



Wadeable Stream Habitat Monitoring at Ocmulgee Mounds National Historical Park

2019 Change Report

Natural Resource Report NPS/SECN/NRR—2020/2200



ON THE COVER

Picture looking downstream from transect 4 at the stream habitat monitoring site on Walnut Creek (OCMU001) at Ocmulgee Mounds National Historical Park. Photograph taken by SECN staff May 8, 2019.

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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, Kennesaw Mountain National Battlefield, Ocmulgee Mounds National Historical Park, Chattahoochee River National Recreation Area, and Congaree National Park. Streams chosen for assessment were specifically targeted for management interest (e.g., trail erosion issues and upstream urban development) or to provide a context for similar-sized stream(s) within the park or network (McDonald and Starkey 2019).

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 September 27, 2017, data were collected at Ocmulgee Mounds National Historical Park (OCMU) to characterize the in-channel and near-stream habitat on a reach of Walnut Creek (OCMU001). These data, along with in-office 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 this reach of Walnut Creek to similar-sized streams at Kennesaw Mountain National Battlefield Park and Chattahoochee National Recreation Area (Cooper et al. 2019). On May 8, 2019, OCMU001 was resurveyed to determine the amount and type of change that occurred within the reach. This report compares the results of the 2019 resurvey to the initial 2017 baseline survey.

Walnut Creek's watershed at OCMU001 has low slope/relief and is covered mostly by forest and agricultural pasture. The major defining characteristics of the stream are the presence of floodplains and natural levees, the lack of riffle habitat, and a homogeneous channel slope throughout the reach.

In-stream habitat changed substantially from 2017 to 2019. In 2019, only a few non-run habitats were identified within the reach (there was a mixture of runs and pools in 2017). Related to the conversion of pools to runs, thalweg depth was shallower in 2019 compared to 2017. Bed material was also finer in 2019 compared to 2017. Additionally, the floodplain surfaces along detailed transects 2 (T6) and 3 (T11) had a significant amount of aggradation. Floodplain aggradation on detailed transects 2 (T6) and 3 (T11), along with the overall shallowing of average thalweg depth within the reach, indicates a substantial amount of sediment is being supplied to the reach.

Due to the reduction in the diversity of in-stream habitat and the increased fining of the bed, OCMU001's in-stream habitat's classification was downgraded from 'poor to fair; to 'poor.' This classification is a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health at Ocmulgee Mounds NHP. The reduction in the quality of the habitat may be a 'natural' fluctuation within the stream network related more to complex response (Schumm 1973) than a permanent change in the reach. The lack of change in the longitudinal profile supports the interpretation that the reach has not undergone a significant permanent change and the additional fine sediment that has been deposited within the reach may move through this portion of the stream network by the next survey (tentatively scheduled for spring or summer 2022).

The major morphological changes observed within the reach were seen on the detailed transects. These changes were related to bank slumping, stream bed restructuring, and floodplain aggradation. Bank slumping was interpreted to have contributed to the large increase in channel-full area on detailed transects 1 (T1) and 2 (T6) as well as the loss of the 'bankfull' surface along river right on detailed transect 3 (T11). This bed restructuring along the detailed transects supports the interpretation that the bed along OCMU001 is highly mobile. The prevalence of slumping along all three detailed transects also suggests the banks are quite unstable. The highly mobile bed and unstable banks should not be interpreted as a management concern and are expected characteristics for streams in this portion of the Upper Coastal Plain. There were no immediate management concerns identified by the survey, except for the high density of exotic invasive vegetation that continues to occupy the area surrounding the stream.

List of Acronyms

ANOVA—Analysis of variance

B—Sand/gravel bar

Be—Bench

Bf—Bankfull

BM—Benchmark

BSi—Bank stability index

CHAT—Chattahoochee National Recreation Area

CONG—Congaree National Park

CV—Coefficient of variance

DEM—Digital elevation model

FP—Floodplain

FPM—Floodplain margin

GCU—Geomorphic channel unit

GIS—Geographic information system

Gl—Glide

HOBE—Horseshoe Bend National Military Park

KEMO—Kennesaw Mountain National Battlefield Park

LWD—Large woody debris

NED—National Elevation Dataset

NL—Natural levee

NLCD—National Land Cover Dataset

NPS—National Park Service

OCMU—Ocmulgee Mounds National Historical Park

P—Pool

Ru—Run

SECN—Southeast Coast Network

SOP—Standard operating procedure

T#—Standard transect

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 collected through this monitoring effort provides park staff with information regarding the physical linkage between streams and park resources. Additionally, this monitoring program provides early warnings of changing conditions that may negatively affect visitor experience and or park infrastructure.

Wadeable stream monitoring is currently implemented at the five SECN inland parks with wadeable streams. These parks include Horseshoe Bend National Military Park (HOBE) in Alabama, Kennesaw Mountain National Battlefield (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 NB, and Chattahoochee 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; and 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 2019). Streams chosen for monitoring were specifically targeted due to management interest (e.g., trail erosion issues and upstream urban development) or to provide a context for similar-sized streams in the park (see suitability reports for each park [cited in this paragraph] for more information).

The objectives of SECN stream habitat monitoring protocol are to:

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

For the purposes of this report, wadeable streams are narrowly defined as small- to medium-sized, perennially flowing waterbodies, with easily identifiable channel banks, that can be accessed and traversed without the use of a watercraft. The wadeable streams referred to herein do not include non-perennial channel-like features (e.g., gullies) typical of highly disturbed landscapes like the Appalachian Piedmont and Upper Coastal Plain.

The objectives of this report are to:

- Present the wadeable stream survey completed at Ocmulgee Mounds NHP during late spring 2019,
- Provide a comparison of the 2019 results to the 2017 ‘baseline’ survey, and
- Explain why this reach of Walnut Creek is changing and its potential trajectory of change.

Study Area

The hydro-climatic conditions of the study area are characterized as humid subtropical with average annual rainfall around 46 inches (117 centimeters [cm]) per year (Wright et al. 2011). Snowfall is negligible and winters are mild; summers are hot and humid. Average monthly temperature ranges from approximately 28°F (-2°C) in December to 94°F (35°C) in July (Wright et al. 2011). Monthly rainfall totals are distributed rather evenly from October through May due to the influence of frontal systems that sweep through the region (Lecce 2000). Convective thunderstorms influence the region from late spring through early fall. While monthly precipitation tends to be high in the summer, the high levels of evapotranspiration attenuate streamflow during this part of the year (Lins 1997).

The natural condition of rivers draining the southeastern U.S. are generally characterized by meandering channels with densely vegetated banks (Leigh 2008). Contemporary river systems in the southeastern U.S. are in variously altered states that reflect multiple legacies of anthropogenic disturbance (James 2018). Beginning in the late 1800s, deforestation, increased row crop agriculture, and a general lack of soil conservation measures caused widespread erosion of topsoil from steeply sloped upland areas in the Appalachian Piedmont (Trimble 1969). Sediment was transported to streams and floodplains, burying productive shoal and riffle habitats. Streams in the region were transformed, from the hard-bottomed, clear-flowing streams described by early land surveyors, into conduits of turbid water and sand. As row-crop agriculture became less dominant and forest cover increased, sediment delivery to streams was reduced and streambeds began to degrade (Schumm et al. 1984). Today, streambed elevations in many of the region's small streams have returned to historic or near historic levels though their geomorphic characteristics (width, depth, 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 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 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 from unstable banks, and finally stabilization and more natural reworking of in-channel alluvium (Figure 1). The exact stage that a particular stream occupies, at a given moment in time, 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 and Upper Coastal Plain 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).

