



Wadeable Stream Habitat Monitoring at Ocmulgee Mounds National Historical Park

2017 Baseline Report

Natural Resource Report NPS/SECN/NRR—2019/2053



ON THE COVER

Picture looking downstream on transect 7 at the wadeable stream monitoring site on Walnut Creek (OCMU001) at Ocmulgee Mounds National Historical Park on September 27, 2017. NPS photo / SECN

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Summary and Key Findings

The Southeast Coast Network (SECN) stream habitat monitoring protocol collects data to give park resource managers insight into the status of and trends in stream and near-channel habitat conditions (McDonald et al. 2018a). Wadeable stream assessments are currently implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park (HOBE), Kennesaw Mountain National Battlefield (KEMO), Ocmulgee Mounds National Historical Park (OCMU), Chattahoochee River National Recreation Area (CHAT), and Congaree National Park (CONG). 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 2019a).

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]); and
- Determine the status of and trends in cross-sectional morphology, longitudinal gradient, and sinuosity of selected wadeable stream reaches.

On September 27, 2017, data were collected at Ocmulgee Mounds National Historical Park (OCMU) to characterize the in- and near-channel habitat on a permanently monumented reach on Walnut Creek (OCMU001). These data, along with in-office analysis of remotely-sensed geographic information system (GIS) data, are presented in this report to describe and compare the watershed-, reach-, and transect-scale characteristics of OCMU001 to selected third-order streams at Chattahoochee River National Recreation Area (CHAT001 and CHAT013) and Kennesaw Mountain National Battlefield Park (KEMO001 and KEMO002).

Reach OCMU001's watershed (Walnut Creek) has low slope/relief and is covered mostly by forest and agricultural pasture. The major defining characteristics of the stream were the presence of floodplains, natural levees, lack of riffle habitat, and homogeneous channel slope throughout the reach. Though the majority of the watershed lies in the Appalachian Piedmont physiographic province, the OCMU001 reach of Walnut Creek lies in the Upper Coastal Plain and is a low energy, depositional environment which is subject to regular flooding and slow post-flood draining.

The channel surveyed at OCMU001 is smaller than expected, given the large size of its watershed. The small channel size is interpreted as evidence that the majority of flood waters that come through Ocmulgee Mounds NHP by way of Walnut Creek do not follow this flow path. Alternatively, flood waters are diverted away from the hillslope, into the wetlands to the west of OCMU001 and into a power line right-of-way east of OCMU001, through a series of flood chutes and side channels. It is suggested that discharge monitoring stations be installed at the railroad bridge that crosses Walnut Creek (upstream of OCMU001), just upstream of OCMU001, and immediately downstream of

OCMU001 to determine the proportion of flow that bypasses the channel at OCMU001 and to determine how much floodwater enters OCMU001 through flood chutes and side channels.

Though the reach had a high abundance of large woody debris (LWD), based on the results of the pebble count and the type/distribution of the geomorphic channel unit (GCU) within the reach, in-stream habitat within the surveyed stream was classified as “poor to fair.” These classifications are generalized interpretations of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Ocmulgee Mounds NHP. Given the complex hydrologic setting of OCMU001, it is difficult to predict this site’s response to changes in sediment supply and LWD, but marked departure from this habitat classification is not anticipated (Allan and Castillo 2007). The stream does not have immediate management concerns, although there is extensive exotic invasive vegetation in the area surrounding and outside of the channel.

Acronyms

ANOVA—Analysis of variance

B—Sand/gravel bar

Be—Bench

Bf—Bankfull

BM—Benchmark

BSi—Bank stability index

CHAT—Chattahoochee National Recreation Area

CONG—Congaree National Park

CV—Coefficient of variation

DEM—Digital elevation model

FP—Floodplain

FPM—Floodplain margin

GCU—Geomorphic channel unit

GIS—Geographic information system

Gl—Glide

HOBE—Horseshoe Bend National Military Park

KEMO—Kennesaw Mountain National Battlefield Park

LWD—Large woody debris

NED—National Elevation Dataset

NL—Natural levee

NLCD—National Land Cover Dataset

NPS—National Park Service

OCMU—Ocmulgee Mounds National Historical Park

P—Pool

Ru—Run

SECN—Southeast Coast Network

SOP—Standard operating procedure

T#—Standard transect

Introduction

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

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

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

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

For the purposes of this report, wadeable streams are narrowly defined as small- to medium-sized, perennially-flowing waterbodies, with easily identifiable channel banks, that can be accessed and traversed without the use of a watercraft. The wadeable streams referred to herein do not include non-perennial channel-like features typical of a highly disturbed and gullied landscape.

This report presents the results of the fall 2017, wadeable stream habitat survey conducted at Ocmulgee Mounds NHP. This report describes the basin characteristics (i.e., basin morphology and

land use/land cover) and the reach-scale physical characteristics of the surveyed stream reach on Walnut Creek (OCMU001). A regional context (Figure B-1 in Appendix B) is provided by comparing OCMU001 to four previously surveyed streams at Kennesaw Mountain NBP (KEMO001 and -002; McDonald and Starkey 2019b) and Chattahoochee River NRA (CHAT001 and -013; McDonald et al. 2019).

Study Area

The hydro-climatic conditions of the study area are characterized as humid subtropical with average annual rainfall around 46 inches (116.8 centimeters [cm]) per year; Wright et al. 2011). Snowfall is negligible and winters are mild; summers are hot and humid. Average monthly temperature ranges from a low in December of approximately 28°F (-2°C) to a high in July of 94°F (35°C; Wright et al. 2011). Monthly rainfall totals are distributed rather evenly from October through May due to the influence of frontal systems that sweep through the region (Lecce 2000). Convective thunderstorms influence the region from late spring through early fall. While monthly precipitation tends to be high in the summer, the high levels of evapotranspiration attenuate streamflow during this part of the year (Lins 1997).

The natural condition of rivers draining the southeastern U.S. 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 region (Trimble 1969). Sediment was transported to streams and floodplains, burying productive shoal and riffle habitats. Streams in the region were transformed, from the hard-bottomed, clear-flowing streams described by early land surveyors, into conduits of turbid water and sand. As row-crop agriculture became less dominant and forest cover increased, sediment delivery to streams was reduced and streambeds began to degrade (Schumm et al. 1984). Today, streambed elevations in many of the region's small streams have returned to historic or near historic levels though their geomorphic characteristics (width, depth, and level of entrenchment) are quite different from early settlement conditions (Schoonover et al 2007; Mukudan et al 2011).

In addition to the legacy effects of agriculture, many Appalachian Piedmont and upper Coastal Plain streams (including those draining to and through Ocmulgee Mounds NHP) have been further subjected to hydrologic alterations caused by urban/suburban development. Increases in impervious surface area associated with development creates conditions that increase the frequency and magnitude of peak discharges (Paul and Meyer 2001). Impervious surface area is also associated with lower-than-normal base flow during dry periods due to impaired groundwater recharge (Rose and Peters 2001). These flow alterations greatly influence available in- and near-stream habitats and can have a large negative 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 regimes it will pass through a series of semi-predictable stages of evolution (James 2018). These stages include aggradation (receiving more sediment than flow regime can transport),

degradation and narrowing (from a reduction in sediment and/or increased runoff), further degradation and widening, and finally stabilization and more natural reworking of in-channel alluvium (Figure 1). The exact stage that each stream is currently experiencing is dependent on the location of the stream within its network and the drainage basin's historical and contemporary land use/land cover conditions. 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).

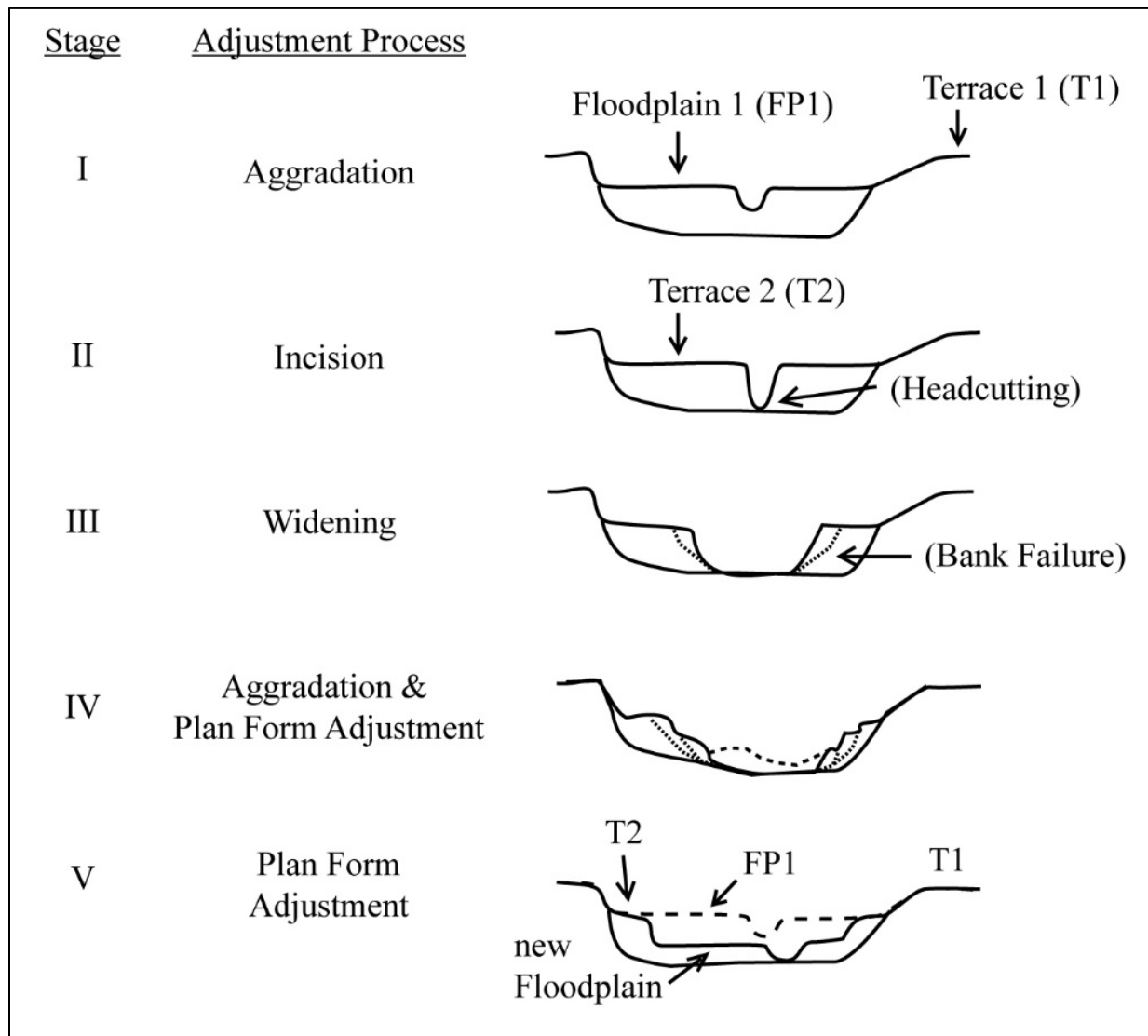


Figure 1. Generalized channel evolution model (modified from Schumm et al. 1984).

Ocmulgee Mounds National Historical Park

Ocmulgee Mounds National Historical Park is located along the Ocmulgee River in the transition zone that separates the Piedmont and Coastal Plain physiographic provinces in Macon, Georgia (Figure 2). The park preserves burial and temple mounds, constructed by American Indians on the uplands overlooking the Oconee River flood plain. The 702-acre (284-hectare [ha]) monument is mostly surrounded by urban and suburban development. Many of the streams draining the uplands portion of the park are heavily impacted by upstream runoff from impervious surfaces and have become entrenched (McDonald and Starkey 2019a).

Development in eastern Macon has altered sediment delivery and streamflow inside the monument's boundaries (Middle Georgia Regional Development Center 2003). Portions of the monument's North Plateau are rapidly eroding and this material is being deposited on the Middle and South Plateaus (KellerLynn 2013). Walnut Creek, the park's largest perennial stream, originates outside of the monument's boundaries and has several upstream areas of severe bank erosion and sedimentation (Middle Georgia Regional Development Center 2003). Within the boundaries of Ocmulgee Mounds NHP, Walnut Creek is an intermittently braided stream system that has a distinct perennial channel (e.g., reach at OCMU001) as well as large flood chutes and side channels that spread out across the Ocmulgee River's extensive flood plain (McDonald and Starkey 2019a).

Roughly 300 acres (121 ha) of the park are classified as emergent wetlands, and stream reconnaissance conducted in 2012 noted extensive beaver activity within the monument along Walnut Creek, which has significantly altered flowing stream habitats in this stream corridor (M.B. Gregory, SECN Program Manager, personal observation). The monitored reach (OCMU001) is located downstream of the area that was influenced by the beavers in 2012. Although the monument owns approximately 1 mile (1.6 kilometers [km]) of river frontage along the Ocmulgee River, the construction of Interstate 16 through the monument's flood plain severed its direct connection with the river.

