistically significantly wider at KEMO002. Like 2019, channel-full width and height, as well as minimum bank height, were statistically significantly different in 2023 (Table 22). The reason differences in channel-full width and height and minimum bank height were not statistically significant in 2017 was due to a misinterpretation of the bankfull and channel full surfaces corrected in 2019 (Bateman McDonald 2020). Vegetation cover was statistically significantly different in 2023 and 2017, and banks were more stable (Bank Stability Index) at KEMO001 in all three survey years (Table 22).

Table 22. Difference in means t-test results comparing the 2023, 2019, and 2017 surveys of KEMO001 and KEMO002. The significance (Sig) 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	Difference	P-Value	Sig.	Difference	P-Value	Sig.	Difference	P-Value	Sig.
Year	2023	2023	2023	2019	2019	2019	2017	2017	2017
Pebble Count (mm)	10.41	< 0.001	***	11.29	< 0.001	***	5.37	< 0.001	***
Thalweg Depth (m)	0.00	0.956	–	–0.15	0.012	*	–0.10	0.087	–
Wetted Width (m)	1.08	0.018	*	–0.54	0.445	–	–1.33	0.010	*
Active Channel Width (m)	−1.18	0.004	**	–0.46	0.455	–	0.21	0.689	–
Minimum Flood Width (m)	−1.12	0.116	–	–1.28	0.093	–	0.64	0.294	–
Channel-full Width (m)	−3.31	0.005	**	–2.75	0.007	**	–0.24	0.485	–
Minimum Flood Height (m)	−0.31	< 0.001	***	–0.50	< 0.001	***	–0.15	0.290	–
Channel-full Height (m)	−0.40	< 0.001	***	–0.54	< 0.001	***	–0.28	0.002	**
Bank Angle (°)	−2	0.663	–	–1	0.868	–	–16	0.034	*
Vegetative Cover (%)	17	0.026	*	7	0.328	–	22	0.003	**
Bank Stability Index	−1.1	0.003	**	–0.9	0.010	*	–0.9	0.032	*

Implications and Synthesis of Results

This section describes the processes observed at each reach and the potential changes that may occur between surveys (the next field surveys are scheduled for Spring or Summer 2026). The processes 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(er), average, high(er)) are in comparison to the other watershed in the report (i.e., KEMO001 compared to KEMO002 or vice versa).

KEMO001—Noses Creek

KEMO001's watershed is steep and covered by forested areas, as well as residential and suburban development. Land use/land cover has not changed appreciably from 2016 to 2021. KEMO001's watershed has a high entire stream gradient and a lower segment gradient (Table 2). The channel gradient lowered 33% since 2019 (Table 14). This reduction in channel gradient is likely related to the loss of the upstream large wood dam, infilling of the associated downstream pool, and subsequent erosion of the sediment deposited in the upper portion of the reach observed in 2019. Exposure (through downcutting) or creation of the bars (deposition) between T10 and T11, and the conversion of a run near T10 to a riffle between 2019 and 2023, support this interpretation of sediment movement related to the loss of the large wood dam. Though the high forest cover and relatively low drainage density likely attenuate flood flows, the high relief (due to Kennesaw Mountain) and relatively high entire stream gradient suggest Noses Creek has a flashy flow regime which questions the stability of sediment deposited (as bars) in the channel. Gage data are needed to confirm this interpretation of flashy flow, and more frequent bed sediment and bar stability surveys are needed to determine the long-term behavior of bars within the reach.

The reach surveyed on Noses Creek is close to a walking trail, and visitors were seen using the stream upstream near the bridge where the banks are lower. In-stream habitat in 2023 was slightly more heterogenous than 2019 (decreased run and increased pool), though still substantially more homogeneous than 2017 (Table 5). Like 2019, GCU changes are interpreted as being related to the after-effects of the large dam breach upstream, and the movement of sediment through the reach. Differences in mean bed sediment at KEMO001 between survey years were not statistically significant and KEMO001 continued to have coarser bed sediment than KEMO002 (Tables 6 and 22). It is unclear how the rainfall prior to the survey influenced the reach but the types and distribution of GCU may have been affected. The changes in GCU and inferred movement of sediment through the reach indicate a suboptimal environment for benthic dwelling invertebrates (Allan and Castillo 2007). While no notes were taken related to macroinvertebrates, two fish mounds were observed within the reach (on river left between T4 and T5 and on river left on T11, Figure 6).

KEMO001 continues to have a low volume of LWD per channel area. While there was a 350% increase in volume per channel area since 2019, this volume was only approximately a third of what was observed at KEMO002 (Table 8). It was predicted in the 2019 report that failure of the large

wood dam might lead to an increase in the LWD observed within the reach but there is not enough data to determine the provenance of the additional pieces.

Based on the GCUs, bed sediment and bar movement, and LWD, KEMO001's in-stream habitat continues to be classified as "poor to fair." Though the GCUs within the reach remained mostly run habitat, additional pools were observed, and the reach appears to be on a trajectory back to what was observed in 2019. As identified in the previous reports, if the bed material fines and if the GCUs become more dominantly run, the habitat classification may degrade to "poor." Alternatively, addition of long-term, stable LWD may increase habitat diversity and provide habitat stability 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 to the longitudinal profile in the upper portions of the reach and the continued development of the elevated entrenched (slump surfaces) in the lower portion of the reach. The main cause of the changes to the longitudinal profile (lower of bed in the upper portions of the reach) is hypothesized to be related to the loss of the upstream large woody debris jam observed in 2019. Loss of this jam greatly increased the energy available to move sediment through the reach. The downcutting observed on detailed transect 3 is direct evidence of this increased energy (Figure 9). Additionally, the development of the bars in the middle portion of the reach (between T6 and T8) as well as the large mid channel bar between T1 and T3 may be the redeposition of the sediment eroded from the upper portions of the reach.

The elevated entrenched surfaces identified in the 2019 report have continued to develop though the trajectory each surface has taken is noticeably different (Figure 16). Four elevated entrenched surfaces have been observed within the reach, one on the meander bend at T1 (which has been substantially reduced in area since 2019), the ones depicted in Figure 16 (on river left between T1 and T5 and on river right between T3 and T6), and the one originally observed in 2017 on river left between T8 and T9 which had been reduced to a relatively small bar in 2023 (Figure 6).