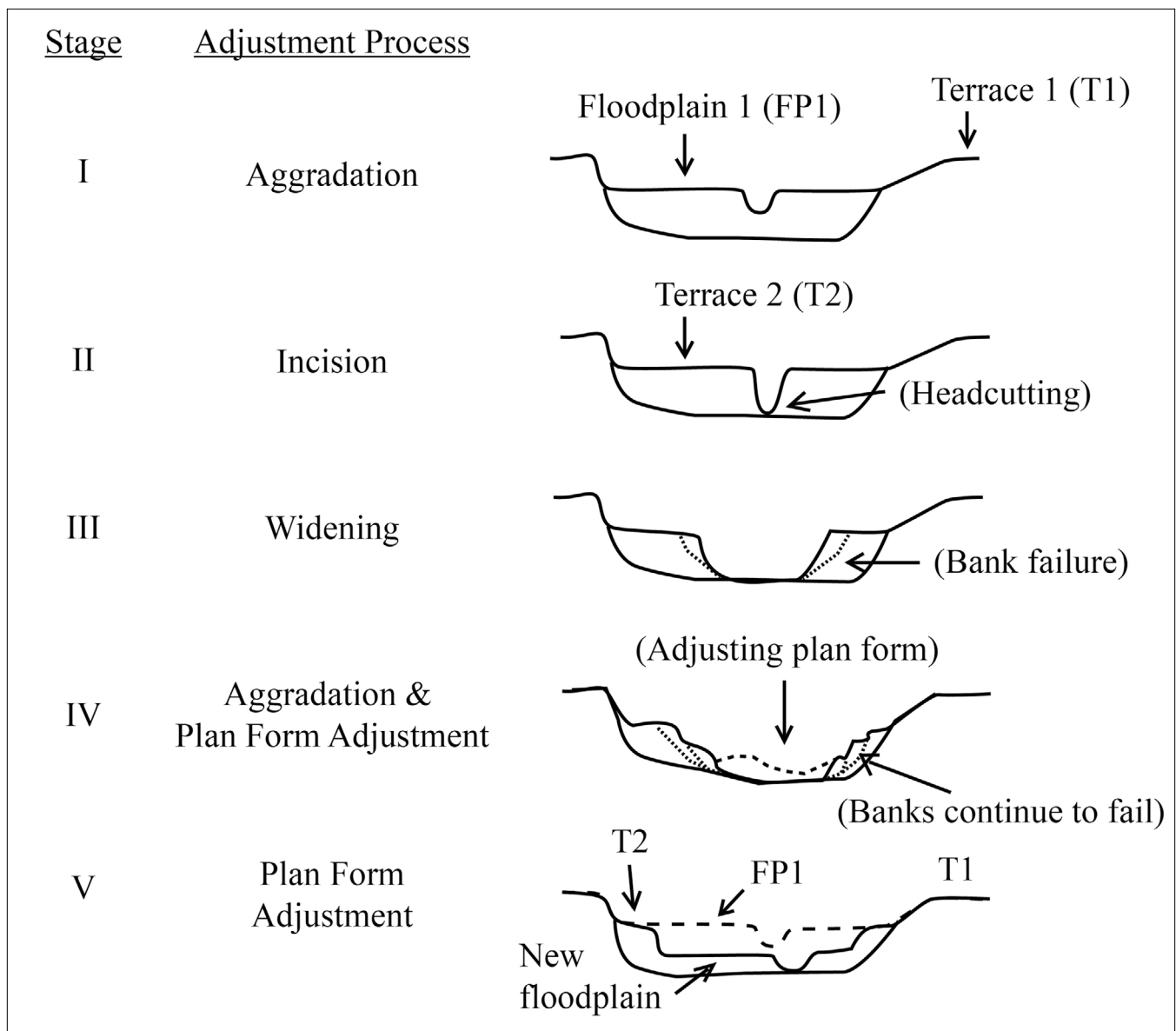


Figure 1. Generalized channel evolution model (modified from Schumm et al. 1984).

Ocmulgee Mounds National Historical Park

Ocmulgee Mounds National Historic 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 monument preserves burial and temple mounds, constructed by American Indians on the uplands overlooking the Ocmulgee 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 2019).

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 the park, Walnut Creek is an intermittently braided stream system with 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 2019).

Roughly 300 acres (121 ha) of Ocmulgee NHP are classified as emergent wetlands, and stream reconnaissance conducted

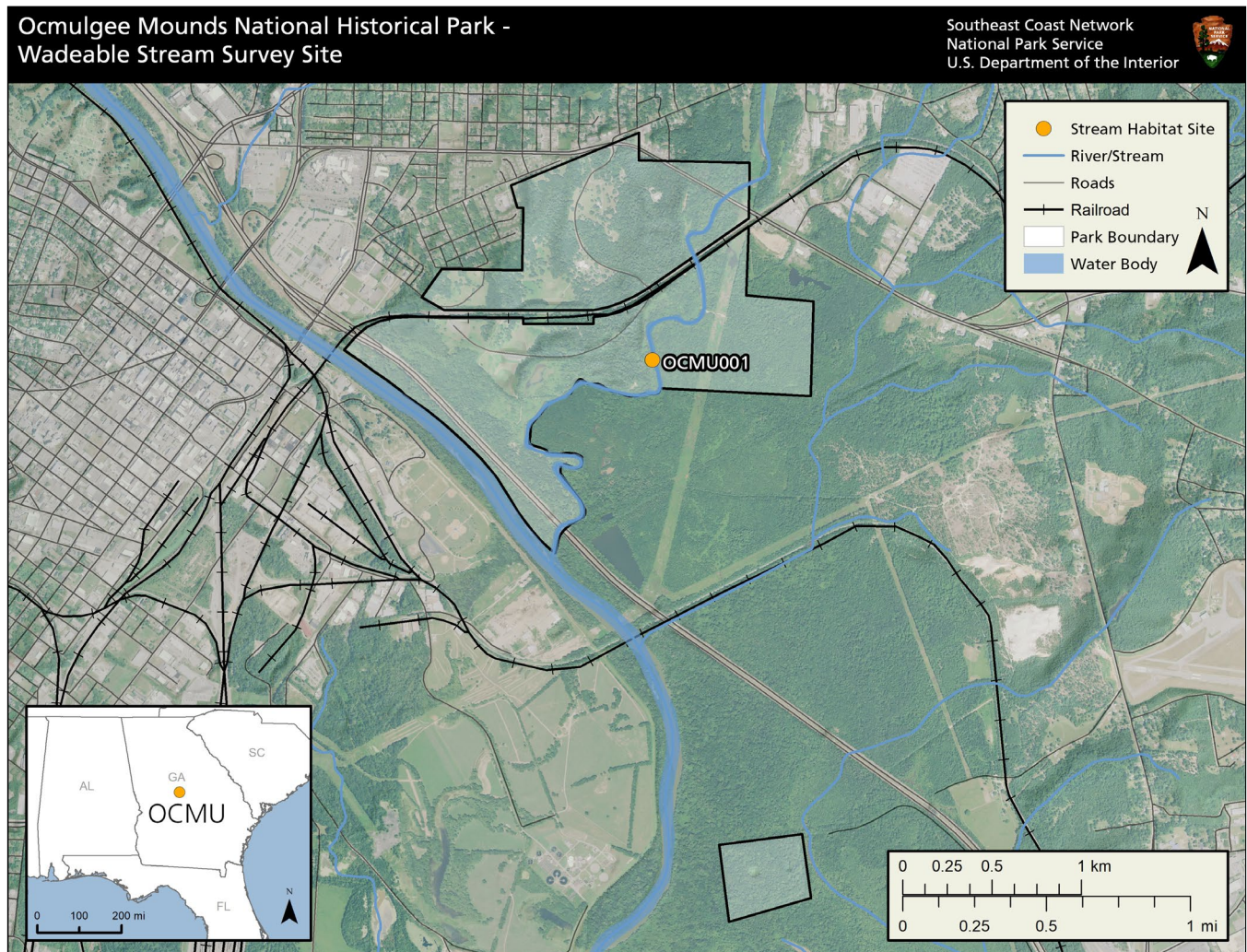


Figure 2. Map showing Ocmulgee Mounds National Historical Park and its wadeable stream site (OCMU001). Aerial imagery (National Agricultural Imagery Program, USDA NRCS 2017) and perennial streams (derived from a 10 meter (32.8 feet [ft]) digital elevation model; data from the U.S. Geological Survey)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

in 2012 noted extensive beaver activity within the park 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 park 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.

Previous Survey

On September 27, 2017, data were collected at Ocmulgee Mounds NHP to characterize the in- and near-channel habitat on a permanently monumented reach on Walnut Creek (OCMU001). These data, along with analysis of geographic information system (GIS) data, are presented in a baseline report (Cooper et al. 2019) that describes and compares 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).

The analysis of the GIS data found Walnut Creek's watershed at OCMU001 has low slope and relief and is covered mostly by forests and agricultural pasture. The major defining characteristics of the stream were the presence of floodplains and natural levees, a lack of riffle habitat, and a homogeneous channel slope throughout the reach. Though the majority of the watershed lies in the Appalachian

Piedmont physiographic province, the OCMU001's reach lies in the Upper Coastal Plain and is a low energy, depositional environment subject to regular flooding and slow post-flood draining.

The channel surveyed at OCMU001 was smaller than expected, given its place in the stream network (fifth Strahler order stream) and the relatively large size of its watershed (approximately 240 square kilometers [93 square miles {mi²}]). Cooper et al. (2019) interpreted the relatively small channel 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 into the wetlands to the southwest of OCMU001 through a power line right-of-way east of OCMU001 and a series of flood chutes and side channels.