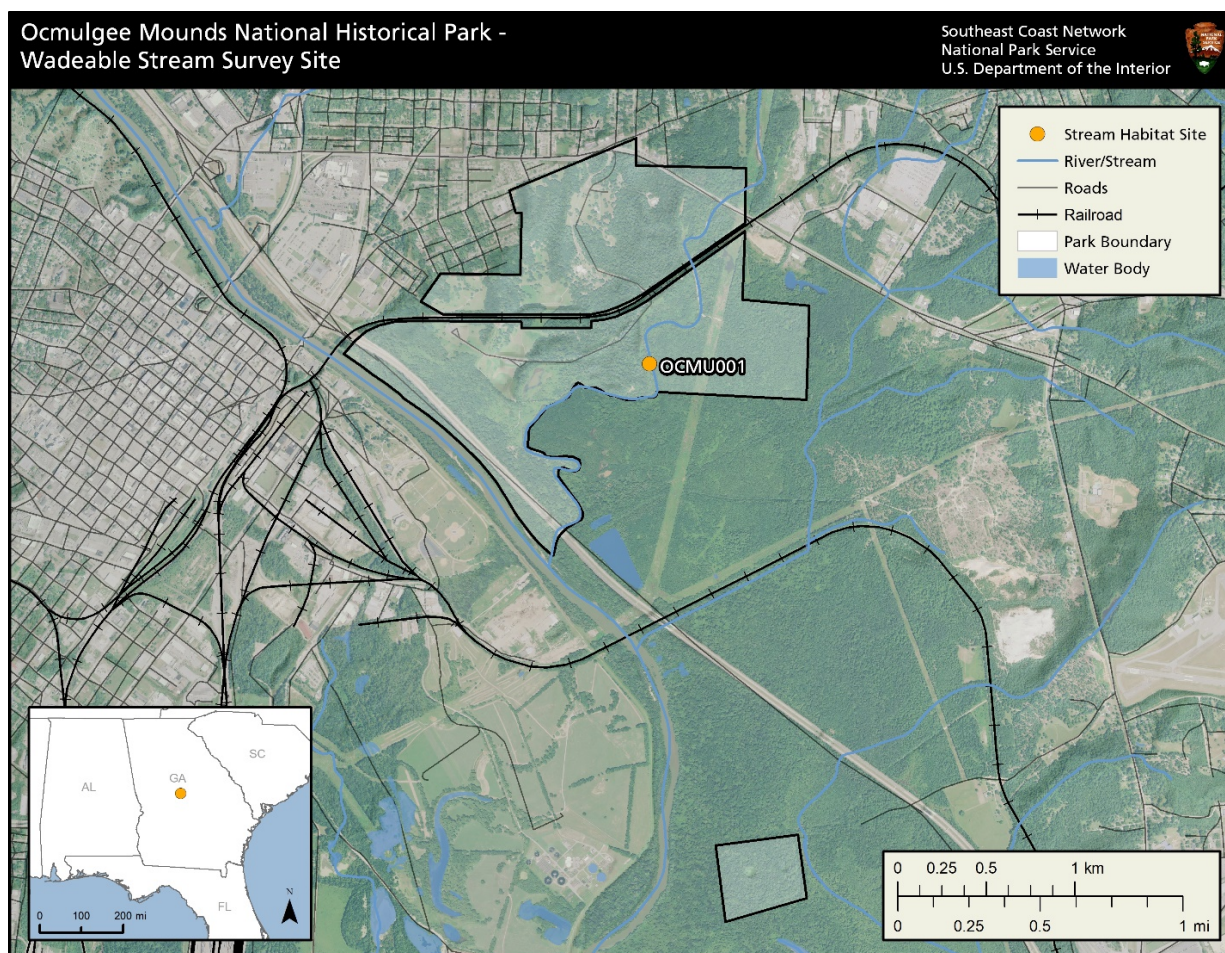


Figure 2. Map showing Ocmulgee Mounds National Historical Park and its wadeable stream site (OCMU001). Aerial imagery (National Agricultural Imagery Program, USDA 2017) and perennial streams (derived from a 10 meter (32.8 feet [ft]) digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

Methods

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

The data collected as part of the SECN wadeable stream monitoring protocol are divided into three scales of analysis: (1) basin-scale characteristics; (2) reach-scale measurements, along and between 11 standard transects per reach, and; (3) detailed cross-sectional measurements, at three of the 11 transects per reach (Figure 3). A table containing a list and definitions of all variables collected under the protocol can be found in Appendix A.

While summarized in this document, a list of standard operating procedures and an overview of the methods used to collect and process the survey data are available in McDonald et al. (2018a).

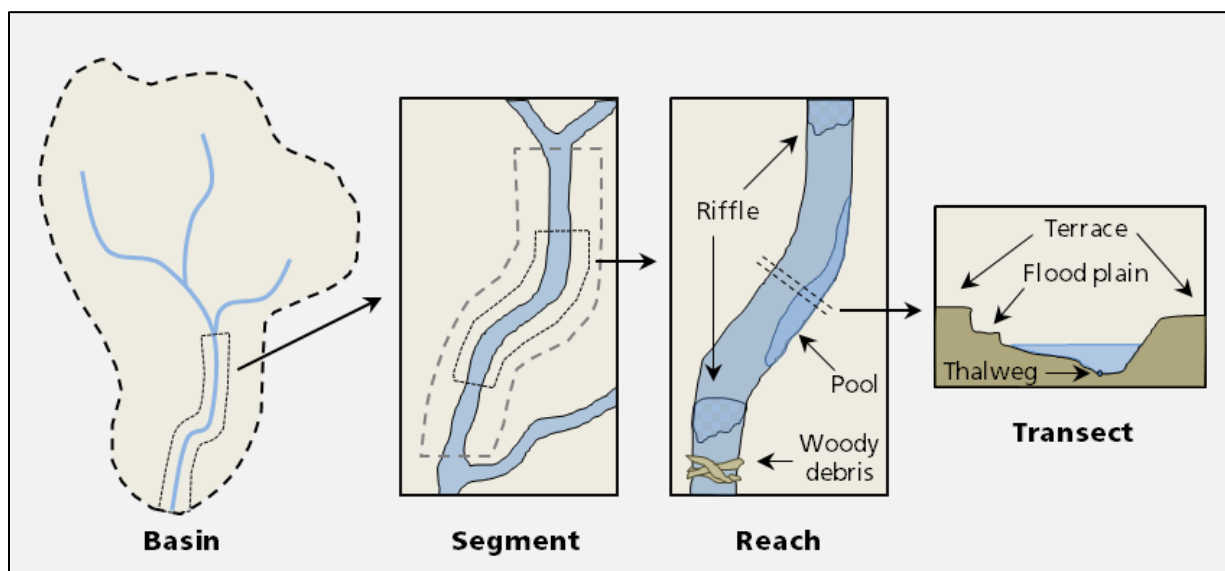


Figure 3. Spatial hierarchy of stream systems and scales of data collection (modified from Fitzpatrick et al. 1998).

Basin Characteristics

Understanding the physical characteristics of a drainage basin as well as the land use and land cover upstream of a reach is critical to understanding changes to and differences between streams. The parameters collected for this protocol describe how dissected the watershed is (drainage density; Knighton 1998), the magnitude and duration of floods (basin shape; Gregory and Walling 1973), the rainfall-runoff potential of a watershed (average watershed slope; Hewlett and Hibbert 1967),

potential sediment yield (basin relief ratio; Strahler 1957), and the amount of energy available to move sediment through a stream network (entire stream gradient; Craig and Rankl 1978; Fitzpatrick et al. 1998). A description of these basin characteristics can be found in McDonald et al. (2018a).

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

Reach-Scale Measurements

The reach-scale characteristics of each monitored reach are measured at and between 11 equidistant transects (distance between transects is two times average wetted width; Figure 4). Reach length is 20 times average wetted width (as determined during the initial survey of the reach). Data collected at each of these transects include: vegetative bank cover, presence of eroding banks, bed and bank material, channel widths (e.g., wetted, active, bankfull, and channel-full widths), water depth, and bank heights/angles. In addition to a qualitative description of bed sediment at each transect, a quantitative measure of bed sediment is obtained by conducting a Wolman pebble count on a representative riffle within the reach (Wolman 1954).

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

To understand in-stream and near-channel habitats, measurements are also taken between each transect. These between transect measurements include: canopy cover, the amount and type of in-stream habitat (e.g., high-energy riffles vs. low-energy pools), an inventory of large woody debris (LWD; defined as greater than 1 meter [3.3 ft] in length and greater than 10 centimeters [3.9 inches {in}] in diameter as defined in McDonald et al. 2018a), and a description of in-channel features (e.g., sand/cobble bars).

Using these measures of in-stream habitat, each stream’s habitat is classified as ‘poor,’ ‘poor-to-fair,’ ‘fair,’ ‘fair-to-good,’ or ‘good.’ These classifications are a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health on each reach. In addition to classifying each stream’s habitat, processes or events are identified that may affect these classifications; either leading to habitat improvement or degradation.

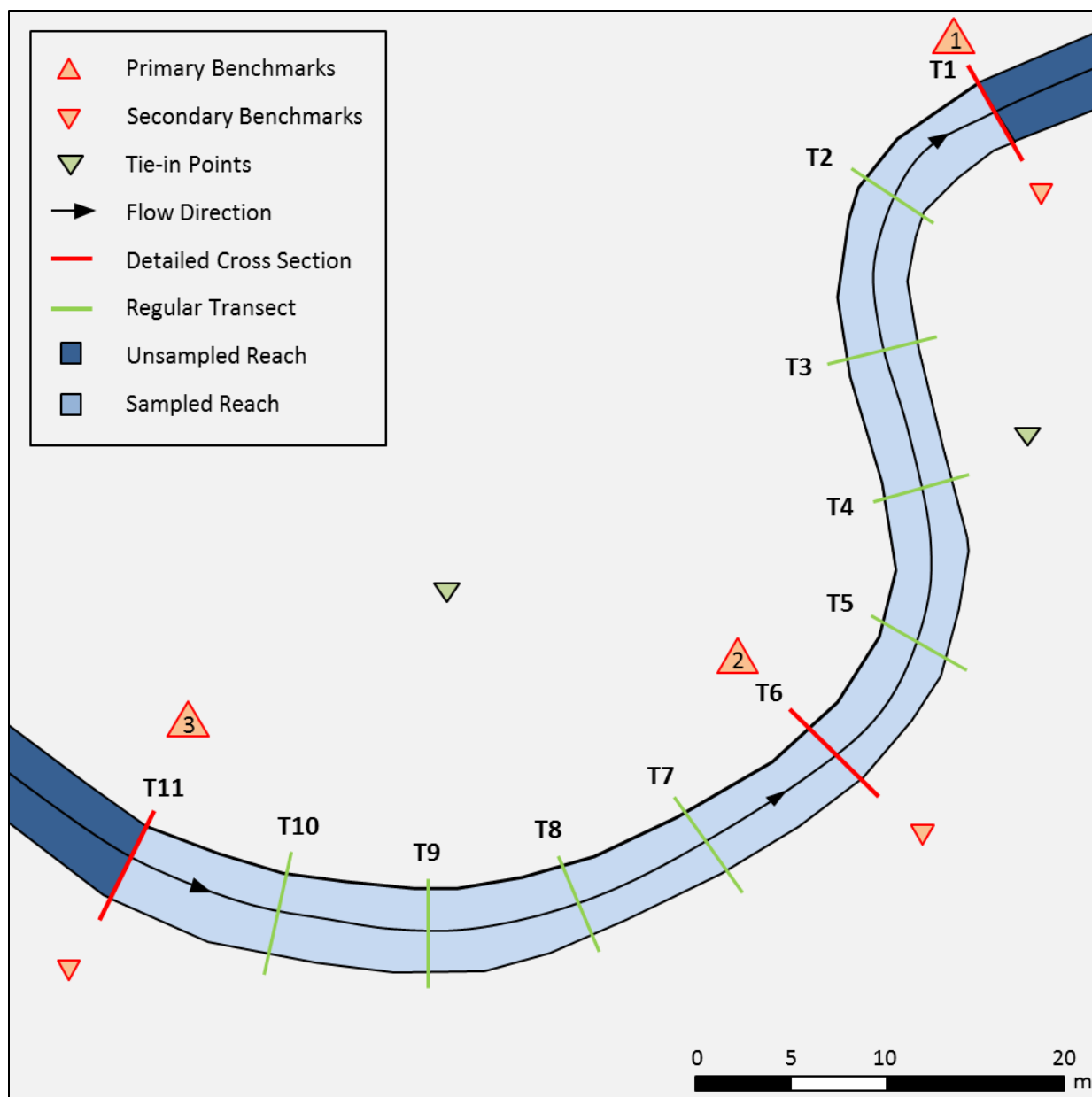


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.