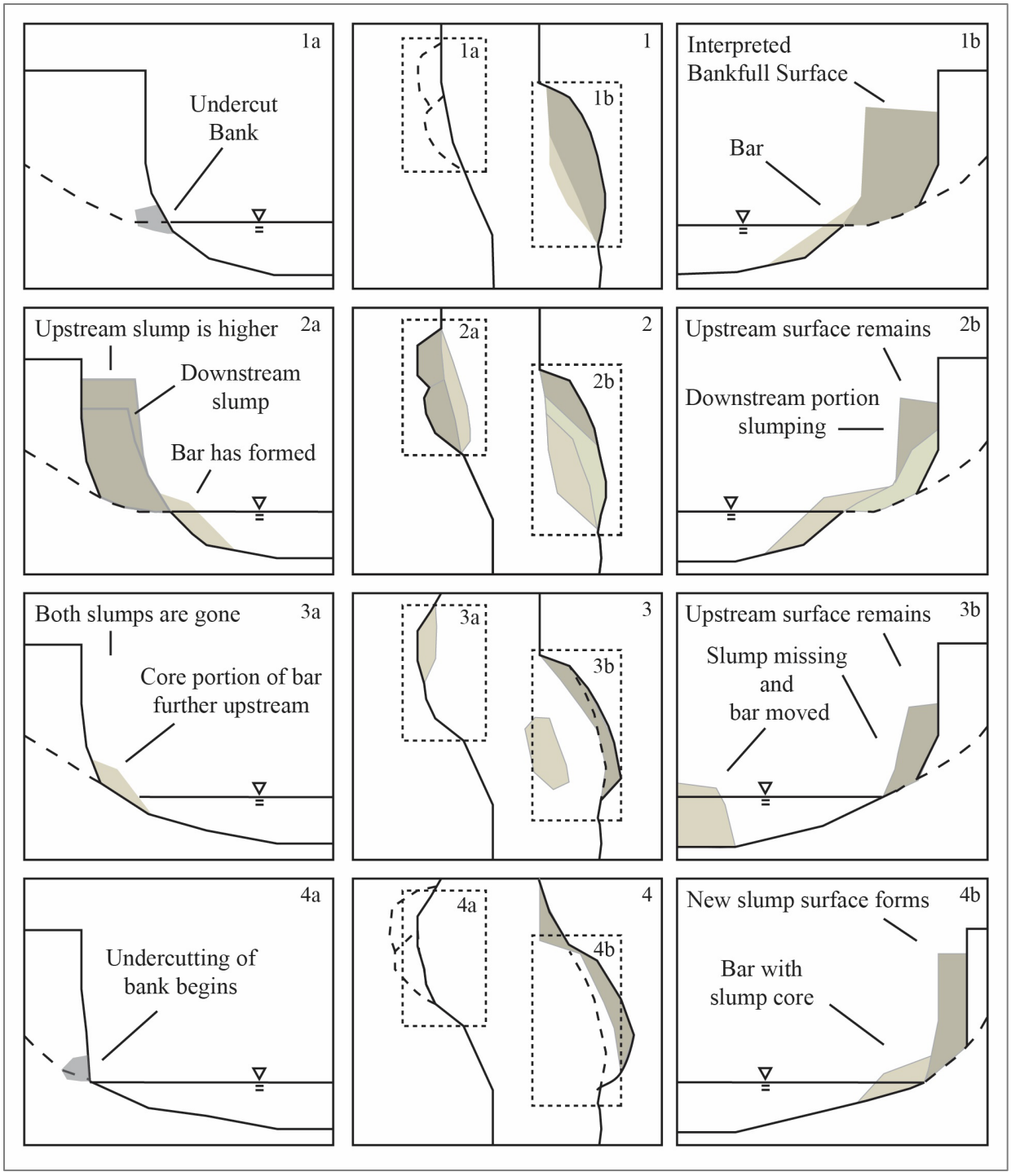


Figure 16. Observed (1–3) and hypothesized future (4) development of the bankfull EE surfaces observed at KEMO001 on river right between T4 and T6 (column a) and on river left between T1 and T4 (column b). The middle column is a look at the planform of the reach between T1 and T6. Row 1 is the 2017 survey, row 2 is the 2019 survey, row 3 is the 2023 survey, and row 4 is hypothesized conditions expected during the 2026 (next scheduled) survey.

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Since 2019, the elevated entrenched surfaces observed on river right between T3 and T6 have been completely lost with only a small (potentially slump-cored) bar left near T5 (Figure 6 and 16). It is hypothesized that the observed sequence of events of undercutting, slumping, and continued loss of bank will repeat, and undercutting and incipient slumping will be observed during the next scheduled survey (Spring or Summer 2026). The elevated entrenched surface observed on river left between T1 and T5 has also changed substantially since 2019. While a significant portion of the surface (mostly the area classified as slumping) was lost, this surface has also grown up- and downstream from where it was observed in 2019. Additionally, it appears the sediment that composed the slump in this portion of the stream may have been redeposited in the middle of the channel forming the bar (or the core of the bar) that was observed in this area in 2023 (Figure 16 [3b]). One of the hypothesized reasons for the difference in development and morphology of the elevated entrenched surfaces depicted in Figure 16 is the increased influence of groundwater on the river left elevated entrenched surface.

A fairly well-developed drainage channel runs through the river left out-of-channel area. This drainage channel enters the stream just downstream of T1 and can be seen in detailed transect 1's cross-section (Figure 6 and 7). Additionally, popout failures (small roughly cylindrical voids in the bank) are prevalent in the T1 river left bank, providing additional evidence of groundwater influencing the reach. It is hypothesized that groundwater allows the development of these rotational slump surfaces by increasing pore water pressure in the bank simultaneously destabilizing the bank (facilitating undercutting) and lubricating failure planes in the bank (leading to slumping). If this hypothesis is correct, in addition to the continued expansion and development of the elevated entrenched surface on river left between T1 and T5, a new elevated entrenched surface should develop on river left near the groundwater seep just upstream of T8 (Figure 6).

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. While sediment and LWD were observed to have been deposited on the trail on river right downstream from the reach, the morphological changes observed within the reach are not expected to affect visitor experience.

KEMO002—Ward Creek

KEMO002's watershed has low slope and relief and has low forest cover. Approximately 72% of Ward Creek's watershed is developed, and 26% is forested (Table 3). KEMO002's watershed has a low entire stream gradient, the lowest segment gradient (one-fifth of KEMO001), and a low channel gradient (Tables 2 and 14). 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. Gage data, however, are needed to confirm this interpretation.

The reach surveyed on Ward Creek (KEMO002) is within 20 meters (65.5 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 has continued its trajectory of change from mostly low energy pools with some runs separating the pools in 2017 (McDonald and Starkey 2019a) to mostly run habitat with some riffles and glides between (Table 5). Two new riffles have developed (between T4 and T5 and between T6 and T7) that may provide much needed semi-permanent structure to the bed that will help improve in-stream habitat. These riffles may be the result of the rainfall events that occurred prior to the 2023 survey (winnowing out the fines and leaving the relatively coarse gravels behind to form the riffles). If possible, future surveys will be done to minimize the impacts antecedent rainfall events might have on in-stream habitat.

The changes in mean bed sediment from 2019 to 2023 were not statistically significant though the smallest size classes increased from fine (<0.06 mm) to sand (2 mm, Tables 6 and 18). These changes indicate a potential increase in the availability of sand sized sediment, a reduction in the supply of fine sediment, or an increase in the energy available to move fine sediment through the system. Additional work is needed to determine how sediment moves through this system (including the caliber and amount of sediment being regularly moved).