Though the reach had a high abundance of large woody debris (LWD), based on the results of a pebble count and the type/distribution of the geomorphic channel unit (GCU) within the reach, in-stream habitat on OCMU001 was classified as "poor to fair" (Cooper et al. 2019). Given the complex hydrologic setting of OCMU001, Cooper et al. (2019) could not predict the site's response to changes in sediment supply and LWD, though they did not expect marked departures from this habitat classification. Finally, the stream did not have immediate management or safety concerns. Though, exotic invasive vegetation (i.e., privet [*Forestiera ligustrina*] and Chinese tallow [*Triadica sebifera*]) was observed in the area surrounding and outside of the channel.

Methods

The habitat characteristics and geomorphic parameters that were selected for monitoring are based on those collected by other federal organizations (USFS, Harrelson et al. 1994; USGS, Fitzpatrick et al. 1998; and EPA, Hughes 2000).

The physical structure of in- and near-stream habitat has a strong influence on the biological communities and overall

ecological integrity of lotic ecosystems (Newson and Newson 2000). Monitoring stream habitat not only provides an understanding of the physical suitability for aquatic species but can also identify stressors that could degrade other park resources and negatively affect visitor experiences.

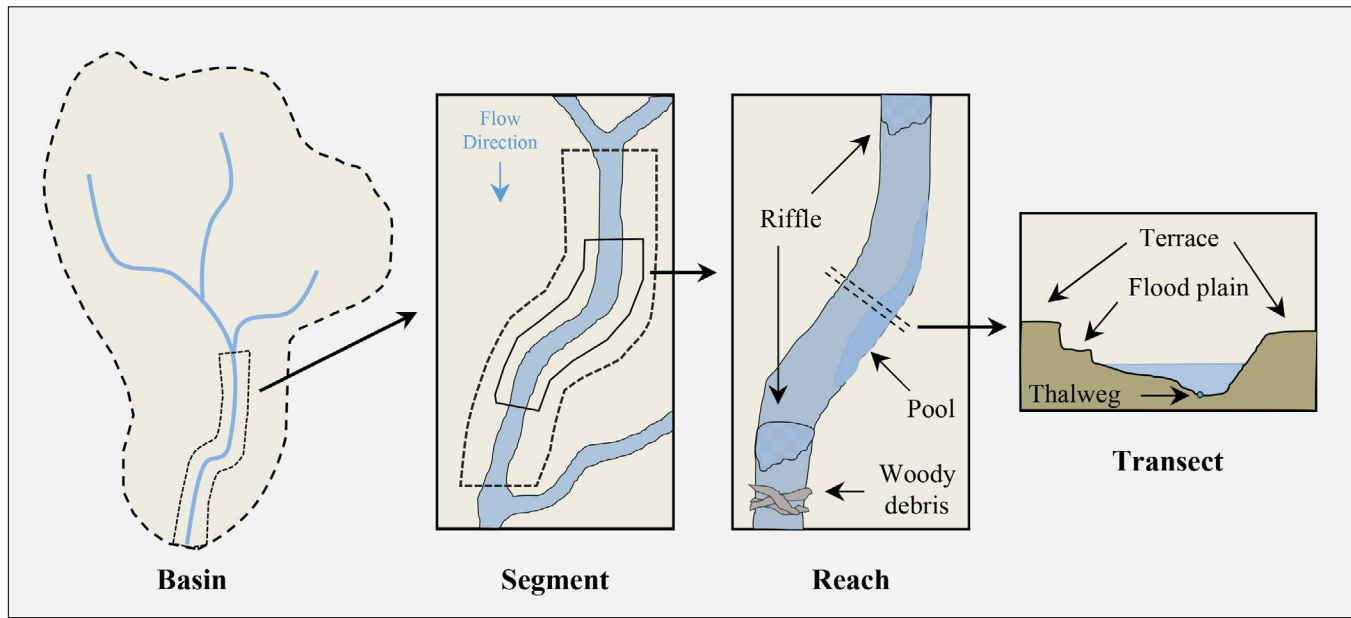


Figure 3. Spatial hierarchy of stream systems and scales of data collection (modified from Fitzpatrick et al. 1998). View in transect diagram is in the downstream direction.

Basin Characteristics

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

description of these basin characteristics can be found in McDonald et al. (2018a).

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

Reach-Scale Measurements

The reach-scale characteristics of each monitored reach are measured at and between 11 equidistant transects (distance between transects is two times average wetted width; Figure 4). Reach length is 20 times average wetted width (as determined during the initial survey of the reach). Data collected at each of these transects include vegetative bank cover, presence of eroding banks, bed and bank material, channel widths (e.g., wetted, active, bankfull,

and channel-full widths), water depth, and bank heights and angles. In addition to bankfull and channel-full bank heights, minimum bank height is also reported. Minimum bank height is the minimum bank height measured on each transect. A quantitative measure of bed sediment is obtained by conducting a Wolman pebble count on a representative riffle within the reach (Wolman 1954).

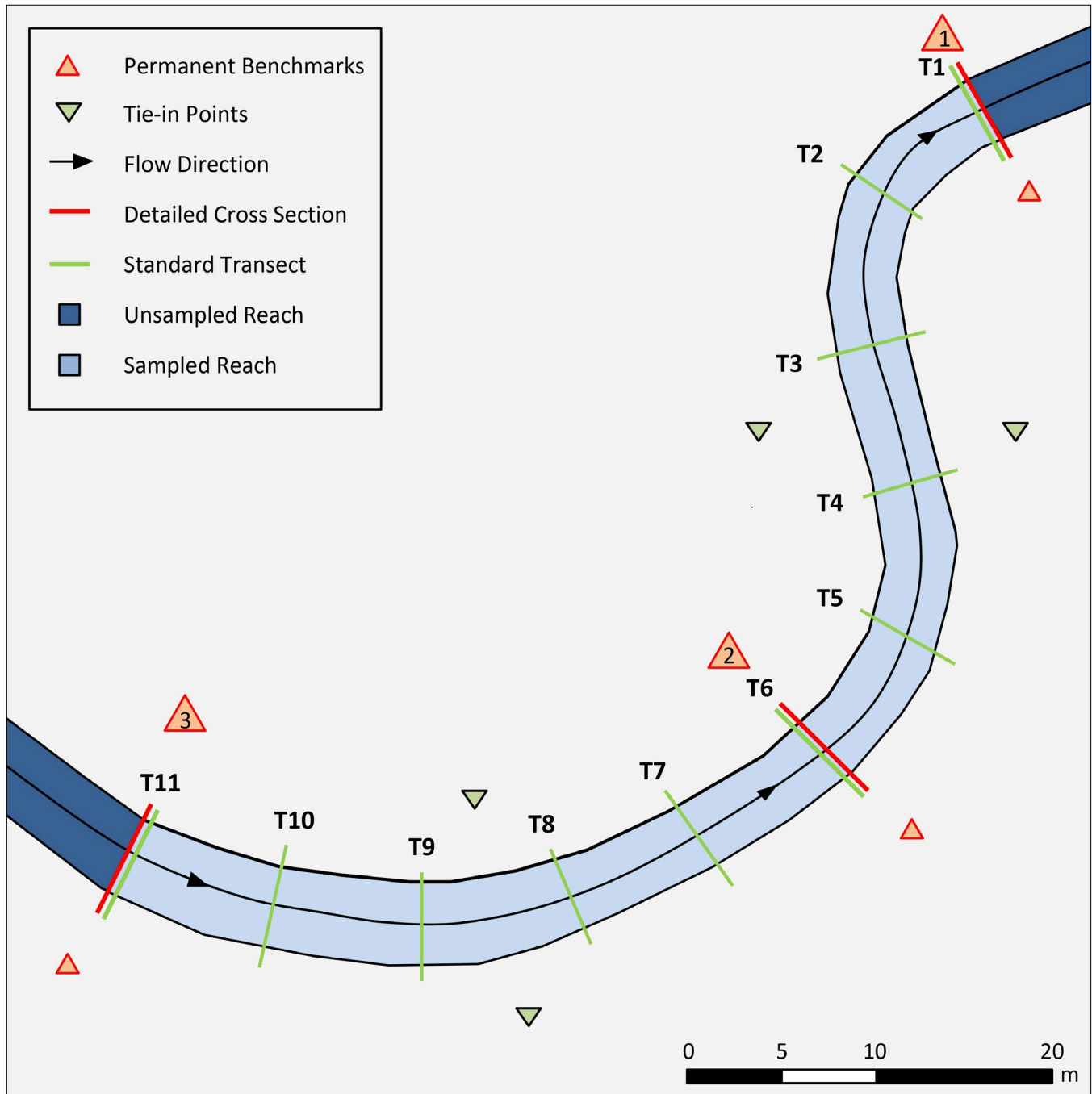


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.