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

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

Detailed Transect Cross-Sections

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

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

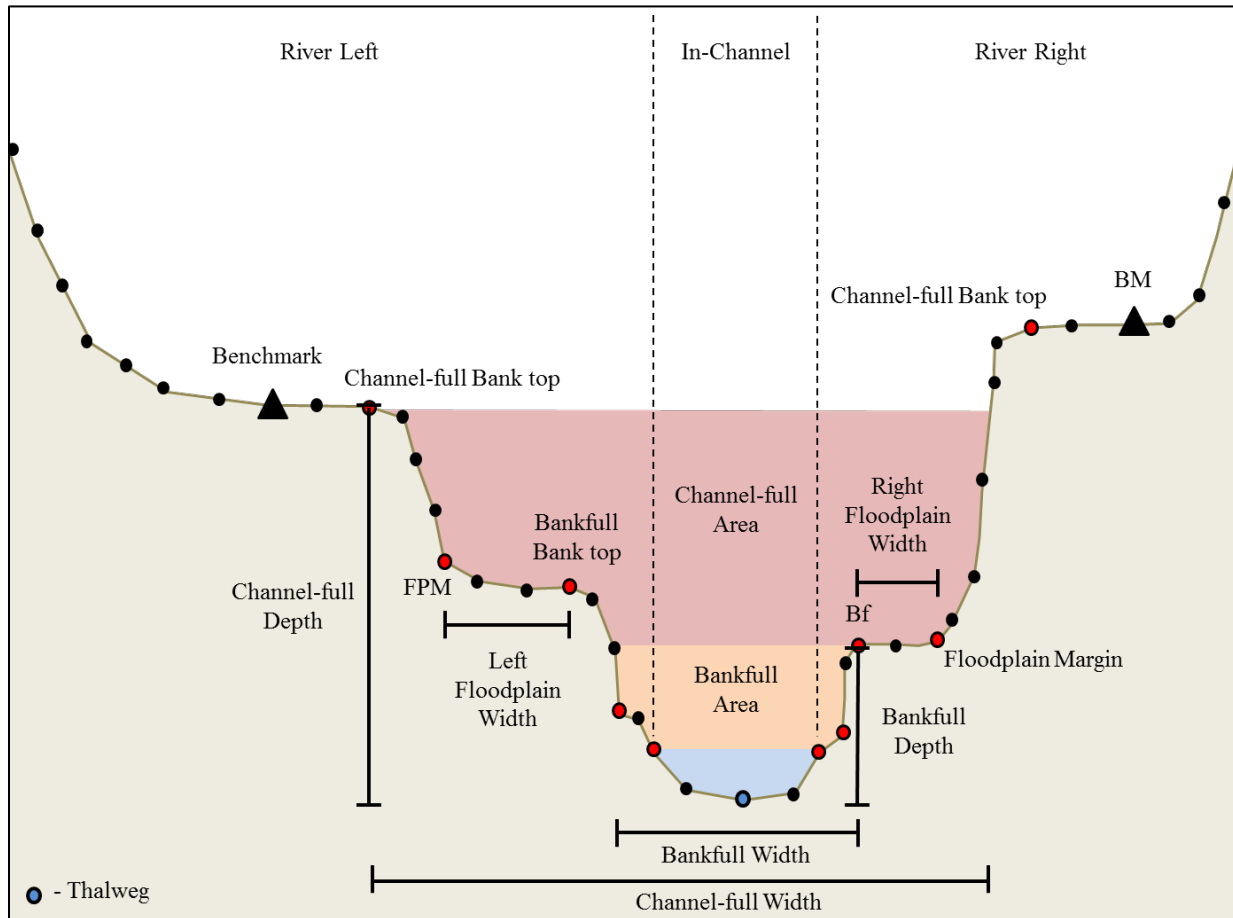


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes baseflow area (light blue) and bankfull area (orange). Channel-full area includes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

Statistical Analysis

The surveyed reach at Ocmulgee Mounds NHP is compared to the largest (third) order streams at Kennesaw Mountain NBP and Chattahoochee River NRA (Figure B-1 in Appendix B). A one-way analysis of variance (ANOVA) test was conducted to determine if there were statistically significant differences in the reach-scale measures of:

1. pebble count data (millimeters);
2. thalweg depth (meters);
3. thalweg position (% distance from left bank);
4. wetted width (meters);
5. active channel width (meters);
6. channel-full width (meters);
7. channel-full height (meters);
8. bank angle ($^{\circ}$); and
9. vegetative cover of the banks (%).

Bankfull width is not included in the statistical analysis because bankfull was not measured on each transect (due to lack of floodplain) and the number of bankfull measurements at each reach was not equal. If the ANOVA test showed a significant difference, a post hoc Tukey test was used to determine where the difference occurred (i.e. from which site(s) does Walnut Creek significantly differ?).

Results

On September 27, 2017, one stream reach (OCMU001, Walnut Creek) was surveyed following the methods outlined in SOP 1.2.16 *Wadeable Stream Reach-Scale Field Data Collection–Version 1.0* (McDonald et al. 2018c) and SOP 1.2.18 *Using a Total Station to Conduct a Stream Survey–Version 1.0* (McDonald et al. 2018d). The surveyed reach is on a fifth-order segment within the Walnut Creek stream network. Field surveys, in-office analyses, and statistical comparisons between the surveyed reach and similar monitored reaches are presented in the following sections. Transect-scale results and data summary tables for OCMU001 are provided in Appendix A. A regional context is provided by including survey results from four previously surveyed third-order streams at Kennesaw National Battlefield Park (KEMO001 and -002; McDonald et al. 2019a) and Chattahoochee National Recreation Area (CHAT001 and -013; McDonald et al. 2019b).

Reach Description

OCMU001—Walnut Creek

OCMU001 is located on Walnut Creek approximately 400 meters (1,312 ft) south of the railroad tunnel on the main park road. There is a social trail along the hilltop in the vicinity of OCMU001, though relatively recent tree falls have blocked most of this trail. OCMU001 has a very sandy bed throughout and its channel has a low degree of entrenchment. Floodplains have developed inset within the higher valley bottom surface (upstream of T3; Figure 6). The reach that was surveyed was 110 meters (361 ft) long with 11 meters (36.1 ft) between transects. The longitudinal profile is very consistent throughout the entire reach (Figure 7). Water surface slope for this section of Walnut Creek was similar to the KEMO reaches (0.0018 m/m, Table 2) but two to three times smaller than the channel slope on the CHAT reaches. The reach at OCMU001 is more sinuous (1.15) than the KEMO and CHAT reaches (1.02–1.14). The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3). Detailed transect 1 (T1) has a relatively high degree of entrenchment (i.e., no floodplain surfaces have developed; Figure 8). On detailed transect 2 (T6), a natural levee has developed separating the floodplain on river right from the main channel. A similar natural levee to floodplain sequence has also developed on detailed transect 3 (on river left; T11). Lower slump surfaces were also observed on detailed transects 2 and 3 (T6 and T11; Figure 8). In 2017, no riffles were identified within the reach; as a result, the pebble count was conducted just upstream of OCMU001 at the nearest riffle (approximately 10 meters upstream of transect 11).

Basin Characteristics

The OCMU001 watershed drains 239.35 square kilometers (92.41 square miles [sq mi]) and is much larger than the watersheds draining to the surveyed streams at Kennesaw Mountain NBP and Chattahoochee River NRA (8.30–16.88 square kilometers [3.20–6.52 sq mi]; Table 3). Most of Walnut Creek's watershed lies north of the park, in the Appalachian Piedmont physiographic province. The portion of OCMU001's watershed that is managed by NPS (0.3%) is more similar to larger Coastal Plain systems than the Appalachian Piedmont-type streams that drain the majority of the watershed. The land use/land cover for the watershed draining to OCMU001 is also quite different from the watersheds draining to the KEMO and CHAT streams. The OCMU001 reach has

far less development (12% versus 46–69%) and far more pasture/grassland (23% versus 0–4%; Table 4).

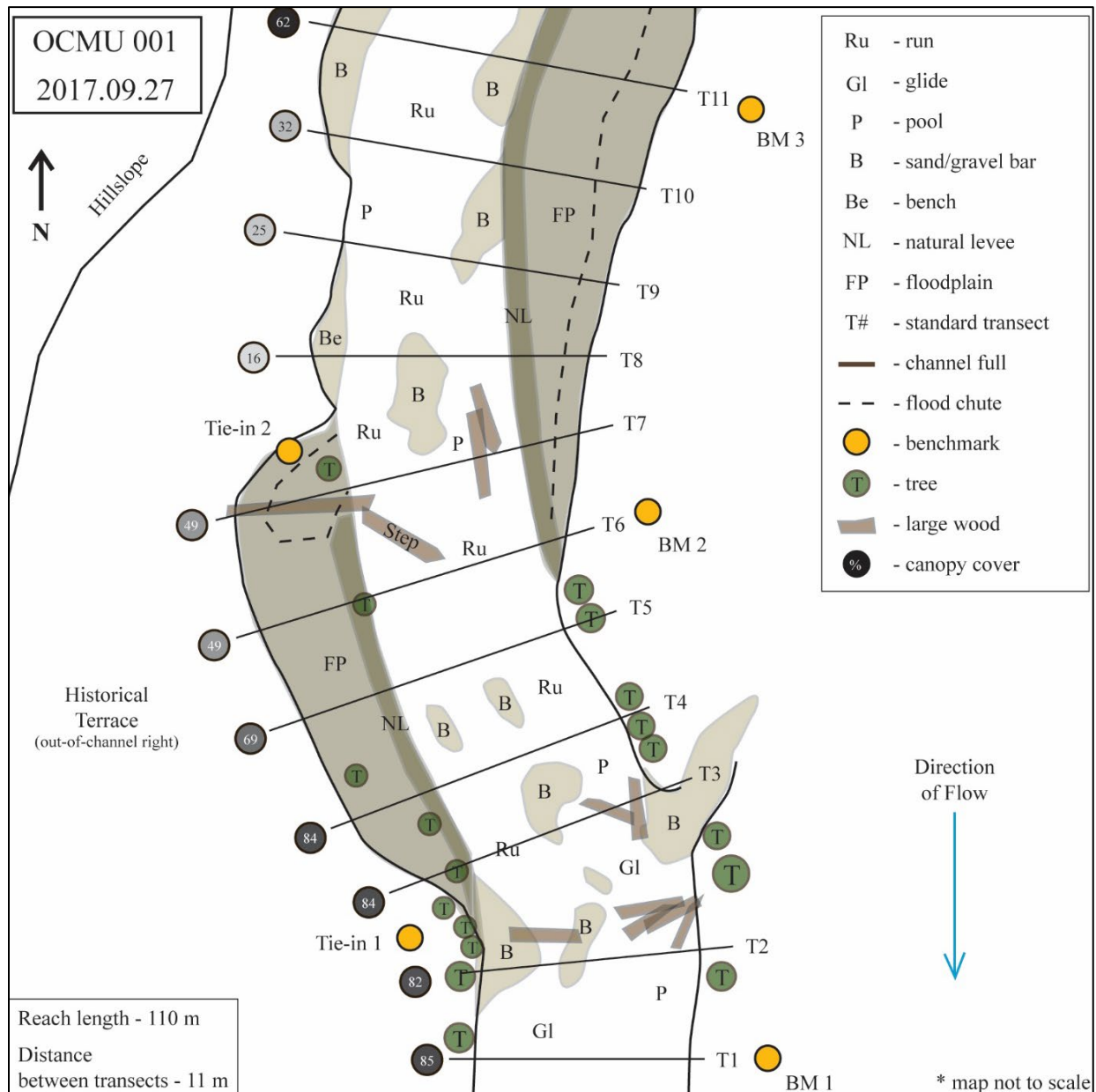


Figure 6. Reach-scale map of OCMU001. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled).