KEMO002 again had the highest volume of LWD per channel area, though this volume was substantially less than what was measured in 2019 (Table 8). All the LWD measured in the downstream portion of the reach in 2019 had moved out of the reach, and the large jam between T6 and T7 was also greatly reduced in size (Figure 11). The LWD step between T9 and T10 was still present during the 2023 survey. Loss of this step could have a substantial effect on GCUs and bed sediment as the reach re-equilibrates to a new energy regime.

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) and the 2019 "change" report (Bateman McDonald 2020), habitat at KEMO002 will continue to be "poor" until stable (non-mobile) in-channel (non-bridging) LWD increases the diversity of habitat and upstream (and within reach) conditions reduce the amount of fine sediment that is stored in the bed of 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 increase in the number and size of in-channel bars and the continued development of the elevated entrenched surfaces. All the bars observed in 2019 were larger in 2023, and two additional bars on river right (between T1 and T2 and between T5 and T6) were also observed (Figure 11). The development of the bar between T5 and T6 is hypothesized to be related to the erosion of the elevated entrenched surfaces on river left between T5 and T9, while the bar on river right between T1 and T2 may be related to the slump surface in this area observed in 2019 (i.e., it may be a slump-cored bar). In addition to being potentially slump-cored, this bar is also downstream from a potential source of sediment, the now completely eroded elevated entrenched surface between T2 and T5 (Figure 11).

The elevated entrenched surfaces on KEMO002 are following trajectories of change similar to what was observed on KEMO001. The elevated entrenched surface between T10 and T11 is very similar (due to the presence of a drainage channel in the out-of-channel area) to the river left surface depicted in Figure 16. This upstream elevated entrenched surface on KEMO002 coupled with the multiple elevated entrenched surfaces either present or observed during one of the surveys on river left suggest groundwater is much more of an influence on the river left bank. A better understanding of groundwater flows within the out-of-channel area of both stream reaches is needed to predict where future elevated entrenched surfaces may develop. Another interesting finding was the inability to identify a “low terrace” between T6 and T9 on river left in 2023. This surface is hypothesized to have slumped down to the level of the lower EE surface observed in 2019. This “loss” of surface potentially shows how mutable these surfaces are and how quickly these higher surfaces can change. While a lot of sediment has moved through this reach and substantial changes were observed, visitor experience is not expected to be affected by the changes that will occur by the next scheduled survey (Spring or Summer 2026).

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 2023 in-stream habitat classification for each surveyed stream is the same as 2017 and 2019 ("poor to fair" on KEMO001 and "poor" on KEMO002). The processes that have a potential impact on these habitat classifications do not appear to have changed substantially since the previous survey.

If the bed material at KEMO001 becomes finer, and the GCUs within the reach become more homogenous, the habitat classification may degrade to "poor." Alternatively, addition of LWD may increase habitat diversity and provide stability that could upgrade the classification to "fair." Loss of the large upstream LWD dam on KEMO001 did not provide the influx of LWD predicted in the 2019 change report (Bateman McDonald 2020). The increase in energy following the loss of this dam is likely why again so few pieces of LWD were again found within the reach. Similar to what was reported in 2019, 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).

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. The stream reaches continue to be affected by episodic and progressive slumping of their banks. Based on the location of these elevated entrenched surfaces within each reach and the different trajectories of development hypothesized in this report, it appears groundwater has a large impact on where and the rate at which these features develop. It is hypothesized that groundwater is affecting the banks by increasing pore water pressure in the banks where it is discharging into the stream, simultaneously destabilizing the bank (facilitating undercutting) and lubricating failure planes in the bank (leading to slumping).

The growth, 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 continues to be stable and has not migrated further headward into the reach. The riffle immediately upstream of the knickpoint appears to provide enough resistance to prevent headward migration of the knickpoint. On KEMO002, the LWD step present since 2017 is a potential area of change that could have a large impact on this reach. Should this step fail, an influx of sediment from upstream may increase the size of the bars found within the reach, which would influence wetted and active channel widths and potentially the longitudinal profile depending on the amount of sediment moved into or out of the system. Similar to the previous reports, no immediate management concerns were identified along either reach. The primary 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 23 contains information about the variables collected using the SECN Wadeable Stream Habitat Monitoring Protocol.

Table 23. Definitions of the variables used in this report.

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 (Homer et al. 2020).
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 meter and are 1 meter or longer.

[A] Collected at each standard transect (11 measurements).

[B] Calculated at each detailed transect (three per reach) using survey data collected using a total station.

Table 23 (continued). Definitions of the variables used in this report.

Variable	Variable Scale	Description
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
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

[A] Collected at each standard transect (11 measurements).

[B] Calculated at each detailed transect (three per reach) using survey data collected using a total station.

Table 23 (continued). Definitions of the variables used in this report.

Variable	Variable Scale	Description
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 (three per reach) using survey data collected using a total station.

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Appendix B. Survey Results for KEMO001

This appendix presents a map of study area watershed (Figure 17), site transect photos (Figures 18–29), data tables (Tables 24–31), and charts of transect profiles (Figures 30–32) from the 2023 site survey at KEMO001.