These data provide an understanding of the geomorphic and or 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 Upper Coastal Plain have bank stability scores of ‘at-risk’ or ‘unstable.’ This condition is consistent with expectations, given that many comparable streams in the region are currently reestablishing functional floodplains within their highly entrenched channel systems.

To understand in-stream and near-channel habitats, measurements are also taken between each transect. These between transect measurements include: canopy cover, the amount and type of geomorphic channel units (GCUs) or in-stream habitat (e.g., high-energy riffles vs. low-energy pools),

an inventory of large woody debris (LWD; defined as greater than 1 meter [3.3 ft] in length and greater than 10 centimeters [3.9 inches {in}] in diameter as defined in McDonald et al. 2018a) within the reach, and a description of in-channel features (e.g., sand or cobble bars). Using these measures of in-stream habitat, each stream’s habitat is classified as ‘poor,’ ‘poor-to-fair,’ ‘fair,’ “fair-to-good,” or “good.” These classifications are a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical characteristics affect biodiversity and stream health on each reach. In addition to classifying each stream’s habitat, processes or events are identified that may influence future classification and lead to habitat improvement or degradation.

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

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

¹ Park and site water-quality index ratings are adapted from ratings established by the EPA (2012).

Detailed Transect Cross-Sections

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

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

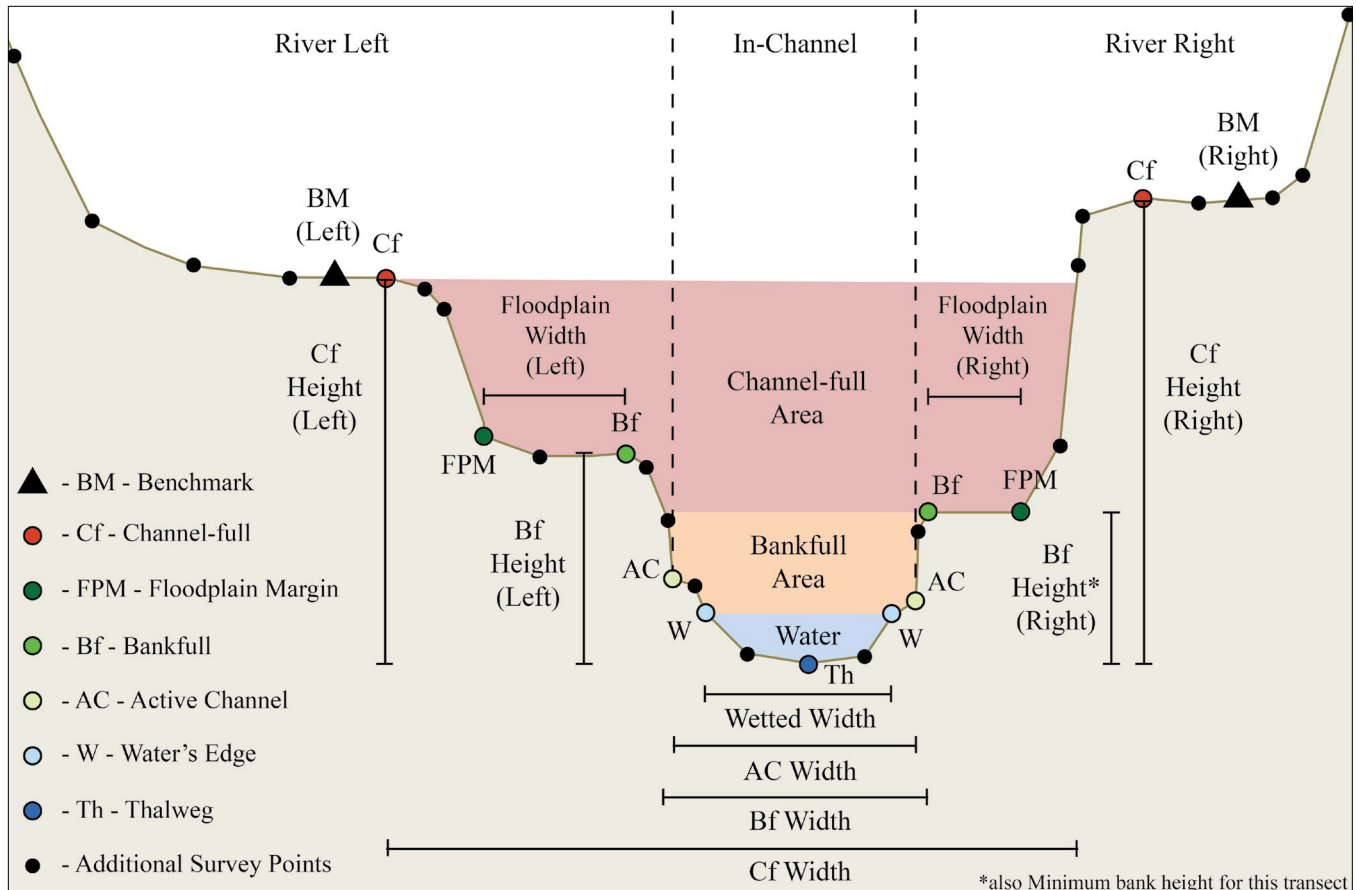


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes light blue (baseflow) and orange portions of the cross-section. Channel-full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

Statistical Analysis

The statistical significance of the difference of means between surveys (2017 and 2019) 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 (m);
5. active channel width (m);
6. channel-full width (m);
7. channel-full height (m);
8. bank angle (°); and
9. vegetative cover of the banks (%).

Bankfull width and height are not included in the statistical analysis because bankfull was not measured on each transect (due to lack of floodplain) and the number of bankfull measurements at each reach and between surveys was not always equal.

Results

On May 8, 2019, one stream reach on Walnut Creek (OCMU001) was surveyed following the methods outlined in SECN SOP 1.2.16 *Wadeable Stream Reach-Scale Field Data Collection–Version 1.0* (McDonald et al. 2018c) and SECN SOP 1.2.18 *Using a Total Station to Conduct a Stream Survey–Version 1.0* (McDonald et al. 2018d). The surveyed reach is on a fifth-order segment of the Walnut Creek stream network. Reach- and detailed transect-scale field survey results, in-office analyses, and statistical comparisons between monitoring years (2017 and 2019) are presented in the following sections. Transect-scale results and data summary tables for the 2019 survey of OCMU001 are provided in Appendix B; see Cooper et al. (2019) for transect-scale results and data summary tables from the 2017 survey.

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). The 2017 survey took place at the beginning of fall, and at the end of a rainy summer (Table 2). In 2019, the survey was conducted one week after a relatively large rainstorm but during a period of time that had much less precipitation than

in 2017. Additionally, there three more large events (greater than 1 inch [2.5 cm]) in the months prior to the 2017 survey.

OCMU001—Walnut Creek

Basin Characteristics

This section provides a brief summary of the basin characteristics of the watershed draining to OCMU001. For a more in-depth look at OCMU001’s basin characteristics and how they compare to third-order watersheds at Kennesaw Mountain NBP and Chattahoochee River NRA, see Cooper et al. (2019). Approximately 240 square kilometers (93 mi²) drain to OCMU001 and OCMU manages 0.65% of the watershed (Table 3). OCMU001’s watershed has low slope and relief and is covered mostly by forested land and grassland or pasture (Cooper et al. 2019). The land use land cover for OCMU001’s watershed has been relatively stable since 2011 (Table 4). The biggest change was an increase in forested land (57% to 64%) and a reduction in grassland or pasture (23% to 14%). Though the majority of the watershed lies in the Appalachian Piedmont physiographic province, OCMU001’s reach lies in the Upper Coastal Plain and is a low energy, depositional environment subject to regular flooding and slow post-flood draining (Cooper et al. 2019).

Table 2. Amount of precipitation and number of precipitation events >1 in in the week and month(s) prior to the 2017 and 2019 wadeable stream surveys at Ocmulgee Mounds NHP. Data from weather co-op station Macon 2.5 NNE.