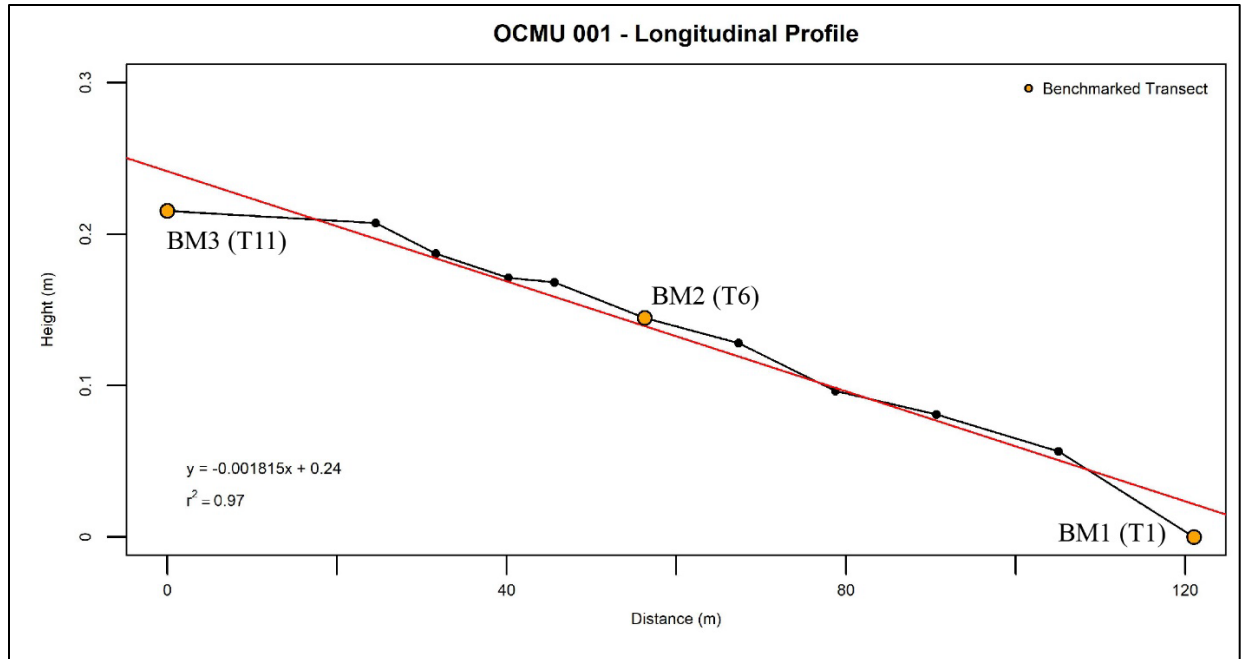


Figure 7. Longitudinal profile for OCMU001. The red line on the graph corresponds to the interpreted slope of the reach. The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

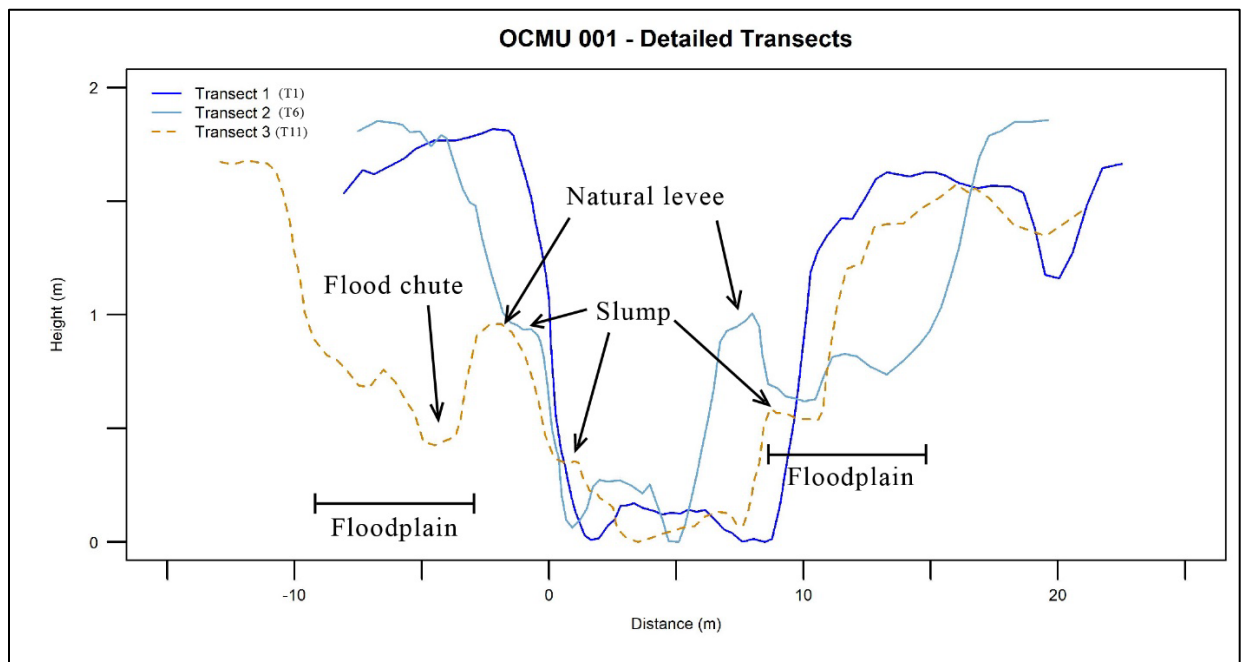


Figure 8. Comparison of the detailed transects at OCMU001. The location of the left channel-full points for each transect are normalized to allow for comparisons between transects. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

Table 2. Comparison of average detailed transect characteristics at OCMU001 versus selected surveyed streams at Kennesaw Mountain NBP and Chattahoochee River NRA [BF—Bankfull; CF—Channel full; m—meters].

Site	n ¹	Slope	Sinuosity	n ²	BF area (m ²)	BF Width (m)	BF Height (m)	CF Area (m ²)	CF Width (m)	CF Height (m)
OCMU001	11	-0.0018	1.15	3	4.56	8.29	0.7	16.03	18.11	1.43
KEMO001	14	-0.0015	1.02	3	3.31	6.34	0.74	8.67	8.76	1.45
KEMO002	11	-0.0019	1.09	3	3.15	6.68	0.7	7.53	8.67	1.28
CHAT001	14	-0.0074	1.07	3	3.97	9.74	0.71	41.4	22.13	2.57
CHAT013	17	-0.0044	1.14	3	5.08	11.39	0.63	26.27	16.72	2.09

¹ Number of slope measurements.

² Number of measurements for bankfull and channel-full area, width, and height.

Table 3. Watershed characteristics for OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013 calculated using the National Elevation Dataset (NED) 10-meter (32.8-ft) digital elevation model [m—meters; km—kilometers].

Basin Characteristic	OCMU001	KEMO001	KEMO002	CHAT001	CHAT013
Drainage Area (sq km)	239.65	8.30	12.66	8.78	16.88
NPS Managed Area (sq km)	0.65	2.80	1.00	0.03	0.29
NPS Managed Area (%)	0.3%	34%	8%	0.4%	2%
Total Stream Length (km)	401.73	12.68	20.82	13.97	27.11
Drainage Density	1.68	1.53	1.94	1.59	1.61
Strahler Order	5	3	3	3	3
Bifurcation Ratio	2.13	1.60	1.77	1.57	1.52
Entire Stream Gradient	0.0021	0.0109	0.0078	0.0146	0.0065
Segment Gradient	0.0014	0.0049	0.0007	0.0070	0.0065
Slope - Average	4.87	6.69	4.50	7.1	8.7
Slope - Std. Dev.	3.52	5.75	3.06	5.1	5.8
Slope - CV	0.72	0.86	0.68	0.71	0.67
Basin Length (km)	39.26	6.35	7.14	7.74	10.66
Basin Shape	0.16	0.21	0.25	0.15	0.15
Basin Relief (m)	127	261	88	125	109
Basin Relief Ratio	0.003	0.041	0.012	0.016	0.010
Elevation - Std. Dev. (m)	21	33	15	21	23

Table 4. Land use/land cover characteristics in 2011 for OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013. The data included in this table are from the National Land Cover Dataset (Homer et al. 2015).

NLCD Classes	OCMU001	KEMO001	KEMO002	CHAT001	CHAT013
Developed Open & Low (%)	11	34	60	54	48
Developed Med. & High (%)	1	12	9	4	12
Forested (%)	57	50	29	37	40
Grassland (%)	23	3	1	4	0
Cultivated (%)	0	0	0	0	0
Wetland (%)	3	0	0	0	0

Walnut Creek at OCMU001 is a fifth-order stream in its stream network. All four of the comparison streams (from KEMO and CHAT) are third-order streams in their respective stream networks. As expected, given the large size of the watershed and higher stream order, OCMU001 drains more total stream length than the KEMO and CHAT sites (Table 3). When normalized by drainage area, drainage density is less similar to the other streams. OCMU001's watershed had the lowest entire stream gradient (three times smaller than the next closest 0.0021 compared to 0.0065 at CHAT013) and had the second lowest segment gradient. Walnut Creek's average watershed slope was second lowest (next to KEMO002) and nearly two times smaller than for CHAT013. OCMU001's basin shape is long and narrow (similar to the CHAT watersheds). OCMU001's watershed had low relief (127 meters [417 ft] versus 261 meters [856 ft] at KEMO001) and the lowest basin relief ratio (0.003) which is more than three times smaller than the next closest basin relief ratio (0.01 for CHAT013; Table 3).

Habitat Characteristics

The geomorphic channel units (GCUs) at OCMU001 consisted mostly of runs and pools (Table 5). OCMU001 had no well-defined riffle habitat within the surveyed reach. Only one slightly higher energy, partially-buried step was observed (Figure 6). Due to the lack of riffles within the reach, the pebble count was conducted just upstream of OCMU001 at the nearest riffle (approximately 10 meters upstream of transect 11). OCMU001's GCU frequency and distribution were most similar to those observed at KEMO002. Though GCUs and channel slope at OCMU001 and KEMO002 were similar, the bed sediment at OCMU001 was significantly finer (Table 6). In fact, the mean bed sediment particle size at OCMU001 was statistically significantly finer than all four of the third-order streams (Table 7). The maximum particle size at OCMU001 was finer than the mean particle size at both CHAT reaches.

Twenty-four pieces of large woody debris (LWD) were found at OCMU001 (Tables 8 and B-3 [in Appendix B]). KEMO002 (n = 25) and CHAT013 (n = 30) had similarly high amounts of LWD. The volume of LWD per channel area at OCMU001 (0.0023 m³/m²) was second only to KEMO002

($0.0054 \text{ m}^3/\text{m}^2$). Canopy cover at OCMU001 was the lowest on average (58% compared to 87-99%) and the most variable ($\text{CV} = 0.44$ compared to 0.05–0.29; Table 9).

Average thalweg depth at OCMU001 (0.40 meters [1.31 ft]) was tied with CHAT001 for deepest average depth (Table 10). Though average thalweg depth at OCMU001 was greater than the other three reaches, the differences were not statistically significant (Table 7). Thalweg position at OCMU001 were less variable than both KEMO sites, and more variable than both CHAT sites (Table 10). Similar to average thalweg depth, differences in mean thalweg position between sites were not statistically significant (Table 7).

Table 5. Comparison of geomorphic channel units (GCU) observed in the area between transects at OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013. The data describe the percent coverage of each type of GCU [SD—standard deviation].

GCU	Site	Frequency	Max (%)	Mean (%)	SD (%)
Riffle	OCMU001	0	0	0	0
	KEMO001	8	90	49	33
	KEMO002	2	25	5	11
	CHAT001	6	100	24	32
	CHAT013	10	85	46	24
Run	OCMU001	9	90	61	30
	KEMO001	6	40	13	14
	KEMO002	5	80	26	33
	CHAT001	5	70	17	23
	CHAT013	3	15	4	6
Glide	OCMU001	2	60	10	21
	KEMO001	1	50	5	16
	KEMO002	1	20	2	6
	CHAT001	1	75	8	24
	CHAT013	1	60	39	27
Pool	OCMU001	10	50	28	14
	KEMO001	9	80	33	27
	KEMO002	10	100	65	32
	CHAT001	8	100	53	39
	CHAT013	10	95	39	27
Step	OCMU001	1	20	2	6
	KEMO001	0	0	0	0
	KEMO002	1	25	3	8
	CHAT001	0	0	0	0
	CHAT013	1	60	6	19

Table 6. Comparison of the particle size distributions of bed sediment (in millimeters) from the pebble count pebble surveys conducted at OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013. The subscripts indicate the percent of the sample that is smaller than the reported diameter.

Statistic	OCMU001 (n=100)	KEMO001 (n = 100)	KEMO002 (n = 100)	CHAT001 (n=100)	CHAT013 (n=100)
Min	0.06	0.06	0.06	2.00	0.06
D ₅	1.00	3.00	1.00	4.90	2.00
D ₁₆	1.00	7.00	1.00	15.00	9.00
D ₅₀	4.00	16.00	12.00	44.00	25.00
Mean	4.54	17.77	12.56	46.10	24.76
D ₈₄	8.00	27.00	20.84	74.16	41.16
D ₉₅	11.95	37.90	29.95	100.35	50.00
Max	21.00	50.00	57.00	187.00	65.00

Table 7. Significance of the differences in the pebble counts, thalweg depths, and thalweg positions of the OCMU001 and the third-order streams based on a post-hoc Tukey analysis. The significance of the differences are indicated by: “–”not significant; “*” p-value <0.05, “**” p-value <0.01, and “***” p-value <0.001. F-value and p-value of ANOVA results are reported as footnotes.

Pairs	Pebble Count				Thalweg				Thalweg Position		
	n ¹	(mm) ²	P-value	Sig.	n ³	Depth (m) ⁴	P-value	Sig.	(%) ⁵	P-value	Sig.
OCMU001 - KEMO001	100	-13.22	< 0.001	***	11	0.18	–	–	0.15	–	–
OCMU001 - KEMO002	100	-7.85	0.011	*	11	0.09	–	–	0.13	–	–
OCMU001 - CHAT001	100	-41.56	< 0.001	***	11	0.01	–	–	-0.01	–	–
OCMU001 - CHAT013	100	-20.22	< 0.001	***	11	0.13	–	–	-0.21	–	–

¹ Number of pebbles

² F(4,100) = 84.66, p < 0.001

³ Number of measurements for thalweg depth and position

⁴ F(4,11) = 2.46, p = 0.057

⁵ F(4,11) = 2.38, p = 0.064

Table 8. Comparison of the summary statistics for the large woody debris measured at OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013 [m—meters].