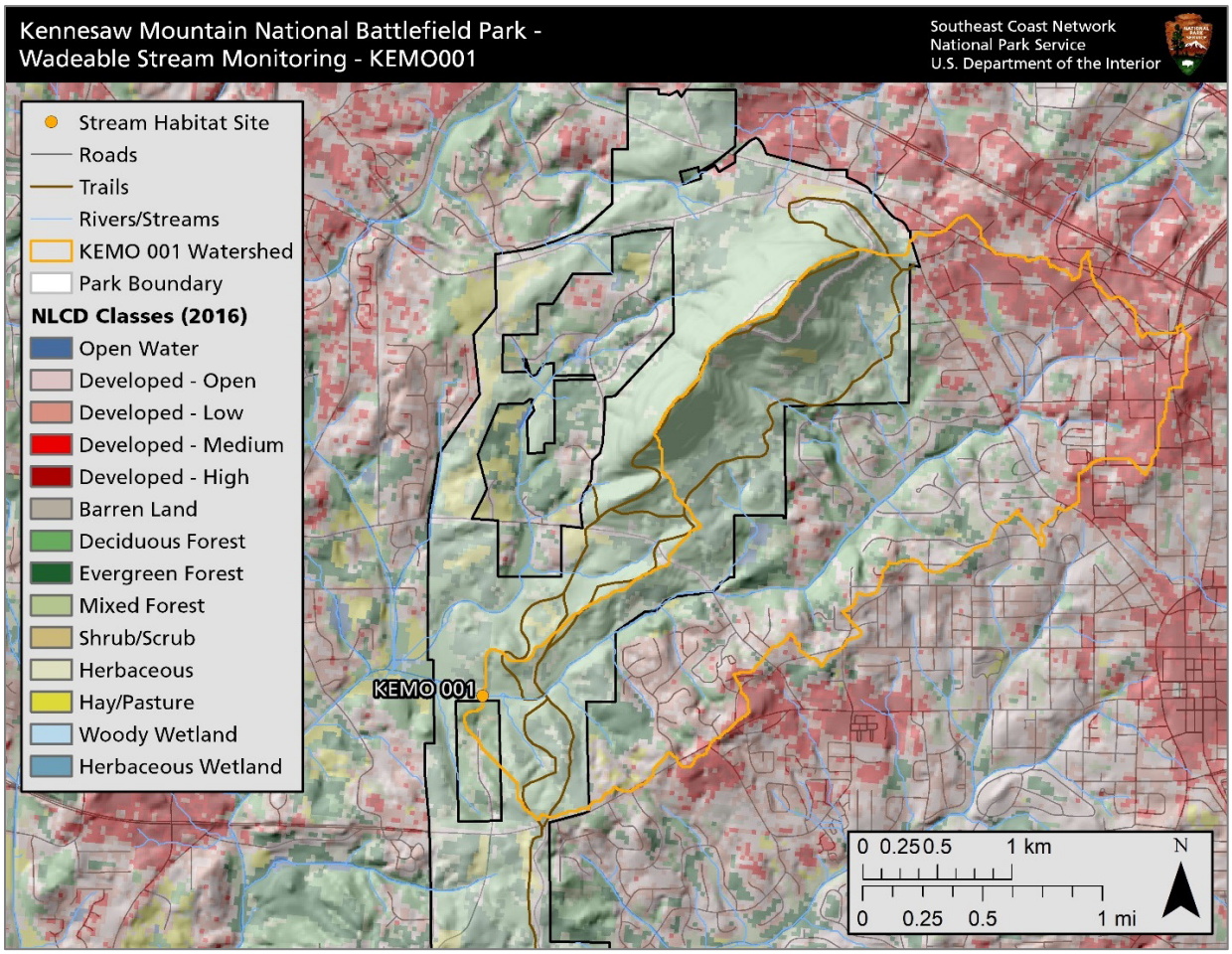


Figure 17. Map showing the watershed draining to KEMO001 at Kennesaw Mountain National Battlefield Park. The land use/land cover (NLCD 2016; Homer et al. 2020), road network (U.S. Census Bureau 2015), and perennial streams (derived from a 10 meter (32.8 ft) digital elevation model (DEM); data available from the U.S. Geological Survey) in the vicinity of the park are also shown.
NPS / SECN



Figure 18. KEMO001 looking upstream from T1 (detailed transect 1).
NPS / SECN



Figure 19. KEMO001 looking downstream on T1 (detailed transect 1).
NPS / SECN



Figure 20. KEMO001 looking at the left bank on T1 (detailed transect 1).
NPS / SECN



Figure 21. KEMO001 looking at the right bank on T1 (detailed transect 1).
NPS / SECN



Figure 22. KEMO001 looking upstream on T6 (detailed transect 2).
NPS / SECN



Figure 23. KEMO001 looking downstream on T6 (detailed transect 2).
NPS / SECN



Figure 24. KEMO001 looking at the left bank on T6 (detailed transect 2).
NPS / SECN



Figure 25. KEMO001 looking at the right bank on T6 (detailed transect 2).
NPS / SECN



Figure 26. KEMO001 looking upstream on T11 (detailed transect 3).
NPS / SECN



Figure 27. KEMO001 looking downstream on T11 (detailed transect 3).
NPS / SECN



Figure 28. KEMO001 looking at the left bank on T11 (detailed transect 3).
NPS / SECN



Figure 29. KEMO001 looking at the right bank on T11 (detailed transect 3).
NPS / SECN

Table 24. Land use/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 25. 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	70	30	0	0	0
2–3	5	60	0	35	0
3–4	0	50	0	50	0
4–5	0	95	0	5	0
5–6	0	100	0	0	0
6–7	50	45	0	5	0
7–8	10	80	0	10	0
8–9	30	40	0	30	0
9–10	75	20	0	5	0
10–11	5	70	0	25	0
Frequency	7	10	0	8	0
Max (%)	75	100	0	50	0
Mean (%)	25	59	0	17	0
SD (%)	30	27	0	17	0

Table 26. Characteristics of the large woody debris observed at KEMO001 [m=meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	4.92	0.14	0.08	10	Bank Protection, Sediment Trap	Buried
2	2.62	0.15	0.05	10	Bank Protection, Sediment Trap	Buried
3	4.86	0.19	0.14	10	Bank Protection, Sediment Trap	Buried
4	1.72	0.13	0.02	9	Jam	Jam
5	2.35	0.21	0.08	8	Sediment Trap	Buried
6	1.20	0.28	0.07	8	Jam, Sediment Trap	Buried
7	2.92	0.22	0.11	8	Jam, Organic Trap	Jam
8	2.47	0.12	0.03	8	Jam	Jam
9	1.26	0.30	0.09	4	None	Buried
10	1.89	0.20	0.06	2	None	Free

Table 27. Variability of canopy cover observed at KEMO001 [Min=minimum; Max=maximum; CV=coefficient of variation; SD=standard deviation].

Transect	Canopy Cover (%)
1	87
2	85
3	94
4	87
5	74
6	81
7	85
8	93
9	87
10	78
11	87
Min (%)	74
Mean (%)	85
Max (%)	94
SD (%)	6
CV	0.07

Table 28. Average reach-scale bank characteristics at KEMO001. “L” indicates left bank, “R” indicates right bank, “SD” is standard deviation, and “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 (R)	CV (L)	CV (R)
Bank Height (m) [A]	11	11	0.82	1.06	1.77	1.66	1.44	1.45	1.48	1.46	0.27	0.18	0.19	0.12
Bankfull Height (m) [A, B]	3	1	0.82	1.06	1.37	1.06	1.10	1.06	1.12	1.06	0.28	–	0.25	–
Channel-full Height (m) [A, B]	11	11	1.41	1.33	1.77	1.66	1.58	1.49	1.56	1.48	0.13	0.12	0.08	0.08
Water Depth at Base (m) [C]	11	11	−0.24	−0.26	−0.07	0.13	−0.13	−0.11	−0.13	−0.12	0.05	0.10	–	–
Bank Undercut (m) [B]	2	2	0.35	0.03	0.80	0.11	0.47	0.07	0.47	0.07	0.47	0.06	1.02	0.81
Undercut Height	2	2	0.40	0.35	0.43	0.46	0.42	0.41	0.42	0.41	0.02	0.08	0.05	0.19
Bank Angle (°)	11	11	29	23	67	69	47	46	48	47	12	14	0.26	0.30
Vegetation Cover (%)	11	11	5	35	90	90	50	68	50	75	28	20	0.56	0.29
Bank Stability [D]	11	11	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.12	1.16	0.09	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 29. 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	4.83	9.20	0.52	8.70	0.77	11.37
Channel-full	10.55	11.22	0.94	9.94	1.39	7.14
Ratio	2.19	1.22	1.79	1.14	1.82	0.63