Time Frame	Length of Period	Total Precipitation (Inches)	Number of Events Greater than 1 Inch
9/20/2017–9/27/2017	One Week	0.00	0
8/27/2017–9/27/2017	One Month	6.92	2
6/27/2017–9/27/2017	Three Months	18.13	4
5/1/2019–5/8/2019	One week	0.86	0
4/8/2019–5/8/2019	One Month	3.62	0
2/8/2019–5/8/2019	Three Months	8.54	1

Table 3. Watershed characteristics for OCMU001 which 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	OCMU001
Drainage Area (km ²)	239.65
NPS Managed Area (km ²)	0.65
NPS Managed Area (%)	0.3%
Total Stream Length (km)	401.73
Drainage Density	1.68
Strahler Order	5
Bifurcation Ratio	2.13
Entire Stream Gradient ¹	0.0021
Segment Gradient ²	0.0014
Slope—Average	4.87
Slope—Std. Dev.	3.52
Slope—Coefficient of variation (CV)	0.72
Basin Length (km)	39.26
Basin Shape ³	0.16
Basin Relief (m)	127
Basin Relief Ratio	0.003
Elevation—Std. Dev. (m)	21

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

² Segment gradient is calculated by dividing the difference in elevations at the top of the stream segment and the bottom of the stream segment by the stream length between.

³ Basin Shape is calculated by dividing drainage area by squared basin length.

Table 4. Land use land cover characteristics in 2011 compared to 2016 for OCMU001. The data included in this table are from the National Land Cover Dataset (Homer et al. 2015; Homer et al. 2020).

Variable	OCMU001 in 2011	OCMU001 in 2016
Developed Open & Low (%)	11	11
Developed Med. & High (%)	1	1
Forested (%)	57	64
Grassland (%)	23	14
Wetland (%)	3	3

Reach Description

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 tree falls continue to block most of this trail. Similar to what was observed during the 2017 survey (Cooper et al. 2019), OCMU001 has a sandy bed throughout the survey reach and the channel has a low degree of entrenchment. Floodplains were again observed, inset within the higher valley bottom surface, between T3 and T8 on river right, and between T6 and the upper extent of the reach on river left (Figure 6). Similar to the 2017

survey, natural levees were observed along the channel-side edge of both floodplain surfaces. Two well-developed ephemeral side channels enter the reach on river left between T2 and T3 and between T4 and T5. The reach that was surveyed was 110 meters (361 ft) long with 11 meters (36 ft) between transects. The following sections describe the differences in the 2017 and 2019 reach-scale habitat characteristics and channel morphology along OCMU001, as well as the changes that were observed on the detailed transects. Transect-scale survey results for OCMU001 can be found in Appendix B.

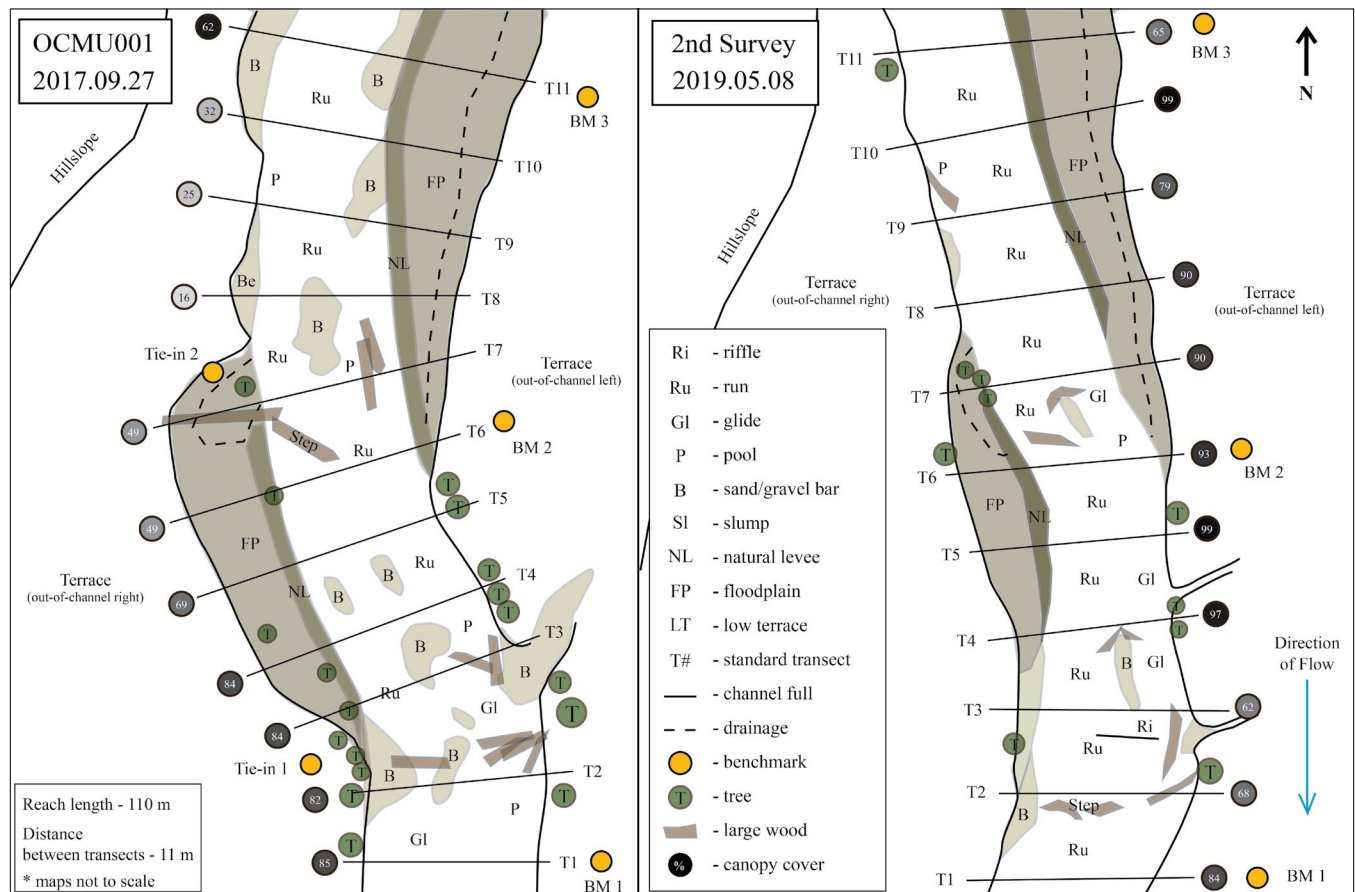


Figure 6. Reach-scale map of OCMU001. Important geomorphic surfaces and in-channel features are labeled to provide a context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect (high and low coverages are labeled). Only the dominant geomorphic channel units (GCU) are labeled on the map. Differences in planform and size of geomorphic surfaces are due to artistic differences and not actual changes (unless noted in the text).

Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) that were observed at OCMU001 during the 2017 and 2019 surveys were slightly different (Table 5). During 2017, the GCUs in the Walnut Creek reach were mostly run (60%) with some pool (28%) and glide (10%). During 2019, the majority of the habitat that was observed was run (88%) followed by glide (8%) and pool (3%). Additionally, in 2019, one small riffle area was observed within the reach. In 2017, no riffles were identified in the reach, so the pebble count was done just upstream of OCMU001 at the nearest riffle (Cooper et al. 2019). Bed sediment in the representative riffle was finer in 2019 compared to 2017 (Table 6), and the difference in the means (3.36 and 4.54 millimeters [0.13 and 0.19 in]) was significant (P-value = 0.012; Table 7). Additionally, almost all sediment size quartiles (i.e., D₅, D₁₆) were finer in 2019 compared to 2017 (Table 6).

Forty-nine pieces of LWD (n = 49) were observed within OCMU001's channel during 2019 (Table 8). This increase in the number of pieces of LWD led to an increase in the total volume of LWD per channel area from 0.0023 m³/m² to 0.0033 m³/m². Canopy cover in 2019 (57%) was similar to 2017 (58%; Table 9). Mean thalweg depth (0.40 and 0.34 meters [1.31 and 1.12 ft]) and mean thalweg position (55% and 53%) were very similar from 2017 to 2019 (Table 10). In 2019, thalweg depths were slightly less variable (CV = 0.21 versus CV = 0.35, in 2017) and thalweg position was slightly more variable (CV = 0.76 versus CV = 0.63, in 2017). The largest difference in thalweg characteristics was the maximum thalweg depth in 2019 (0.46 meters [1.5 ft]) was 0.20 meters [0.66 ft] shallower than in 2017 (0.66 meters [2.17 ft]; Table 10).

Table 5. Geomorphic channel units (GCUs) observed in the area between transects during the 2017 and 2019 surveys at OCMU001 [SD—standard deviation].