Statistic	Site	n	Length (m)	Diameter (m)	Volume (m ³)
Minimum	OCMU001	24	1.00	0.12	0.01
	KEMO001	11	0.56	0.10	0.01
	KEMO002	25	0.94	0.10	0.01
	CHAT001	16	2.51	0.12	0.04
	CHAT013	30	1.06	0.10	0.01
Mean	OCMU001	24	2.48	0.21	0.09
	KEMO001	11	2.91	0.12	0.03
	KEMO002	25	3.89	0.19	0.13
	CHAT001	16	6.60	0.18	0.20
	CHAT013	30	2.94	0.21	0.15
Maximum	OCMU001	24	7.50	0.37	0.24
	KEMO001	11	10.00	0.16	0.10
	KEMO002	25	9.59	0.47	0.48
	CHAT001	16	13.17	0.43	0.74
	CHAT013	30	7.17	0.46	0.82
Standard deviation	OCMU001	24	1.75	0.07	0.07
	KEMO001	11	3.02	0.02	0.03
	KEMO002	25	2.66	0.10	0.13
	CHAT001	16	3.20	0.08	0.20
	CHAT013	30	1.54	0.10	0.19
Sum	OCMU001	24	—	—	2.10
	KEMO001	11	—	—	0.34
	KEMO002	25	—	—	3.31
	CHAT001	16	—	—	3.23
	CHAT013	30	—	—	4.51
Per Channel Area (m ³ /m ²)	OCMU001	—	—	—	0.0023
	KEMO001	—	—	—	0.0005
	KEMO002	—	—	—	0.0054
	CHAT001	—	—	—	0.0015
	CHAT013	—	—	—	0.0019

Table 9. Comparison of the variability in canopy cover at OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013 [SD—Standard deviation; CV—Coefficient of variation].

Site	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
OCMU001	11	16	58	85	25	0.44
KEMO001	11	81	87	96	5	0.05
KEMO002	11	76	89	96	6	0.07
CHAT001	11	34	99	74	21	0.29
CHAT013	11	75	93	85	6	0.07

Table 10. Comparison of reach-scale averaged thalweg conditions at OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013 [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Thalweg	Site	n	Min	Mean	Max	SD	CV
Depth (m)	OCMU001	11	0.21	0.40	0.66	0.14	0.35
	KEMO001	11	0.09	0.22	0.44	0.12	0.52
	KEMO002	11	0.09	0.32	0.49	0.13	0.42
	CHAT001	11	0.13	0.40	0.71	0.22	0.56
	CHAT013	11	0.14	0.27	0.77	0.19	0.70
Position ¹ (%)	OCMU001	11	5	55	95	35	0.63
	KEMO001	11	10	41	90	28	0.68
	KEMO002	11	5	43	90	36	0.84
	CHAT001	11	5	56	90	33	0.58
	CHAT013	11	30	77	95	20	0.26

¹ position is percent distance from left active channel bank

Channel Morphology

The average wetted width of Walnut Creek at OCMU001 (7.2 meters [23.6 ft]) was wider and less variable than the KEMO and CHAT channels (3.04–6.68 meters [9.97–21.92 ft]; Table 11). Differences in mean wetted width were statistically significant between OCMU001 and both KEMO sites (Table 12). Average active channel width at OCMU001 (8.41 meters [27.59 ft]) was similar to the CHAT reaches (8.01–8.95 meters [26.28–29.36 ft]) and larger than the KEMO reaches (5.40–5.61 meters [17.72–18.41 ft]; Table 11). Differences in mean active channel width between OCMU001 and the KEMO reaches were statistically significant (Table 12). Variability in active channel widths (CV) at OCMU001 (0.16) was the second lowest (0.13 at KEMO001; Table 11). Average bankfull width at OCMU001 (10.98 meters [36.02 ft]) was second to only CHAT013 (11.09 meters [36.38 ft]; Table 11). As mentioned earlier, differences in mean bankfull width were not statistically compared because of the inconsistent number of bankfull widths available to measure within each reach. Average channel-full width at OCMU001 (18.27 meters [59.94 ft]) was statistically significantly larger than all the third-order streams except for CHAT013 (14.77 meters [48.46 ft]; Table 12). Variability in channel-full width at OCMU001 (0.25) was slightly lower than at the CHAT reaches (0.26–0.30) and nearly two times greater than the KEMO reaches (0.09 on both reaches; Table 11).

Walnut Creek's (OCMU001) average minimum bank height (1.28 meters [4.20 ft]) was less than the height of the banks along both CHAT reaches (1.84–2.17 meters) and was very similar to the banks along both KEMO reaches (1.31–1.49 meters [4.30–4.89 ft]; Table 13). OCMU001 had the highest average bankfull height (1.04 meters [3.41 ft]) of the reaches compared in this report (0.73–0.94 meters [2.40–3.08 ft]; Table 13). Additionally, the height of the bankfull surface at OCMU001 was the least variable. Average channel-full bank height at OCMU001 (1.56 meters [5.12 ft]) was statistically significantly less than all of the other reaches except for KEMO001 (1.44–2.37 meters [4.72–7.76 ft]; Table 13 and 14). Similar to bankfull bank heights, channel-full bank heights at OCMU001 were less variable than the other four reaches (Table 13).

Table 11. Comparison of reach-scale averaged width characteristics of OCMU001, KEMO001, KEMO002, CHAT001, and CHAT013 [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Widths	Site	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Wetted	OCMU001	11	5.82	7.20	8.67	0.98	0.14
	KEMO001	11	1.71	3.04	4.44	0.96	0.31
	KEMO002	11	2.48	4.37	6.11	1.20	0.27
	CHAT001	11	4.34	6.59	12.26	2.30	0.35
	CHAT013	11	3.27	6.68	9.30	2.27	0.34
Active Channel	OCMU001	11	5.82	8.41	11.16	1.37	0.16
	KEMO001	11	4.65	5.61	7.16	0.70	0.13
	KEMO002	11	3.33	5.40	7.36	1.52	0.28
	CHAT001	11	5.70	8.01	14.55	2.45	0.31
	CHAT013	11	6.35	8.95	14.00	2.27	0.25
Bankfull	OCMU001	9	7.21	10.98	13.25	1.84	0.17
	KEMO001	5	4.80	6.37	7.70	1.06	0.17
	KEMO002	7	4.86	6.00	7.49	0.97	0.16
	CHAT001	6	7.16	9.44	12.76	2.14	0.23
	CHAT013	3	10.55	11.09	11.75	0.61	0.05
Channel-Full	OCMU001	11	10.45	18.27	23.01	4.62	0.25
	KEMO001	11	7.55	8.51	9.65	0.76	0.09
	KEMO002	11	7.36	8.75	9.55	0.81	0.09
	CHAT001	11	8.97	14.14	20.95	3.72	0.26
	CHAT013	11	10.46	14.77	26.65	4.44	0.30

Table 12. Significance of the differences in diagnostic channel widths at OCMU001 (fifth-order) versus surveyed streams at Kennesaw Mountain NBP and Chattahoochee River NRA (third-order), based on a post-hoc Tukey analysis. The significance of the differences are indicated by: “–” not significant; “**” p-value <0.05, “***” p-value <0.01, and “****” p-value <0.001. F-value and p-value of ANOVA results are reported as footnotes [m—meters].

Pairs	Wetted				Active Channel			Channel-full Width		
	n ¹	Width (m) ²	P-value	Sig	Width (m) ³	P-value	Sig	(m) ⁴	P-value	Sig
OCMU001 - KEMO001	11	4.15	< 0.001	***	2.80	0.005	**	9.76	< 0.001	***
OCMU001 - KEMO002	11	2.82	0.002	**	3.01	0.002	**	9.52	< 0.001	***
OCMU001 - CHAT001	11	0.61	0.911	–	0.40	0.984	–	4.13	0.043	*
OCMU001 - CHAT013	11	0.52	0.948	–	-0.55	0.951	–	3.50	0.118	–

¹ Number of measurements of wetted width, active-channel width, and channel-full width

² F(4,11) = 12.74, p < 0.001

³ F(4,11) = 9.48, p < 0.001

⁴ F(4,11) = 17.28, p < 0.001

Table 13. Comparison of average reach-scale bank characteristics at OCMU, and the third-order streams at Kennesaw Mountain NBP, and Chattahoochee River NRA [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	Site	n	Min	Mean	Max	SD	CV
Minimum Bank Height ^{1,2} (m)	OCMU001	22	0.77	1.28	1.88	0.31	0.25
	KEMO001	22	0.51	1.31	1.74	0.32	0.24
	KEMO002	22	0.34	1.49	2.20	0.54	0.36
	CHAT001	22	0.57	1.84	3.15	0.83	0.45
	CHAT013	22	0.47	2.17	2.99	0.62	0.28
Bankfull Height ^{1,3} (m)	OCMU001	12	0.77	1.04	1.32	0.18	0.17
	KEMO001	5	0.51	0.73	1.01	0.19	0.26
	KEMO002	7	0.34	0.75	1.02	0.23	0.31
	CHAT001	6	0.57	0.94	1.34	0.26	0.28
	CHAT013	3	0.47	0.74	1.19	0.39	0.54

¹ above thalweg

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

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

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

Table 13 (continued). Comparison of average reach-scale bank characteristics at OCMU, and the third-order streams at Kennesaw Mountain NBP, and Chattahoochee River NRA [m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	Site	n	Min	Mean	Max	SD	CV
Channel-full Height ¹ (m)	OCMU001	22	1.28	1.56	1.88	0.14	0.09
	KEMO001	22	1.18	1.44	1.74	0.14	0.10
	KEMO002	22	0.96	1.72	2.20	0.36	0.21
	CHAT001	22	0.74	2.09	3.15	0.75	0.36
	CHAT013	22	1.96	2.37	2.99	0.29	0.12
Bank Undercut ³ (m)	OCMU001	2	0.05	0.10	0.14	0.06	0.67
	KEMO001	1	—	0.14	—	—	—
	KEMO002	2	0.37	0.44	0.51	0.10	0.22
	CHAT001	5	0.20	0.59	1.62	0.60	1.02
	CHAT013	7	0.09	0.21	0.54	0.15	0.71
Bank Angle (°)	OCMU001	22	23.2	48.77	85.40	20.14	0.41
	KEMO001	22	3	40	72	20	0.50
	KEMO002	22	9	56	90	27	0.48
	CHAT001	22	14	48	118	27.28	0.57
	CHAT013	22	6	60	88	27.38	0.46
Vegetation Cover (%)	OCMU001	22	10	58	100	29.51	0.51
	KEMO001	22	0	40	85	28.11	0.69
	KEMO002	22	0	18	50	18.03	0.99
	CHAT001	22	5	53	100	31.14	0.58
	CHAT013	22	0	34	60	18.60	0.54
Bank Stability ⁴	OCMU001	22	8.50	12.48	15.00	1.93	0.15
	KEMO001	22	11.50	13.50	16.00	1.28	0.09
	KEMO002	22	11.50	14.43	15.75	1.30	0.09
	CHAT001	22	7.00	12.73	17.00	2.25	0.18
	CHAT013	22	9.00	13.70	18.00	2.51	0.18

¹ above thalweg

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

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

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

Table 14. Significance of the differences of the channel-full heights, bank angles, and vegetative cover at OCMU001 (fifth order) and the third-order streams at Kennesaw Mountain NBP and Chattahoochee River NRA, based on a post-hoc Tukey analysis. The significance of the differences are indicated by: “–”not significant; “*” p-value <0.05, “**” p-value <0.01, and “***” p-value <0.001. F-value and p-value of ANOVA results are reported as footnotes [m—meters].

Pairs	Channel-full Height				Bank Angle (°) ³			Vegetative Cover (%) ⁴		
	n ¹	(m) ²	P-value	Sig.		P-value	Sig.		P-value	Sig.
OCMU001 - KEMO001	22	0.12	0.856	–	8.6	–	–	17	0.177	–
OCMU001 - KEMO002	22	-0.16	< 0.686	–	-7.2	–	–	40	< 0.001	***
OCMU001 - CHAT001	22	-0.53	< 0.001	***	1.2	–	–	4	0.981	–
OCMU001 - CHAT013	22	-0.81	< 0.001	***	-10.8	–	–	23	0.026	*

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

² F(4,22) = 19.83, p < 0.001

³ F(4,22) = 2.08, p < 0.088

⁴ F(4,22) = 8.32, p < 0.001

Two undercuts were observed and measured at OCMU001 (Table 13). The average depth of these undercuts (0.10 m) was less than the other monitored reaches (0.14–0.59 meters [0.46–1.94 ft]). Bank angles at OCMU001 ranged from 23.2° to 85.4° (Table 13). Differences in bank angles at Ocmulgee Mounds NHP, Kennesaw Mountain NBP, and Chattahoochee River NRA were not statistically significant (Table 14). OCMU001’s banks had the highest average vegetation cover (58% compared to 18 % at KEMO002 and 53% at CHAT001; Table 13). Differences in bank vegetation cover between OCMU001 and KEMO002 as well as CHAT013 were statistically significant (Table 14). The average bank stability score for OCMU001 was classified as “unstable” (see Methods section for how to interpret bank stability scores). The minimum bank stability score at OCMU001 was classified as “at-risk.” None of the OCMU001 banks scored higher than 15 (“unstable”). OCMU001 had a lower average bank stability score (12.48) than all the third-order KEMO and CHAT reaches (12.73–14.43). Variability in bank stability scores at OCMU reaches (0.15) was greater than the KEMO reaches (0.09) and less than the CHAT reaches (0.18).