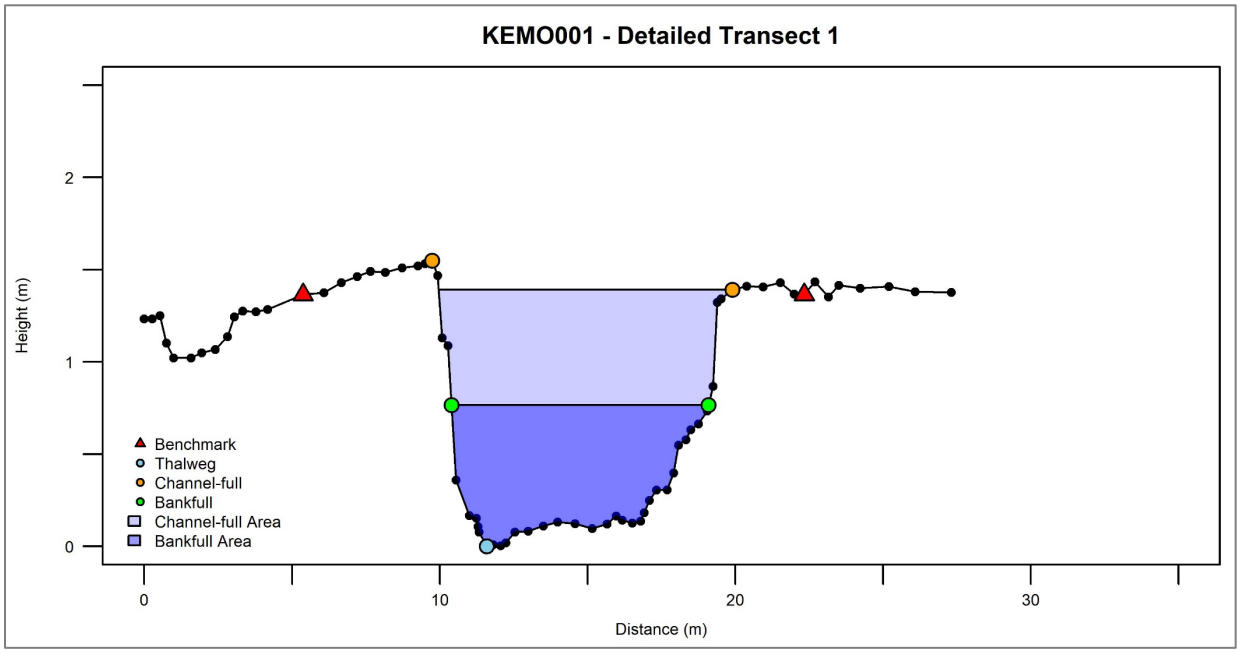


Figure 30. Detailed transect 1 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.
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Table 30. 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	6.62	8.31	0.80	7.30	1.13	6.46
Channel-full	8.48	10.04	0.84	8.92	1.36	6.57
Ratio	1.28	1.21	1.06	1.22	1.20	1.02

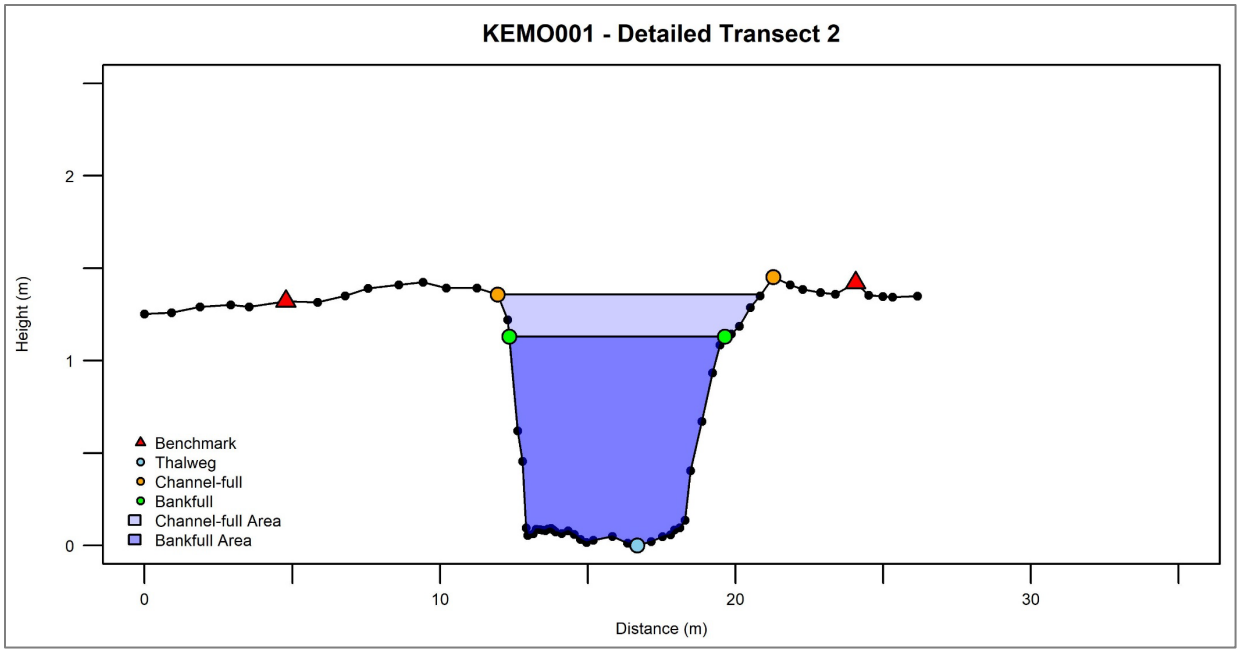


Figure 31. Detailed transect 2 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

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Table 31. 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	4.14	9.01	0.46	8.26	0.77	10.80
Channel-full	11.32	11.53	0.98	9.93	1.58	6.28
Ratio	2.73	1.28	2.13	1.20	2.07	0.58