GCU Type	Site	Year	Frequency	Max (%)	Mean (%)	SD (%)
Rifle	OCMU001	2017	0	0	0	0
	OCMU001	2019	1	5	1	2
Run	OCMU001	2017	9	90	61	30
	OCMU001	2019	10	100	88	13
Glide	OCMU001	2017	2	60	10	21
	OCMU001	2019	3	30	8	13
Pool	OCMU001	2017	10	50	28	14
	OCMU001	2019	3	10	3	4
Step	OCMU001	2017	1	20	2	6
	OCMU001	2019	1	10	1	3

Table 6. Particle size distributions of bed sediment (in millimeters [mm]) from the pebble counts conducted during 2017 and 2019 at OCMU001. The subscripts indicate the percent of the sample that is smaller than the reported diameter.

Statistic	OCMU001 (n=100) in 2017	OCMU001 (n=100) in 2019
Min	< 0.062	< 0.062
D ₅	1.00	< 0.062
D ₁₆	1.00	1.00
D ₅₀	4.00	3.00
Mean	4.54	3.36
D ₈₄	8.00	6.00
D ₉₅	11.95	8.95
Max	21.00	11.00

Table 7. Difference in means t-test results comparing the 2017 and 2019 surveys of OCMU001. The significance of the differences is indicated by: “–” not significant or “*” p-value <0.05 [m—meters; mm—millimeters].

Measurement	n	OCMU001 in 2017	OCMU001 in 2019	P-value	Significance
Pebble Count (mm)	100	4.54	3.36	0.012	*
Thalweg Depth (m)	11	0.40	0.34	0.226	–
Thalweg Position (%)	11	0.55	0.53	0.889	–
Wetted Width (m)	11	7.20	8.01	0.054	–
Active Channel Width (m)	11	8.41	8.43	0.969	–
Channel-full Width (m)	11	18.27	20.06	0.346	–
Minimum Bank Height (m)	22	1.28	1.29	0.895	–
Channel-full Height (m)	22	1.56	1.62	0.161	–
Bank Angle (°)	22	48.77	36.35	0.019	*
Vegetative Cover (%)	22	57.73	56.82	0.906	–

Table 8. Summary statistics for the large woody debris measured in 2017 and 2019 at OCMU001 [m—meters].

Statistic	Site	Year	n	Length (m)	Diameter (m)	Volume (m ³)
Min	OCMU001	2017	24	1.00	0.12	0.01
	OCMU001	2019	49	1.02	0.10	0.01
Mean	OCMU001	2017	24	2.48	0.21	0.09
	OCMU001	2019	49	2.61	0.18	0.09
Max	OCMU001	2017	24	7.50	0.37	0.24
	OCMU001	2019	49	7.48	0.67	1.45
SD	OCMU001	2017	24	1.75	0.07	0.07
	OCMU001	2019	49	1.40	0.11	0.21
Sum	OCMU001	2017	24	–	–	2.10
	OCMU001	2019	49	–	–	4.59
Per Channel Area (m ³ /m ²)	OCMU001	–	–	–	–	0.0023
	OCMU001	–	–	–	–	0.0033

Table 9. Descriptive statistics for reach-scale canopy cover in 2017 and 2019 at OCMU001 [SD—standard deviation; CV—coefficient of variation].

Site	Year	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
OCMU001	2017	11	16	58	85	25	0.44
OCMU001	2019	11	6	57	100	36	0.62

Table 10. Reach-scale averaged thalweg conditions in 2017 and 2019 at OCMU001 [SD—standard deviation; CV—coefficient of variation].

Thalweg	Site	Year	n	Min	Mean	Max	SD	CV
Depth (m)	OCMU001	2017	11	0.21	0.40	0.66	0.14	0.35
	OCMU001	2019	11	0.20	0.34	0.46	0.07	0.21
Position ¹ (%)	OCMU001	2017	11	5	55	95	35	0.63
	OCMU001	2019	11	5	53	95	40	0.76

¹ position is percent distance from left active channel bank

Channel Morphology

Wetted widths were on average wider during 2019, 8.01 meters (26.28 ft) compared to 7.20 meters (23.62 ft) in 2017 (Table 11). This difference in mean wetted width between survey years was not significant (p-value = 0.054; Table 7). Mean active channel widths, were similar in 2019 (8.43 meters [27.66 ft]) compared to 2017 (8.41 meters [27.59 ft]; Table 11), and this slight difference was not significant (Table 7). One more bankfull width was measured in 2019 (n = 10) than in 2017 (n = 9; Table 11). Bankfull widths were, on average, slightly narrower in 2019 (10.63 meters [34.88 ft] versus 10.98 meters [36.02 ft]). Differences in mean bankfull width were not statistically compared because there were not an equal number of bankfull widths measured each year. Mean channel-full width was wider in 2019 (20.06 meters [65.81 ft]) compared to 2017 (18.27 meters [59.94 ft]; Table 11), though this difference was not significant (p-value = 0.346; Table 7).

Mean minimum bank height (lowest bank height on a transect), mean bankfull height, and mean channel-full height in 2019 (1.29 meters [4.23 ft], 1.00 meter [3.28 ft], and 1.62 meters [5.31 ft], respectively) were all similar to their

2017 means (1.28 meters [4.20 ft], 1.04 meters [3.41 ft], and 1.56 meters [5.12 ft], respectively; Table 12). The difference in mean channel-full height between survey years was not significant (p-value = 0.161; Table 7). Like 2017, variability in channel-full heights was low (CV = 0.09[2017] and 0.07 [2019]; Table 12).

The same number of undercuts were measured in 2017 and 2019 (n = 2; Table 12). The mean depth of undercut during 2017 (0.10 meter [0.33 ft]) was much less than the mean undercut depth in 2019 (0.52 meters [1.71 ft]). Bank angles were on average less steep during 2019 (36°) compared to 2017 (49°; Table 12) and this difference was significant (p-value = 0.019; Table 7). Bank vegetation cover was similar in 2019 (57%) compared to 2017 (58%; Table 12). This slight difference was not significant (p-value = 0.906; Table 7). Mean and maximum bank stability scores in 2019 (11.57 and 14.00) were lower (more stable) in 2019 compared to 2017 (12.48 and 15.00; Table 12). While the minimum (most stable) score in 2019 (9.5) was slightly higher (less stable) than 2017 (8.5), these minimum scores are both classified as 'at-risk' (Table 1).

Table 11. Reach-scale width characteristics in 2017 and 2019 at OCMU001 [m—meters; SD—standard deviation; CV—coefficient of variation].

Widths	Site	Year	n	Min	Mean	Max	SD	CV
Wetted	OCMU001	2017	11	5.82	7.20	8.67	0.98	0.14
	OCMU001	2019	11	6.30	8.01	9.13	0.88	0.11
Active Channel	OCMU001	2017	11	5.82	8.41	11.16	1.37	0.16
	OCMU001	2019	11	6.42	8.43	9.41	0.83	0.10
Bankfull	OCMU001	2017	9	7.21	10.98	13.25	1.84	0.17
	OCMU001	2019	10	7.87	10.63	12.10	1.26	0.12
Channel-Full	OCMU001	2017	11	10.45	18.27	23.01	4.62	0.25
	OCMU001	2019	11	11.91	20.06	25.50	4.06	0.20

Table 12. Reach-scale averaged bank characteristics in 2017 and 2019 at OCMU001 [m—meters; SD—standard deviation; CV— coefficient of variation].

Bank Characteristics	Site	Year	n	Min	Max	Mean	SD	CV
Minimum Bank Height ^{1,2} (m)	OCMU001	2017	22	0.77	1.28	1.88	0.31	0.25
	OCMU001	2019	22	0.72	1.29	1.91	0.37	0.28
Bankfull Height ^{1,3} (m)	OCMU001	2017	12	0.77	1.04	1.32	0.14	0.17
	OCMU001	2019	12	0.72	1.00	1.35	0.19	0.20
Channel-full Height ¹ (m)	OCMU001	2017	22	1.28	1.56	1.88	0.14	0.09
	OCMU001	2019	22	1.42	1.62	1.91	0.11	0.07
Bank Undercut ³ (m)	OCMU001	2017	2	0.06	0.10	0.14	0.06	0.57
	OCMU001	2019	2	0.08	0.52	0.95	0.62	1.19
Bank Angle (°)	OCMU001	2017	22	23	49	85	20	0.41
	OCMU001	2019	22	12	36	61	13	0.35
Vegetation Cover (%)	OCMU001	2017	22	10	58	100	30	0.51
	OCMU001	2019	22	20	57	90	20	0.36
Bank Stability ⁴	OCMU001	2017	22	8.50	12.48	15.00	1.93	0.15
	OCMU001	2019	22	9.50	11.57	14.00	1.18	0.10

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

Detailed Transects

The detailed transects on OCMU001 were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3). Average bankfull area increased by 0.94 square meters (10.12 ft²) from 2019 (5.50 square meters [59.20 ft²]) to 2017 (4.56 square meters [49.08 ft²]; Table 13). There were also increases in average bankfull width (0.63 meters [2.07 ft]) and average bankfull height (0.10 meters [0.33 ft]). Like bankfull area, channel-full area increased by 3.51 square meters (37.78 ft²) from 2019 (19.54 square meters [210.33 ft²]) to 2017 (16.03 square meters [172.55 ft²]; Table 13). There were also increases in average channel-full width (1.52 meters [4.99 ft]) and

average channel-full height (0.24 meters [0.79 ft]). Water surface slope (longitudinal profile) for this section of Walnut Creek was 0.0017 m/m in 2019 and 0.0018 m/m in 2017 (Figure 7; Table 13). The longitudinal profile is relatively flat in the middle and upstream portions of the stream and is influenced by two LWD steps (rise in water surface elevation) on T2 and T8. The reach is relatively straight and sinuosity (1.04) did not change between survey years (Table 13). The change in bankfull and channel-full characteristics of each detailed transect are described in the following three paragraphs.