Channel slope at OCMU001 (0.0018 m/m) was very similar to the KEMO reaches (0.0015 and 0.0019 m/m) but less than the CHAT reaches (0.0044 and 0.0074 m/m; Table 2). Reach sinuosity at OCMU001 (1.15) was similar to CHAT013 (1.14) and higher than the other three reaches (1.02–1.09). Average bankfull area of the detailed cross-sections at OCMU001 (4.56 m²) was second to only CHAT013 (5.08 square meters [54.68 sq ft]). Bankfull heights at OCMU001 were similar to those measured at the other streams. Bankfull widths were wider at Ocmulgee Mounds NHP compared to Kennesaw Mountain NBP, but narrower compared to the detailed transects at

Chattahoochee River NRA. Channel-full area at OCMU001 (16.03 square meters [172.55 sq ft]) was greater than the KEMO reaches (7.53 and 8.67 square meters [81.05 and 93.32 sq ft]) and less than the CHAT reaches (26.27 and 41.40 square meters [282.77 and 445.62 sq ft]). The large channel-full areas for the CHAT reaches were due to the wider incipient floodplain areas that have developed beneath the historical terraces along these streams by lateral channel migration and slumping (McDonald et al. *in review*).

Implications and Synthesis of Results

This section describes the processes that were observed at OCMU001 and the potential changes that may occur between surveys (field surveys were completed in spring 2019). The processes that are described will be explained within the context of the objectives of the protocol (i.e., basin characteristics that affect channel morphology and habitat, and the status of channel morphology and habitat characteristics).

OCMU001 – Walnut Creek

OCMU001's watershed is large (239 square kilometers [92.3 sq mi], Table 3) and is mostly covered by forested areas (57%) and grassland/pasture (23%, Table 4). Approximately 12% of Walnut Creek's watershed is developed, 1% of which is covered by medium- and/or high-intensity development. Though OCMU001's watershed has a low percentage of urban or suburban land cover (and associated impervious surfaces), the high percentage of the watershed covered by pastured lands along the stream network may contribute to flashier stormflows than expected based on the high forest cover (Price et al. 2011). OCMU001's watershed has a low entire stream gradient (0.0021 m/m), a low segment gradient (0.0014 m/m), and a low reach gradient (0.0018 m/m, Tables 2 and 3). OCMU001's watershed has relatively low average slope (4.87°), moderately high drainage density (1.68 km/km²), low basin shape (0.16; long and narrow watershed), and a very low basin relief ratio (0.003; Table 3). The majority of OCMU001's watershed lies in the Appalachian Piedmont physiographic province. The lower portion (where OCMU001 is in the network) flows over the Fall Line into the Coastal Plain. This transition has a large influence on the expected flood regime. In the Appalachian Piedmont portions of the watershed, slope and gradients are higher and flashier flow regimes are expected (compared to the lower portions of the watershed). As the Appalachian Piedmont areas drain to the Coastal Plain, watershed, segment, and channel slope all decrease greatly. This lowering of slope will greatly reduce available stream power and associated ability to transport and erode sediment. Additionally, the reductions in slope likely create conditions that increase flood water retention times and potentially causes greater flood stage heights because the water is not quickly moved through the system; though, gage data are needed to confirm these interpretations.

Though the reach that was surveyed on Walnut Creek (OCMU001) is within 100 meters (328 ft) of a social trail, visitors are not expected to interact with the stream along the surveyed reach. In-stream habitat was mostly run, pool, and glide habitats (Table 5). Habitat was evenly distributed throughout the reach with runs and glides separating the pools (Figure 6). The mean diameter of bed sediment at OCMU001 (4.54 millimeters [0.18 in]) was statistically significantly finer than all the other stream reaches that were compared in this report (range of 12.56 millimeters [0.49 in; KEMO002] to 46.10

millimeters [1.81 in; CHAT001]; Table 7). The statistically significant differences in bed material at OCMU001 compared to the other streams is likely due to the large differences in watershed, segment, and channel slope. The relatively low channel slope of the KEMO reaches was interpreted as being the main cause of the differences in bed sediment between these streams and the CHAT reaches (McDonald and Starkey 2019b). Additionally, Walnut Creek (OCMU001) is also likely receiving high sediment yields from the relatively steep upstream (Appalachian Piedmont) portions of its watershed. The high sediment yield from upstream coupled with lower segment and channel slopes along OCMU001's surveyed reach creates an environment that favors deposition over transportation or erosion.

OCMU001 had one of the highest volumes of LWD per channel area of the stream reaches compared in this report. The abundance of LWD is a positive benthic macroinvertebrate habitat attribute, yet the high amount of sandy and fine bed material suggest that the bed sediment is highly mobile. This potentially highly mobile bed may put the stream at greater risk of habitat degradation for benthic dwelling invertebrates (Allan and Castillo 2007). Additionally, this reach lacked habitat heterogeneity thought to promote biodiversity (Allan and Castillo 2007; Palmer et al. 2010). Even though the reach had a high abundance of LWD, based on the low-energy GCUs and sandy bed sediment, OCMU001's in-stream habitat was classified as "poor to fair." This classification is a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Ocmulgee Mounds NHP. Given the complex hydrologic setting of OCMU001, it is difficult to predict this site's response to changes in sediment supply and LWD, but marked departure from this habitat classification is not anticipated (Allan and Castillo 2007).

The major defining characteristics of the stream were the presence of natural levees and floodplains, a lack of riffle habitat, and the relatively gentle channel slope. Though the overall watershed mostly lies in the Appalachian Piedmont, OCMU001 is a low energy, depositional environment which will continue to be subject to regular flooding and slow post-flood draining. It is expected that floodplains will continue their development and in-channel bars will continue to expand. OCMU001's watershed is more than an order of magnitude larger than the largest third-order stream included in this report (239 square kilometers [92.3 sq mi] compared to 17 square kilometers [6.6 sq mi] at CHAT013). Surprisingly, OCMU001's (fifth order) channel has similar morphology to the third-order streams surveyed at Kennesaw Mountain NBP and Chattahoochee River NRA. This is because during large flood events, Walnut Creek does not behave like a meandering stream system. Reconnaissance of the streams at Ocmulgee Mounds NHP identified many flood channels and braided features in Walnut Creek's out-of-channel area upstream of the monitored segment (McDonald and Starkey 2019a). The relatively small channel surveyed at OCMU001 is interpreted as evidence that the majority of flood waters that come through the park by way of Walnut Creek do not follow this flow path. Alternatively, flood waters are diverted away from the hillslope, into a power line right-of-way and then into the wetlands to the west of OCMU001, through a series of flood chutes and side channels (Figure 9). It is suggested that discharge monitoring stations be installed at the railroad bridge that crosses Walnut Creek (upstream of OCMU001), just upstream of OCMU001, and immediately

downstream of OCMU001 to determine the proportion of flow that bypasses the channel at OCMU001 and to determine how much floodwater enters OCMU001 through flood chutes and side channels.

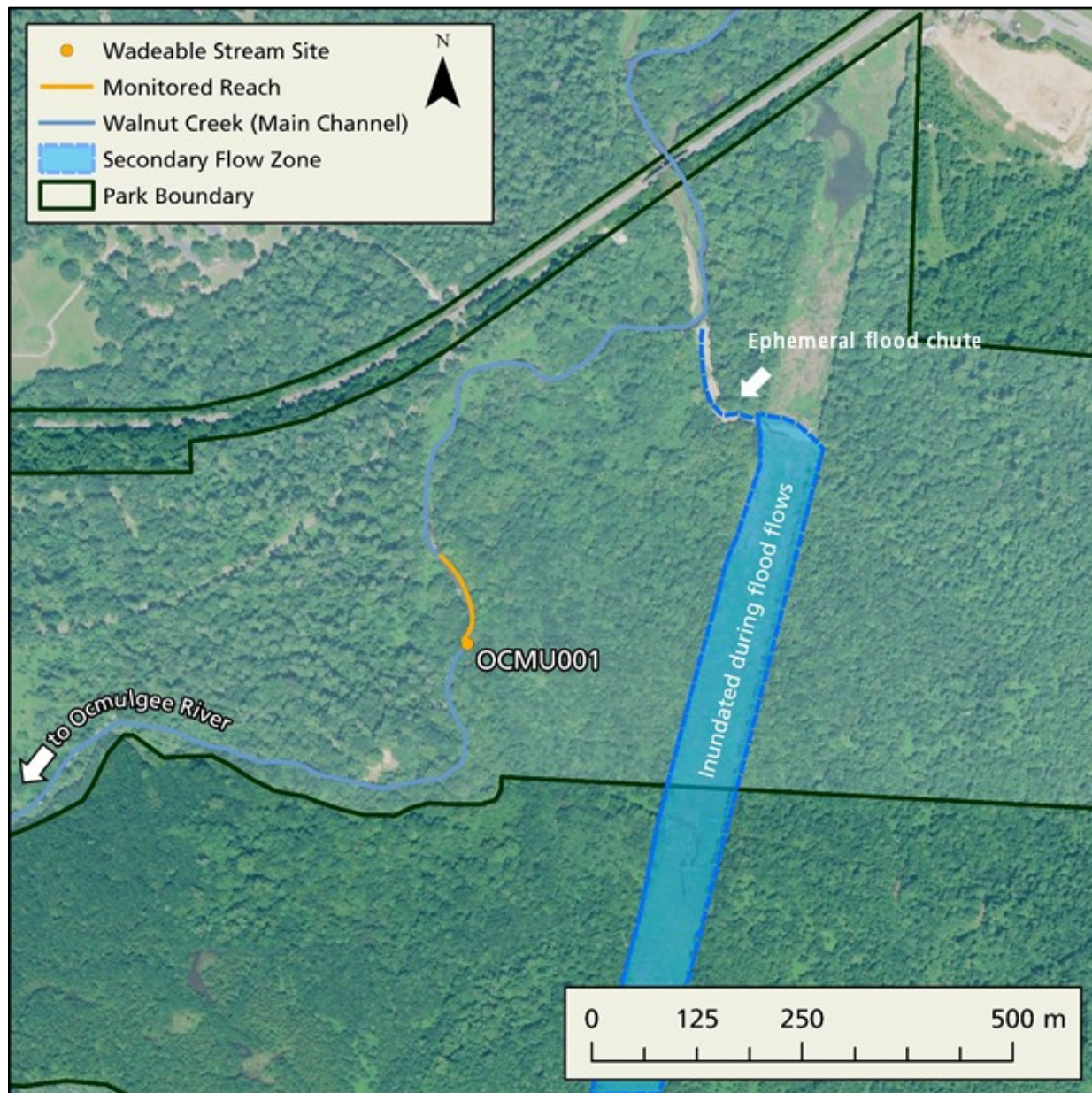


Figure 9. Map depicting the flow pattern of Walnut Creek at OCMU001. Note the ephemeral flood channel which carries flow into the power line right-of-way east of the monitored reach.

Conclusion

OCMU001's watershed (Walnut Creek) has low slope/relief and is covered mostly by forest and agricultural pasture. The major defining characteristics of the stream were the presence of floodplains, natural levees, lack of riffle habitat, and homogeneous channel slope throughout the reach. Though the majority of the watershed lies in the Appalachian Piedmont physiographic province, the OCMU001 reach of Walnut Creek lies in the Upper Coastal Plain and is a low energy, depositional environment which is subject to regular flooding and slow post-flood draining.

The channel surveyed at OCMU001 is smaller than expected, given the large size of its watershed. The small channel size is interpreted as evidence that the majority of flood waters that come through OCMU by way of Walnut Creek do not follow this flow path. Alternatively, flood waters are diverted away from the hillslope, into the wetlands to the west of OCMU001 and into a power line right-of-way east of OCMU001, through a series of flood chutes and side channels. It is suggested that discharge monitoring stations be installed at the railroad bridge that crosses Walnut Creek (upstream of OCMU001), just upstream of OCMU001, and immediately downstream of OCMU001 to determine the proportion of flow that bypasses the channel at OCMU001 and to determine how much floodwater enters OCMU001 through flood chutes and side channels.

Though the reach had a high abundance of LWD, based on the results of the pebble count and the type/distribution of GCU within the reach, in-stream habitat within the surveyed stream was classified as "poor to fair." These classifications are generalized interpretations of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Ocmulgee Mounds NHP. Given the complex hydrologic setting of OCMU001, it is difficult to predict this site's response to changes in sediment supply and LWD, but marked departure from this habitat classification is not anticipated (Allan and Castillo 2007). The stream does not have immediate management concerns, although there is extensive exotic invasive vegetation in the area surrounding and outside of the channel.