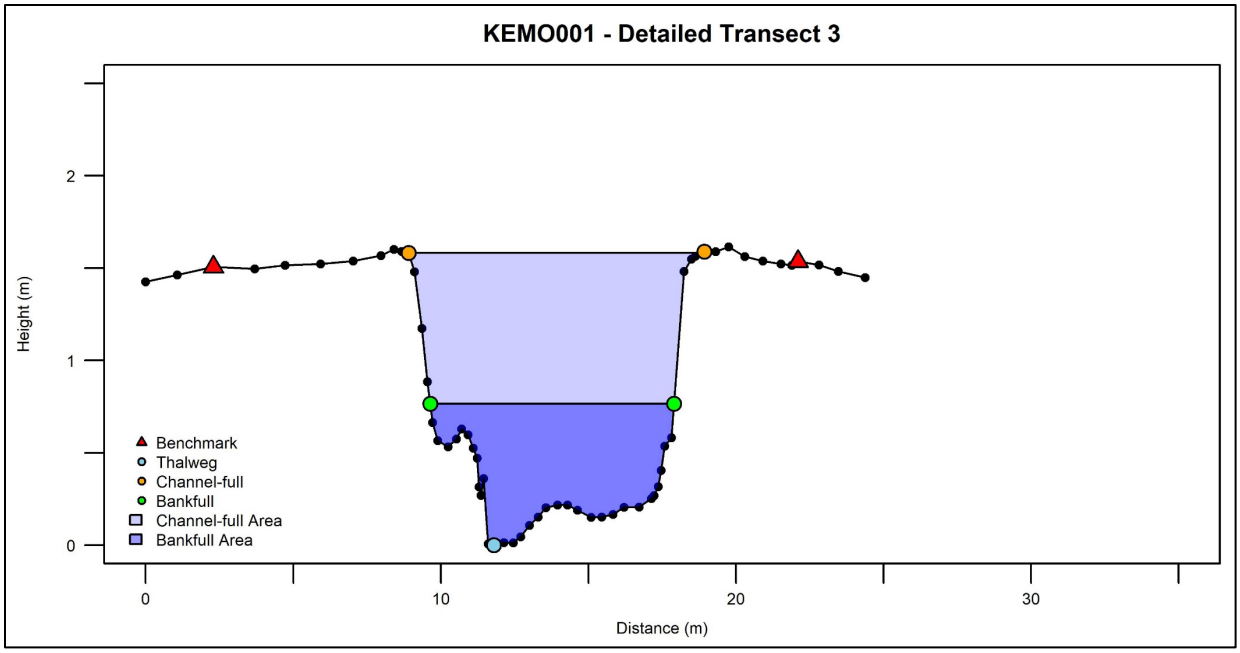


Figure 32. Detailed transect 3 at KEMO001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

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Appendix C. Survey Results for KEMO002

This appendix presents a map of study area watershed (Figure 33), site transect photos (Figures 34–45), data tables (Tables 32–39), and charts of transect profiles (Figures 46–48) from the 2023 site survey at KEMO002.

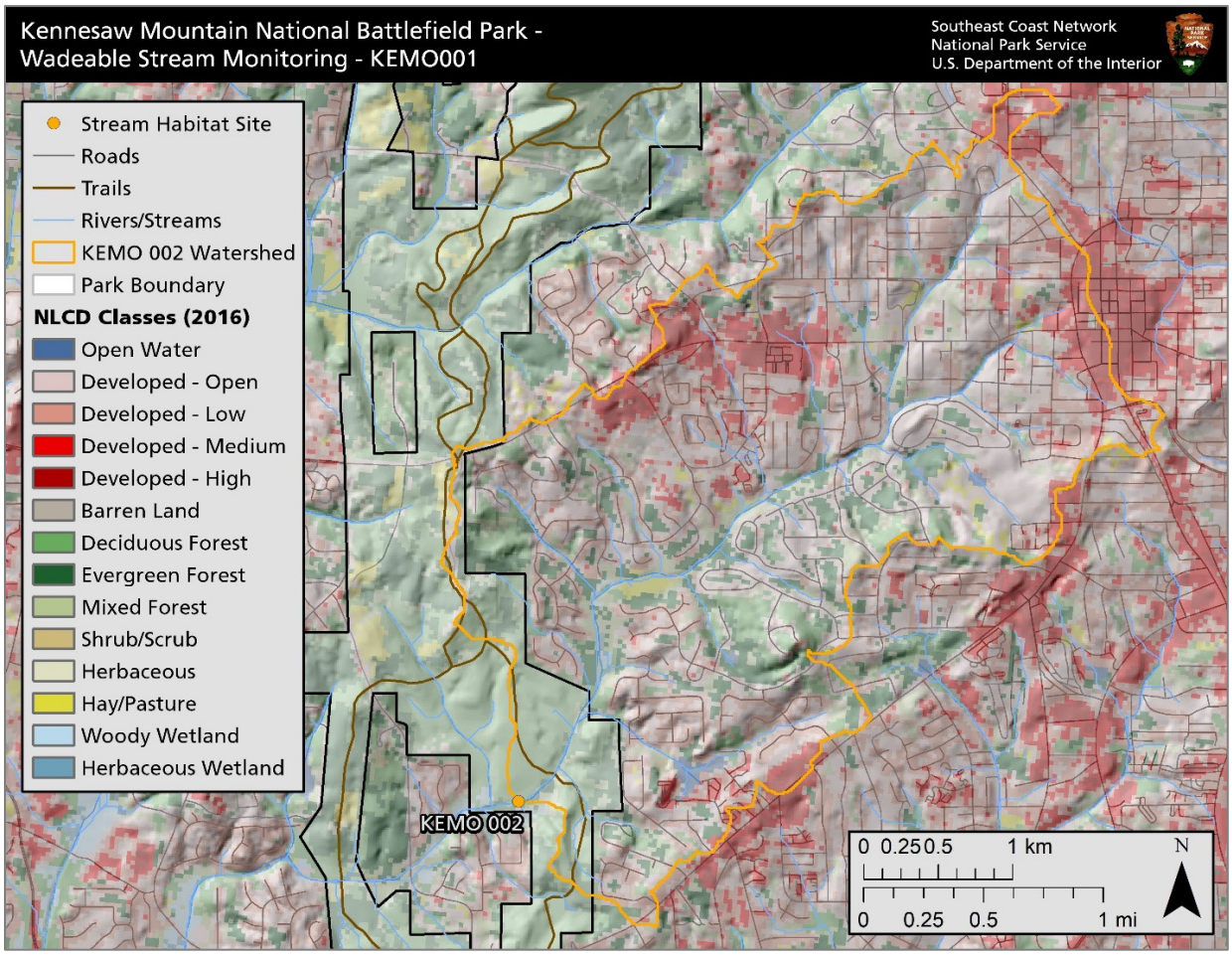


Figure 33. Map showing the watershed draining to KEMO002 at Kennesaw Mountain National Battlefield Park. The land use/land cover (NLCD 2016, Homer et al. 2020), road network (U.S. Census Bureau 2015), and perennial streams (derived from a 10 m digital elevation model (DEM); data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

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Figure 34. KEMO002, looking upstream on T1 (detailed transect 1).
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Figure 35. KEMO002, looking downstream on T1 (detailed transect 1).
NPS / SECN



Figure 36. KEMO002, looking at the left bank on T1 (detailed transect 1).
NPS / SECN



Figure 37. KEMO002, looking at the right bank on T1 (detailed transect 1).
NPS / SECN