Table 13. Comparison of 2017 and 2019 reach scale and average detailed transect characteristics at OCMU001 [n^1 —Collected at each standard transect; n^2 —calculated at each detailed transect; m—meters].

Site	Year	n^1	Slope	Sinuosity	n^2	Bankfull Area (m^2)	Bankfull Width (m)	Bankfull Height (m)	Channel-full Area (m^2)	Channel-full Width (m)	Channel-full Height (m)
OCMU001	2017	11	0.0018	1.04	3	4.56	8.29	0.70	16.03	18.11	1.43
OCMU001	2019	11	0.0017	1.04	3	5.50	8.92	0.79	19.54	19.63	1.67
Difference	2017–2019	–	0.0001	0.00	–	0.94	0.63	0.10	3.51	1.52	0.24

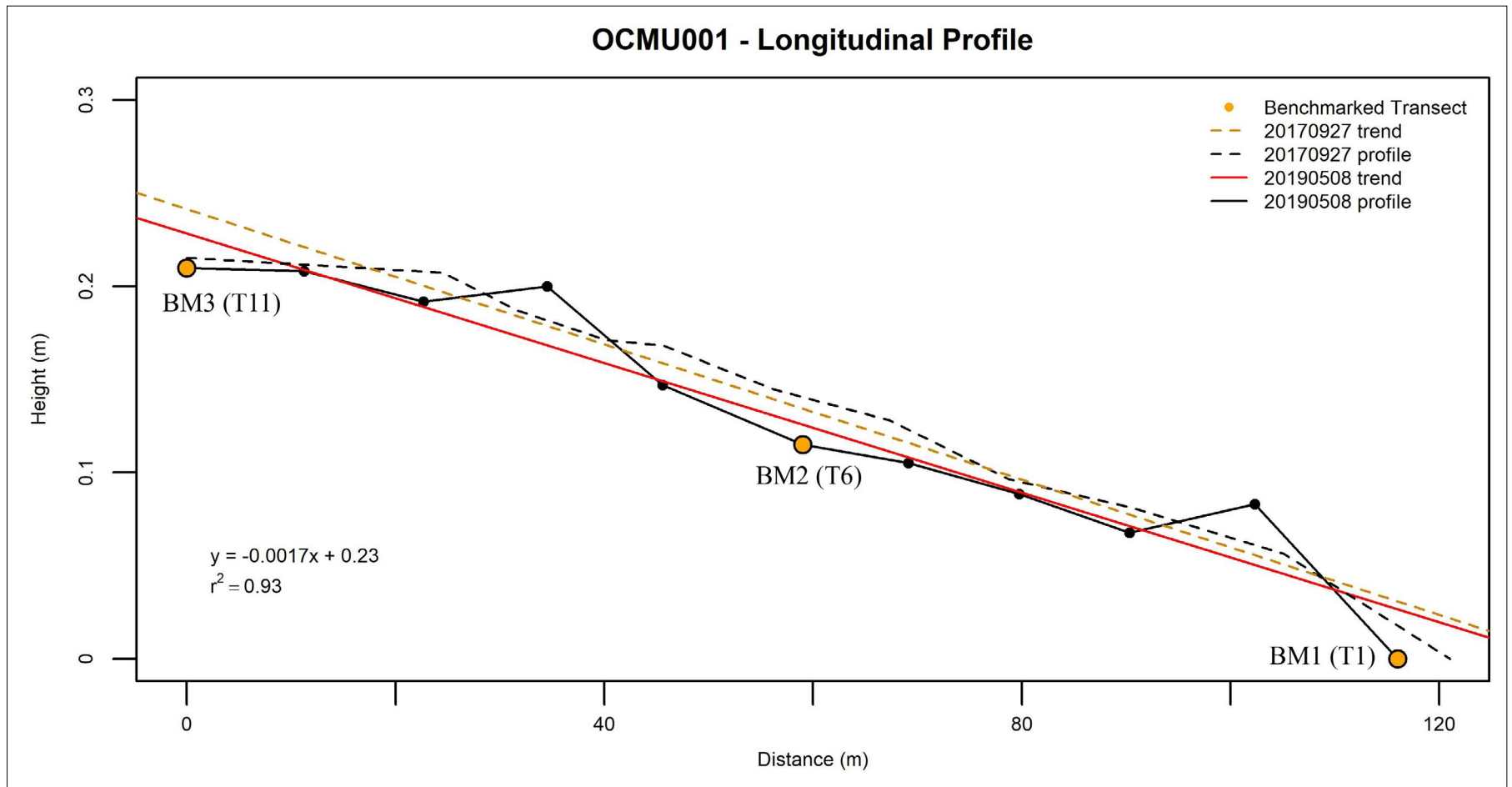


Figure 7. Longitudinal profile for OCMU001. The red line on the graph corresponds to the interpreted slope of the reach (-0.0017 m/m). The r^2 value describes the strength of the trend line. The 'T#' in parentheses indicates the standard transect number on which the detailed transects were surveyed.

Detailed transect 1 (T1) is entrenched and no floodplains or incipient floodplain surfaces were present (Figure 8). In order for changes in the bed and bank to be quantified, bankfull cross-sectional area and width were estimated using the reach-scale average bankfull height from the 2017 survey. Bankfull cross-sectional area on detailed transect 1 decreased by 0.70 square meters (7.53 ft²) and bankfull width decreased by 0.13 meters (0.43 ft; Table 14). The thalweg on detailed transect 1 (T1) has incised slightly and the incipient mid-channel bar that was observed during 2017 has either eroded away or migrated downstream (Figure 8). A new mid-channel bar has developed on detailed transect

1 and has fully breached the water surface. Channel-full area on detailed transect 1 increased by 2.73 square meters (29.39 ft²) from 2017 (12.94 square meters [139.29 ft²]) to 2019 (15.67 square meters [168.67 ft²]; Table 14). The 2017-interpreted channel-full surface on river right is no longer a flat surface (due to bank slumping) and channel-full on this side of the stream had to be placed further away from the channel and higher up the bank. As a result of this change in the interpreted extent of channel-full on river right, both channel-full width and channel-full height increased on detailed transect 1 (1.85 meters and 0.26 meters [6.07 ft and 0.85 ft], respectively; Table 14).

Table 14. Changes to cross-sectional characteristics on detailed transect 1 at OCMU001 [m—meters].