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Appendix A. Explanation of Variables

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

Variable	Variable Scale	Description
Drainage Area	Basin	The topographical area to which precipitation, sediment, and dissolved constituents are funneled to a common outlet point along a given stream channel (Dunne and Leopold 1978).
Total Stream Length	Basin	The sum of the length of perennial streams within a watershed.
Drainage Density	Basin	The ratio of total stream length to drainage area.
Basin Length	Basin	The length of the line that bisects a watershed running from outlet to drainage divide.
Basin Shape	Basin	Drainage area divided by basin length squared (Horton 1932)
Average Watershed Slope	Basin	Within watershed, average of the slope values of each pixel of a digital elevation model.
Standard Deviation of Slope	Basin	Within watershed, standard deviation of the slope values of each pixel of a digital elevation model.
Basin Relief	Basin	Within watershed, maximum elevation minus minimum elevation
Standard Deviation of Elevation	Basin	The standard deviation of elevation within a watershed.
Basin Relief Ratio	Basin	A ratio calculated by dividing basin relief by basin length.
Entire Stream Gradient	Basin	The difference in elevation at 85% and 10% of the main stem stream length divided by the stream length between the two points (Fitzpatrick et al. 1998).
Segment Gradient	Basin	The difference in elevation between the upstream extent of the stream segment and the downstream extent of the stream segment, divided by the length of the stream segment.
Strahler Stream Order	Basin	A stream ordering system where order increases when two orders of the same magnitude join.
Bifurcation Ratio	Basin	The ratio of streams in a given Strahler order to streams in the next highest order (e.g., number of first order streams/number of second order streams).
Land Use/Land Cover	Basin	Land use/land cover is derived from the NLCD dataset (Homer et al. 2001; Fry et al. 2006; Homer et al. 2015).

¹ collected at each standard transect (11 measurements)

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

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

Variable	Variable Scale	Description
Geomorphic Channel Units	Reach	Geomorphic channel units are a way to classify in-channel habitat (e.g., riffles and pools)
Large Woody Debris	Reach	Pieces of woody material that have a diameter greater than 0.1 m and are 1 m or longer.
Pebble Count	Reach	The size and distribution of 100 particles (pebble count) from a representative riffle (Wolman 1954).
Canopy Closure	Reach ¹	The average of four measurements (looking upstream, downstream, and at each bank) taken using a spherical densiometer.
Reach Sinuosity	Reach	Sinuosity is calculated by dividing reach length by valley length.
Longitudinal Profile	Reach	The gradient of the line that connects the tops of the steps and riffles within a reach (channel slope)
Wetted Width	Transect ¹	Wetted channel width is measured where water is flowing (including undercuts)
Active Channel Width	Transect ¹	Active channel width is measured to the beginning of vegetation within the stream channel
Bankfull Width	Transect ^{1,2}	Bankfull widths should only be measured if there is a floodplain (or incipient floodplain) present
Bankfull Height	Transect ^{1,2}	The height of the channel bank where a floodplain is present
Bankfull Area	Transect ²	The cross-sectional area of a stream channel at bankfull stage (height) measured perpendicular to flow
Bankfull Perimeter	Transect ²	The length of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at bankfull discharge
Bankfull Hydraulic Radius	Transect ²	A measure of hydraulic efficiency defined by the ratio between bankfull area and bankfull perimeter
Channel-full Width	Transect ^{1,2}	Channel full widths are measured from the top of the lowest bank that is not a floodplain.
Channel-full Height	Transect ^{1,2}	The height of the channel bank where a floodplain is not present (channel-full height is also measured where a floodplain is inset within an entrenched channel)
Channel-full Area	Transect ²	The cross-sectional area of a stream channel at bankfull stage measured perpendicular to flow

¹ collected at each standard transect (11 measurements)

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

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

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

¹ collected at each standard transect (11 measurements)

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

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Appendix B. Survey Results for OCMU 001

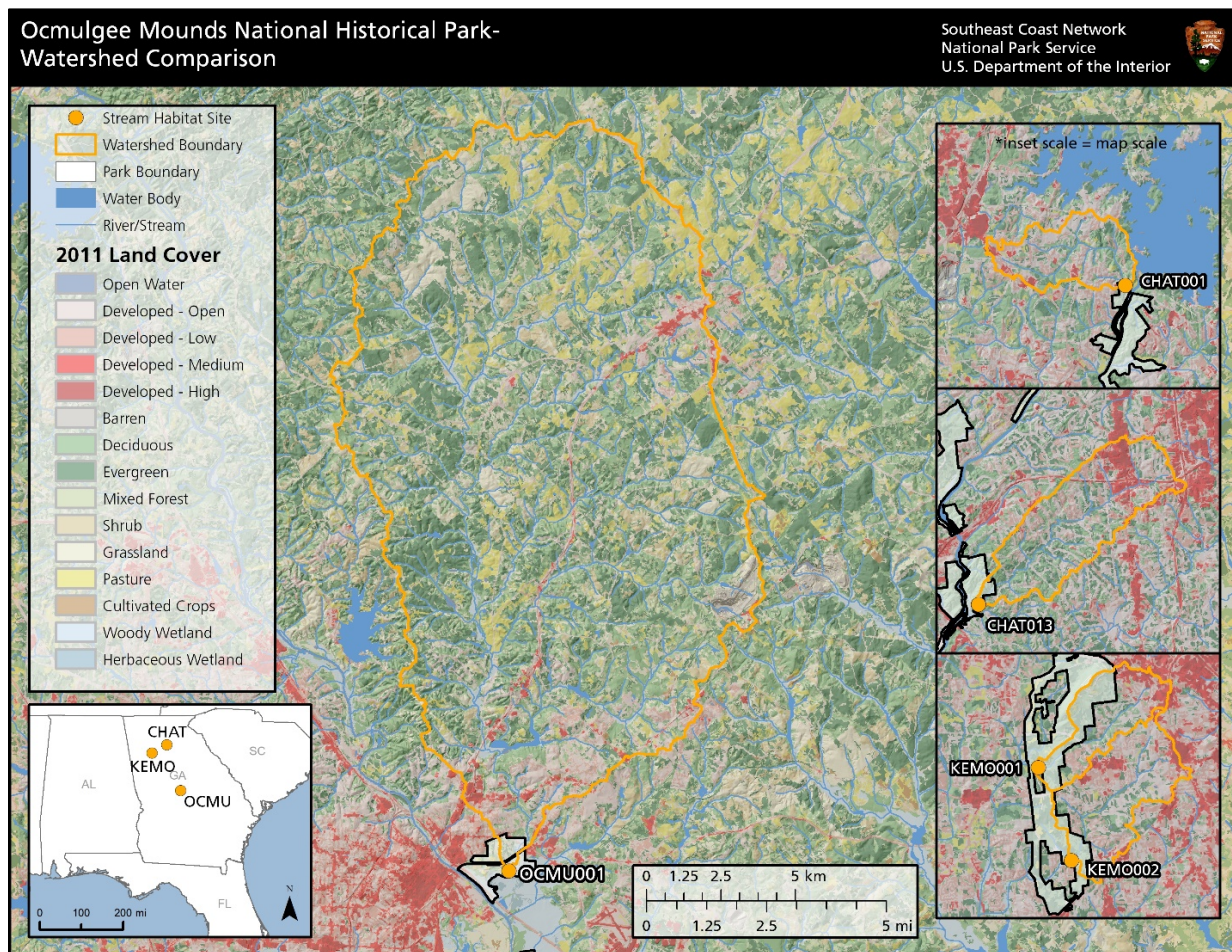


Figure B-1. Map display of watershed size for OCMU001 versus KEMO and CHAT watersheds.



Figure B-2. Photograph taken on OCMU001 looking upstream from T1 (detailed transect 1).



Figure B-3. Photograph taken on OCMU001 looking downstream from T1 (detailed transect 1).



Figure B-4. Photograph taken on OCMU001 facing the left bank on T1 (detailed transect 1).



Figure B-5. Photograph taken on OCMU001 facing the right bank on T1 (detailed transect 1).



Figure B-6. Photograph taken on OCMU001 looking upstream from T6 (detailed transect 2).



Figure B-7. Photograph taken on OCMU001 looking downstream from T6 (detailed transect 2).



Figure B-8. Photograph taken on OCMU001 facing the left bank on T6 (detailed transect 2).



Figure B-9. Photograph taken on OCMU001 facing the right bank on T6 (detailed transect 2).



Figure B-10. Photograph taken on OCMU001 looking upstream from T11 (detailed transect 3).

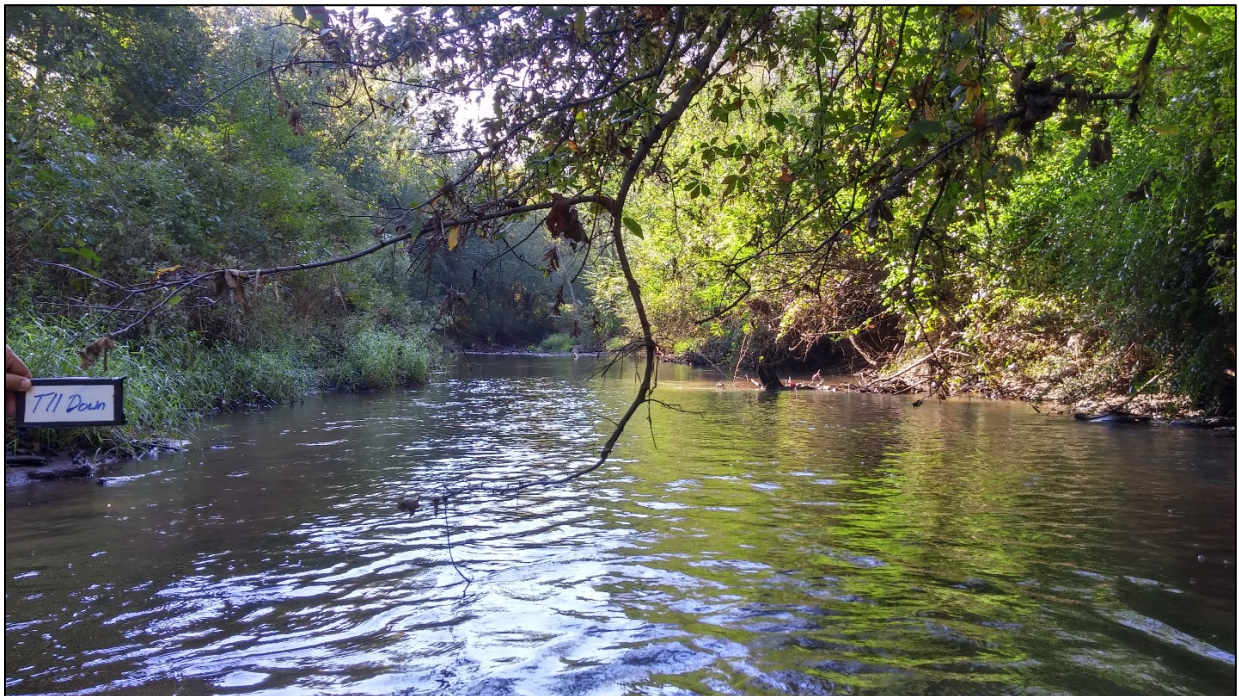


Figure B-11. Photograph taken on OCMU001 looking downstream from T11 (detailed transect 3).



Figure B-12. Photograph taken on OCMU001 facing the left bank on T11 (detailed transect 3).



Figure B-13. Photograph taken on OCMU001 facing the right bank on T11 (detailed transect 3).

Table B-1. Land use/land cover characteristics for 2001, 2006, and 2011 for OCMU001. The data included in this table are from the National Land Cover Dataset (Homer et al. 2001; Fry et al. 2006; Homer et al. 2015).

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed
Open Water	1	1	1
Developed - Open ¹	8	8	9
Developed - Low ¹	2	3	2
Developed - Medium ¹	1	1	1
Developed - High ¹	0	0	0
Barren	1	1	1
Deciduous	31	31	28
Evergreen	25	24	22
Mixed Forest	7	7	6
Shrub	0	2	3
Grassland	11	10	14
Pasture	10	9	9
Cultivated	0	0	0
Woody Wetland	3	3	3
Herbaceous Wetland	0	0	0

¹ refers to the intensity or type of development

Table B-2. Geomorphic channel units (GCU) observed in the area between transects at OCMU001. The data describe the percent coverage of each type of geomorphic channel unit.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	0	60	40	0
2–3	0	25	35	40	0
3–4	0	50	0	50	0
4–5	0	80	0	20	0
5–6	0	85	0	15	0
6–7	0	50	0	30	20
7–8	0	80	0	20	0
8–9	0	90	0	10	0
9–10	0	60	0	40	0
10–11	0	90	0	10	0
Frequency	0	9	2	10	1
Max (%)	0	90	60	50	20
Mean (%)	0	61	10	28	2
Median (%)	0	70	0	25	0
SD (%)	0	30	21	14	6

Table B-3. Characteristics of the large woody debris observed at OCMU001 [m—meters].