Figure 38. KEMO002, looking upstream on T6 (detailed transect 2).
NPS / SECN



Figure 39. KEMO002, looking downstream on T6 (detailed transect 2).
NPS / SECN



Figure 40. KEMO002, looking at the left bank on T6 (detailed transect 2).
NPS / SECN



Figure 41. KEMO002, looking at the right bank on T6 (detailed transect 2).
NPS / SECN



Figure 42. KEMO002, looking upstream on T11 (detailed transect 3).
NPS / SECN



Figure 43. KEMO002, looking downstream on T11 (detailed transect 3).
NPS / SECN



Figure 44. KEMO002, looking at the left bank on T11 (detailed transect 3).
NPS / SECN



Figure 45. KEMO002, looking at the right bank on T11 (detailed transect 3).
NPS / SECN

Table 32. 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 33. Geomorphic channel units (GCU) observed in the area between transects at KEMO002. The data describe the percent coverage of each type of GCU [Min=minimum; Max=maximum; SD=standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	95	0	5	0
2–3	0	80	20	0	0
3–4	0	70	30	0	0
4–5	40	50	10	0	0
5–6	0	30	0	70	0
6–7	40	20	10	30	0
7–8	0	100	0	0	0
8–9	0	90	10	0	0
9–10	0	60	0	10	30
10–11	0	90	0	10	0
Frequency	2	10	5	5	1

Table 33 (continued). Geomorphic channel units (GCU) observed in the area between transects at KEMO002. The data describe the percent coverage of each type of GCU [Min=minimum; Max=maximum; SD=standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
Max (%)	40	100	30	70	30
Mean (%)	8	69	8	13	3
SD (%)	17	28	10	22	9

Table 34. Characteristics of the large woody debris observed at KEMO002 [m=meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	1.02	0.11	0.01	10	Bank Protection	Buried
2	6.50	0.18	0.17	10	None	Bridge
3	6.61	0.16	0.13	10	None	Bridge
4	1.69	0.31	0.13	10	Bank Protection	Buried
5	1.26	0.13	0.02	9	Sediment Trap	Buried
6	1.22	0.12	0.01	9	Sediment Trap	Buried
7	1.20	0.14	0.02	9	Organic Trap	Jam
8	2.65	0.26	0.14	9	Sediment Trap, Pool Formation	Buried
9	4.56	0.16	0.09	9	Sediment Trap, Pool Formation	Buried
10	1.69	0.16	0.03	9	Jam	Buried
11	4.26	0.16	0.09	9	Sediment Trap, Pool Formation	Buried
12	1.62	0.13	0.02	9	None	Buried
13	1.43	0.26	0.08	8	Bank Protection	Buried
14	1.23	0.16	0.02	8	None	Buried
15	2.30	0.17	0.05	8	None	Buried
16	9.54	0.19	0.27	6	None	Bridge
17	13.68	0.26	0.73	6	Jam	Bridge
18	1.31	0.28	0.08	6	None	Buried
19	1.96	0.20	0.06	6	Bank Protection	Buried
20	3.73	0.26	0.20	3	Organic Trap	Buried

Table 35. Variability of canopy cover observed at KEMO002 [Min=minimum; Max=maximum; CV=coefficient of variation; SD=standard deviation].

Transect	Canopy Cover (%)
1	81
2	78
3	84
4	90
5	93
6	88
7	88
8	84
9	90
10	96
11	90
Min (%)	78
Mean (%)	87
Max (%)	96
SD (%)	5
CV	0.06

Table 36. Average reach-scale bank characteristics at KEMO002. “L” indicates left bank, “R” indicates right bank, “SD” is standard deviation, and “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 (R)	CV (L)	CV (R)
Bank Height (m) [A]	11	11	1.07	1.29	2.18	1.98	1.74	1.78	1.87	1.85	0.33	0.22	0.19	0.12
Bankfull Height (m) [A, B]	4	3	1.07	1.29	1.53	1.87	1.36	1.53	1.42	1.44	0.20	0.30	0.15	0.20
Channel-full Height (m) [A, B]	11	11	1.86	1.71	2.18	2.04	1.98	1.89	1.95	1.91	0.10	0.09	0.05	0.05
Water Depth at Base (m) [C]	11	11	−0.70	−0.49	−0.07	−0.12	−0.32	−0.26	−0.29	−0.20	0.21	0.14	–	–
Bank Undercut (m) [B]	1	3	0.21	0.17	0.21	0.65	0.21	0.34	0.21	0.19	–	0.27	–	0.81
Bank Angle (°)	11	11	14	24	66	86	46	52	42	47	17	21	0.37	0.40
Vegetation Cover (%)	11	11	5	5	80	80	39	45	30	50	26	24	0.67	0.53
Bank Stability [D]	11	11	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.40	0.95	0.11	0.08

[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 37. 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	4.25	8.19	0.52	7.63	0.77	9.97
Channel-full	12.87	12.10	1.06	10.57	1.80	5.89
Ratio	3.03	1.48	2.05	1.39	2.35	0.59

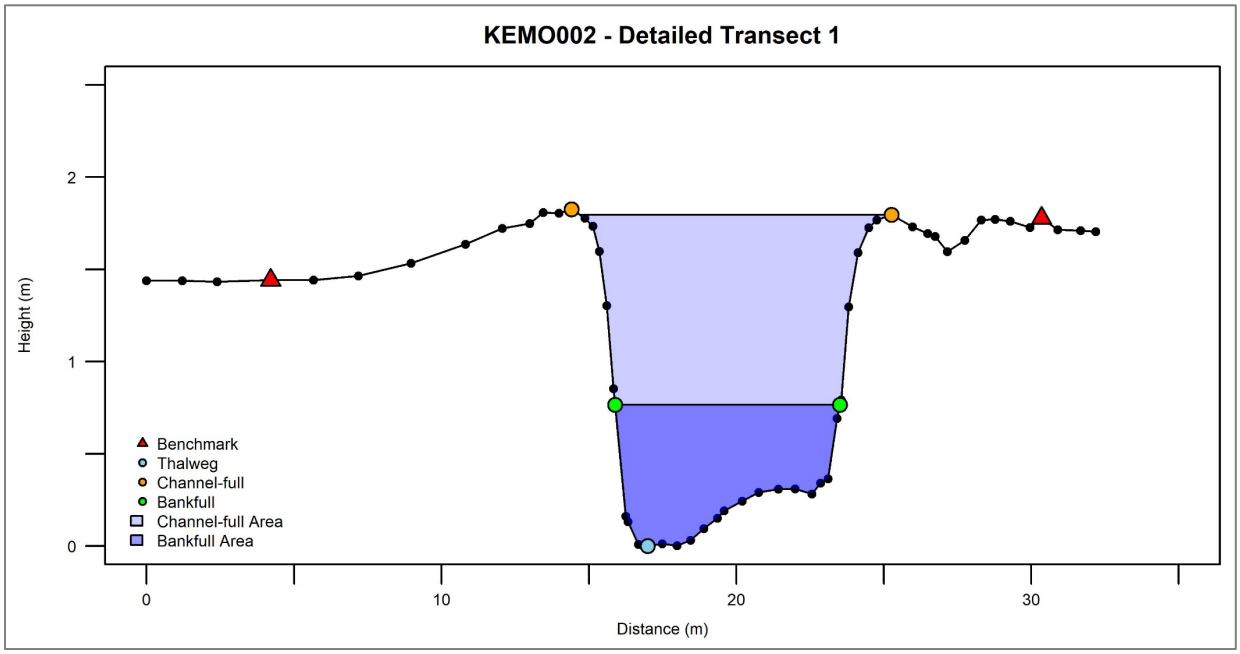


Figure 46. Detailed transect 1 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.
NPS / SECN

Table 38. 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	9.77	11.15	0.88	10.11	1.44	7.04
Channel-full	15.25	15.78	0.97	14.59	1.87	7.82
Ratio	1.56	1.42	1.10	1.44	1.30	1.11

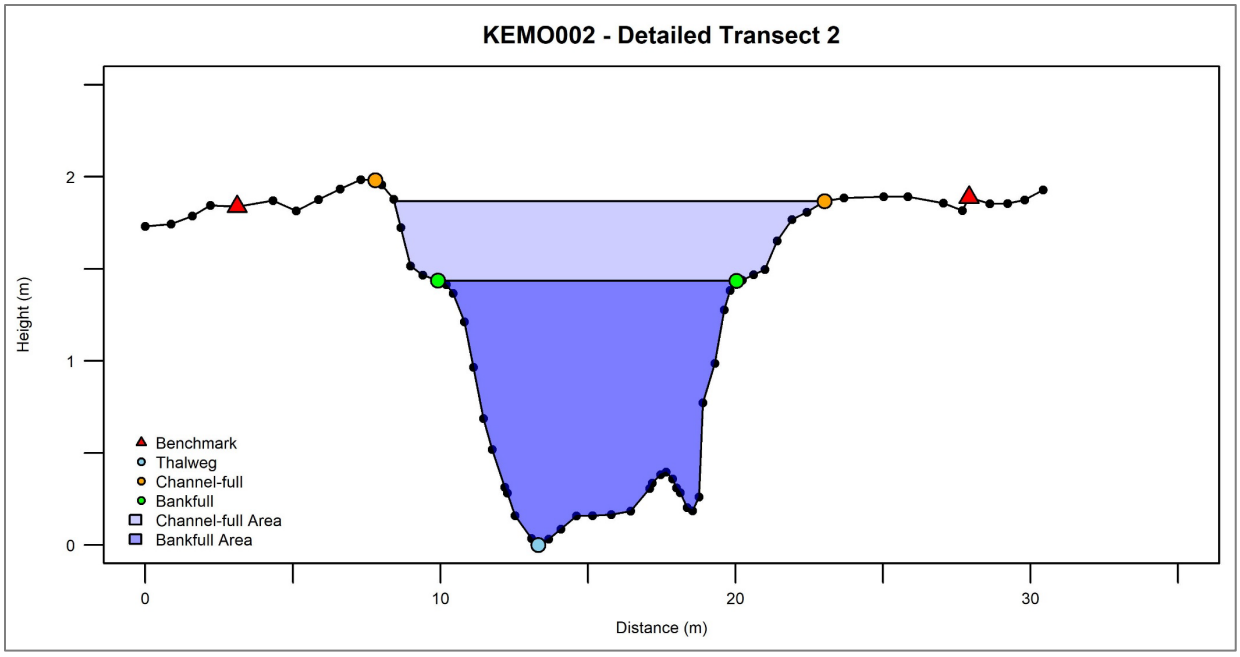


Figure 47. Detailed transect 2 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

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Table 39. 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	9.21	11.62	0.79	10.43	1.39	7.49
Channel-full	14.07	15.98	0.88	14.40	1.80	8.00
Ratio	1.53	1.37	1.11	1.38	1.29	1.07

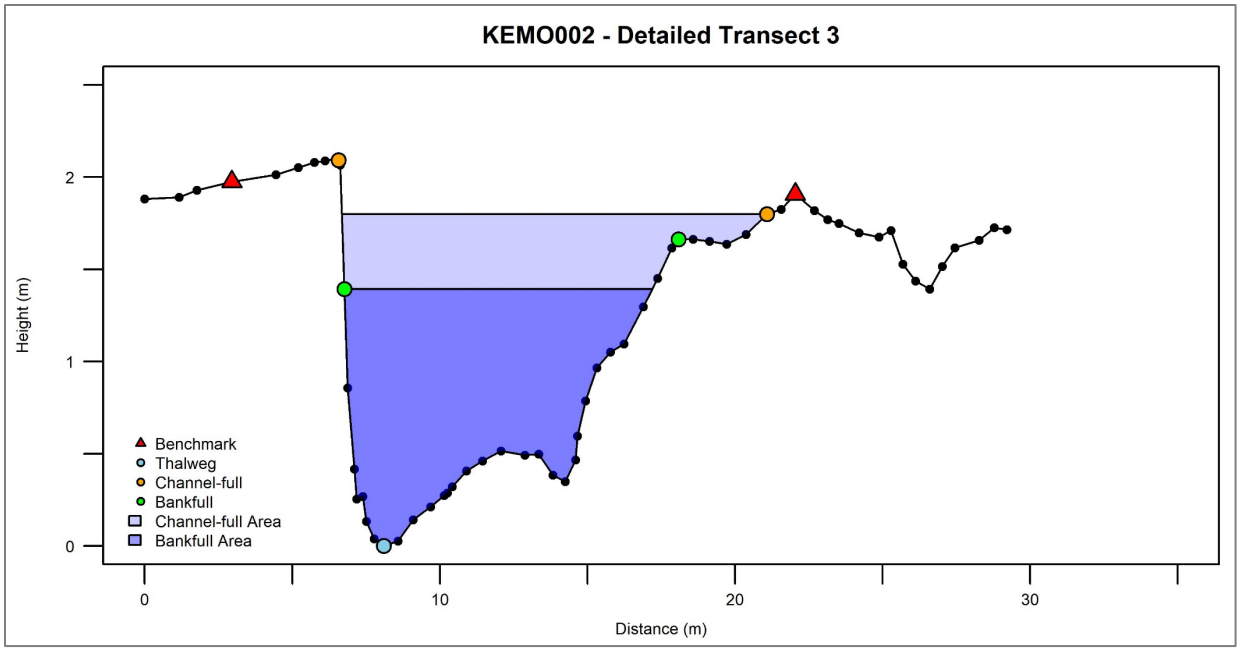


Figure 48. Detailed transect 3 at KEMO002. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

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