LWD ID	Length (m)	Diameter (m)	Volume (m³)	Transect Interval	Function	Position
1	7.50	0.12	0.08	9	None	Buried
2	1.22	0.18	0.03	9	None	Buried
3	4.22	0.13	0.06	8	Bank protection	Buried
4	1.07	0.27	0.06	7	Jam, Pool formation	Jam
5	1.24	0.33	0.11	7	Jam, Pool formation	Jam
6	3.93	0.16	0.08	7	Jam	Jam
7	3.35	0.26	0.18	7	Pool formation	Buried
8	3.16	0.31	0.24	6	Step formation	Buried
9	1.60	0.21	0.06	6	None	Buried
10	1.00	0.19	0.03	5	None	Buried
11	1.05	0.20	0.03	5	Organic trap	Buried
12	1.16	0.37	0.12	4	Organic trap	Buried
13	1.66	0.18	0.04	4	Jam	Jam
14	3.14	0.21	0.11	3	Organic and sediment trap	Buried
15	4.00	0.25	0.20	3	Organic and sediment trap	Buried
16	6.37	0.15	0.11	3	None	Bridge
17	1.43	0.24	0.06	2	Jam	Jam
18	1.07	0.15	0.02	2	Organic trap	Jam
19	3.22	0.29	0.21	2	Jam	Jam
20	1.93	0.12	0.02	2	Jam	Jam
21	2.18	0.30	0.15	2	Bank protection, Jam	Jam
22	1.72	0.22	0.07	1	Organic and sediment trap, Pool formation	Buried
23	1.09	0.14	0.02	1	Sediment trap	Buried
24	1.09	0.12	0.01	1	Organic and sediment trap	Buried

Table B-4. Variability of canopy cover observed at OCMU001.

Transect	Canopy Cover (%)
1	85
2	82
3	84
4	84
5	69
6	49
7	49
8	16
9	25
10	32
11	62
Min (%)	16
Max (%)	85
Mean (%)	58
Median (%)	62
SD (%)	25
CV	0.44

Table B-5. Average reach-scale bank characteristics at OCMU001 [L—indicates left bank; R—indicates right bank; m—meters; SD—Standard deviation; CV—Coefficient of variation].

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)	SD (L)	SD (R)	CV (L)	CV (R)
Bank Height ¹ (m)	11	11	0.77	0.82	1.88	1.57	1.32	1.23	1.32	1.28	0.36	0.27	0.27	0.22
Bankfull Height ^{1,2} (m)	6	6	0.77	0.82	1.32	1.31	1.04	1.04	1.04	1.02	0.19	0.19	0.18	0.18
Channel-full Height ^{1,2} (m)	11	11	1.46	1.28	1.88	1.81	1.60	1.52	1.60	1.55	0.14	0.13	0.08	0.09
Water Depth at Base ³ (m)	11	11	-0.12	-0.12	0.18	0.08	0.00	0.00	0.00	0.00	0.09	0.06	—	—
Bank Undercut ² (m)	1	1	0.05	0.14	0.05	0.14	0.05	0.14	0.05	0.14	—	—	—	—
Bank Angle (^o)	11	11	24	23	85	78	48	50	46	53	20	21	0.42	0.42
Vegetation Cover (%)	11	11	10	10	100	100	61	54	60	60	32	28	0.53	0.51
Bank Stability ⁴	11	11	At-Risk	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	2.26	1.55	0.19	0.12

¹ above thalweg

² statistics are based on the transects where feature is present (# in parentheses)

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

⁴ See Table 1 for explanation of scores

Table B-6. Cross-sectional characteristics for detailed transect 1 at OCMU001 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	8.79	10.94	0.80	10.15	1.04	9.76
Channel-full	12.94	13.06	0.99	12.04	1.43	8.45
Ratio	1.47	1.19	1.23	1.19	1.37	0.87

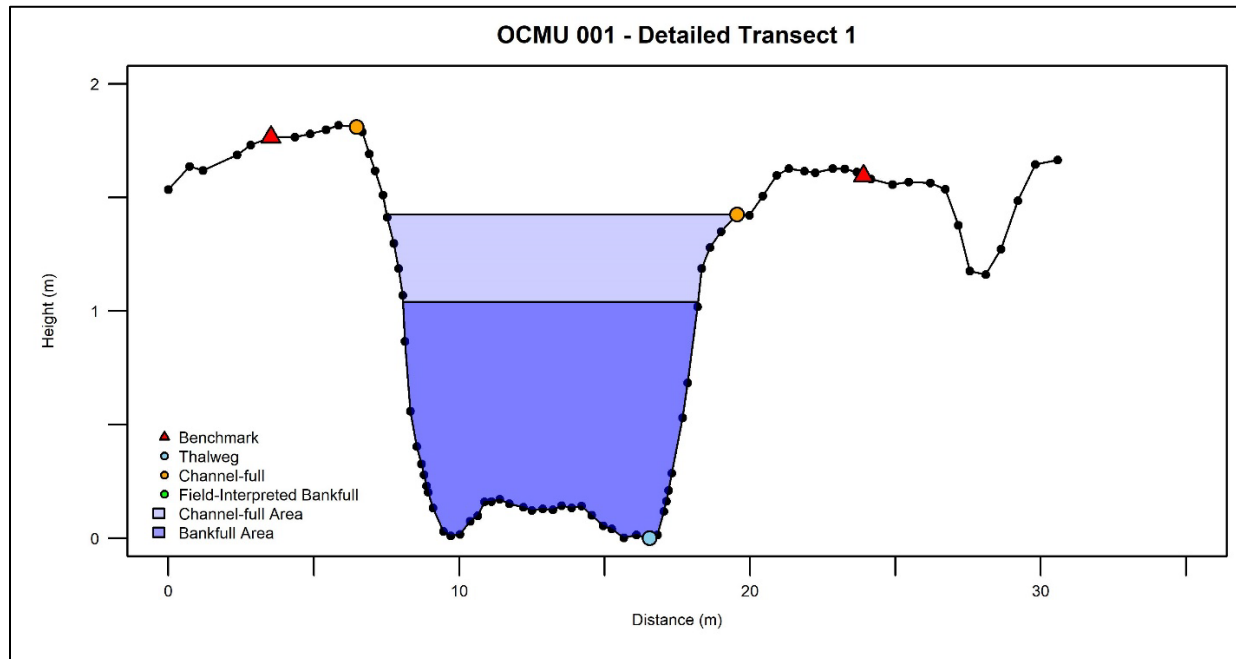


Figure B-14. Detailed transect 1 at OCMU001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Additionally, the channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). If no bankfull surfaces were present at the cross-section, bankfull area was interpolated by determining hydraulic radius when the water surface is at the reach averaged bankfull height above thalweg.

Table B-7. Cross-sectional characteristics for detailed transect 2 at OCMU001 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	2.56	6.80	0.38	6.38	0.62	10.30
Channel-full	15.76	20.31	0.78	19.34	1.48	13.07
Ratio	6.15	2.99	2.06	3.03	2.39	1.27

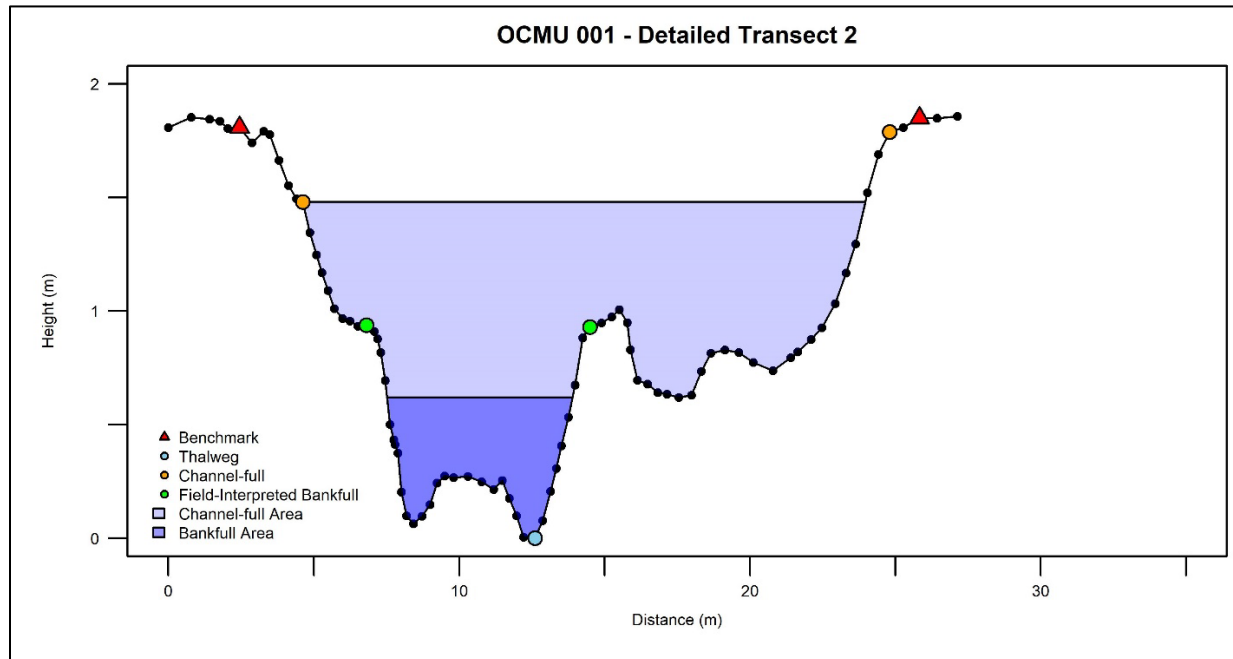


Figure B-15. Detailed transect 2 at OCMU001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). When bankfull height above thalweg was greater than the lowest out-of-channel surface (LooC), bankfull area was interpolated using LooC height to determine the hydraulic radius at this height.

Table B-8. Cross-sectional characteristics for detailed transect 3 at OCMU001 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	2.34	8.50	0.28	8.34	0.43	19.57
Channel-full	19.38	23.78	0.82	22.94	1.38	16.57
Ratio	8.28	2.80	2.96	2.75	3.25	0.85

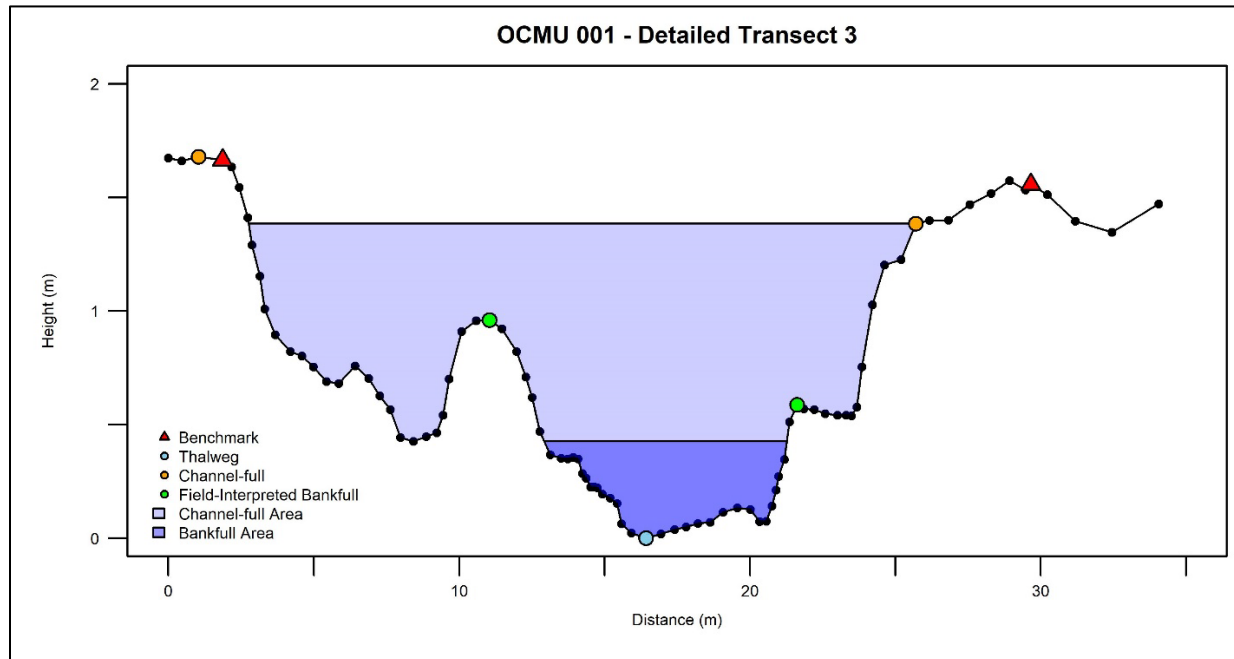


Figure B-16. Detailed transect 3 at OCMU001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). When bankfull height above thalweg was greater than the lowest out-of-channel surface (LooC), bankfull area was interpolated using LooC height to determine the hydraulic radius at this height.

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