Type	Year	Area (m ²)	Width (m)	Height (m)
Bankfull	2017	8.79	10.15	1.04
	2019	8.43	10.01	1.04
Change	2017–2019	-0.36	-0.13	0.00
Channel-Full	2017	12.94	12.04	1.43
	2019	15.67	13.89	1.68
Change	2017–2019	2.73	1.85	0.26

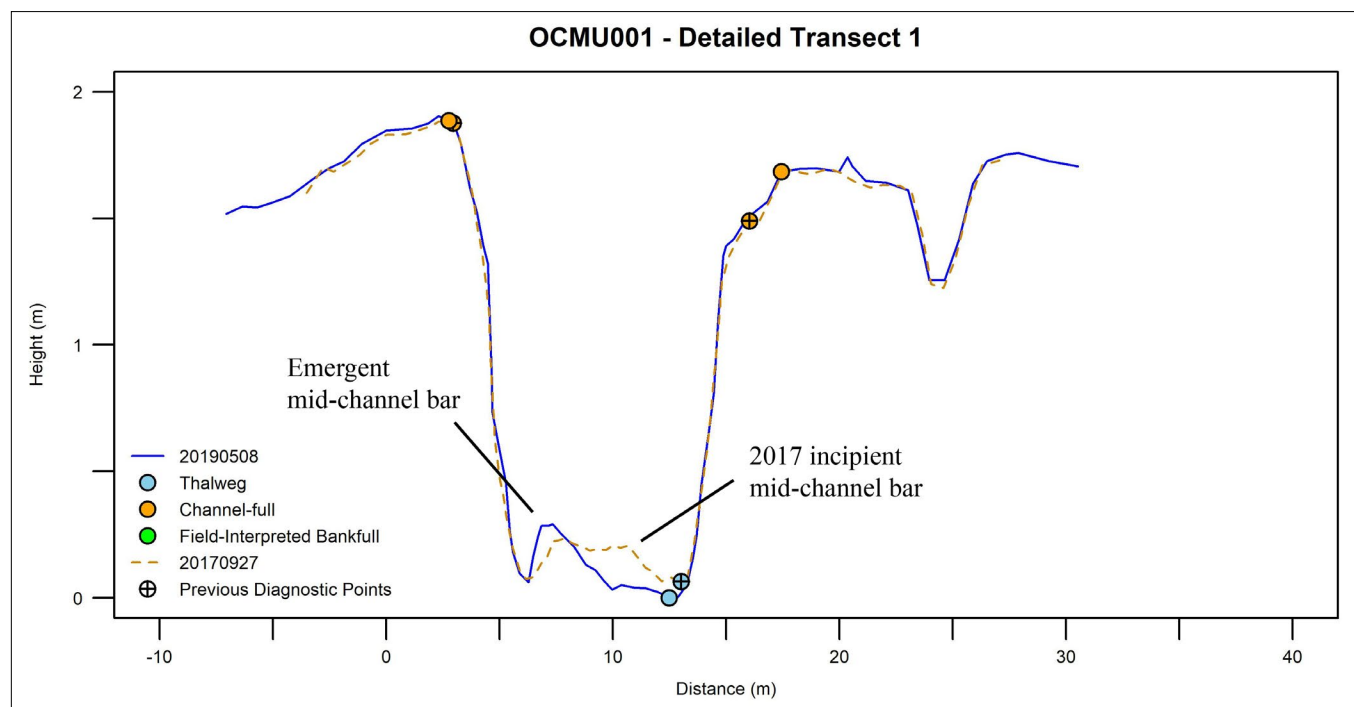


Figure 8. Differences between 2017 and 2019 surveys of detailed transect 1 at OCMU001. View is in the downstream direction (river left is on the left).

Bankfull cross-sectional area on detailed transect 2 (T6) increased by 1.17 square meters (12.59 ft²) from 2017 (2.56 square meters [27.56 ft²]) to 2019 (3.73 square meters [40.15 ft²]; Table 15). Slightly different interpretations of where the bankfull tops are (Figure 9) led to a slight increase in bankfull width (0.51 meters [1.67 ft]; Table 15). In addition to the increase in bankfull width, erosion of the 2017 incipient mid-channel bar contributed to the increase in bankfull area (Figure 9). Like river right on detailed transect 1, the 2017-interpreted channel-full surface on river left

on detailed transect 2 is no longer a flat surface (due to bank slumping) and channel-full on river left stream is now approximately 0.31 meters [1.02 ft] higher. Though there was a substantial amount of aggradation on the floodplain surface on river right on detailed transect 2 (which would decrease channel-full area; Figure 9), due to the large increase in channel-full height, channel-full area increased by 6.22 square meters [66.95 ft²] from 2017 (15.76 square meters [169.64 ft²]) to 2019 (21.98 square meters [236.58 ft²]).

Table 15. Changes to cross-sectional characteristics on detailed transect 2 at OCMU001 [m—meters].

Type	Year	Area (m ²)	Width (m)	Height (m)
Bankfull	2017	2.56	6.38	0.62
	2019	3.73	6.89	0.70
Change	2017–2019	1.17	0.51	0.08
Channel-Full	2017	15.76	19.34	1.48
	2019	21.98	21.56	1.79
Change	2017–2019	6.22	2.21	0.31

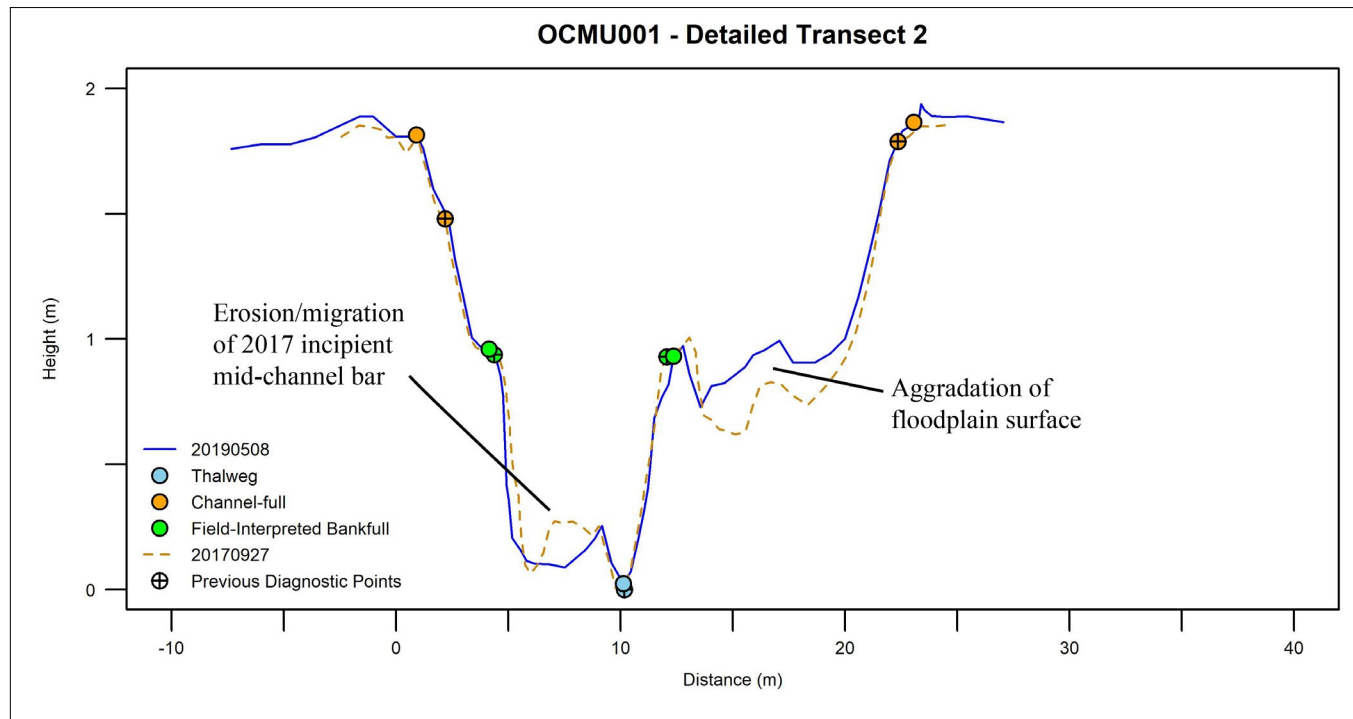


Figure 9. Differences between 2017 and 2019 surveys of detailed transect 2 at OCMU001. View is in the downstream direction (river left is on the left).

Bankfull cross-sectional area on detailed transect 3 (T11) increased by 2.00 square meters (21.53 ft²) from 2017 (2.34 square meters [25.19 ft²]) to 2019 (4.34 square meters [46.72 ft²]; Table 16). This large increase in bankfull area is due to the loss of the ‘floodplain’ surface along river right that was observed in 2017, coupled with a slight incision of the thalweg (Figure 10). Channel-full area on detailed transect 3

increased by 1.59 square meters [17.11 ft²] from 2017 (19.38 square meters [208.60 ft²]) to 2019 (20.97 square meters [225.72 ft²]; Table 16). Aggradation of sediment on the floodplain surface on river left offset some of the increase in channel-full area caused by the loss of the floodplain surface on river right (Figure 10).

Table 16. Changes to cross-sectional characteristics on detailed transect 3 at OCMU001 [m—meters].

Type	Year	Area (m ²)	Width (m)	Height (m)
Bankfull	2017	2.34	8.34	0.43
	2019	4.34	9.86	0.64
Change	2017–2019	2.00	1.52	0.21
Channel-Full	2017	19.38	22.94	1.38
	2019	20.97	23.45	1.52
Change	2017–2019	1.59	0.51	0.14

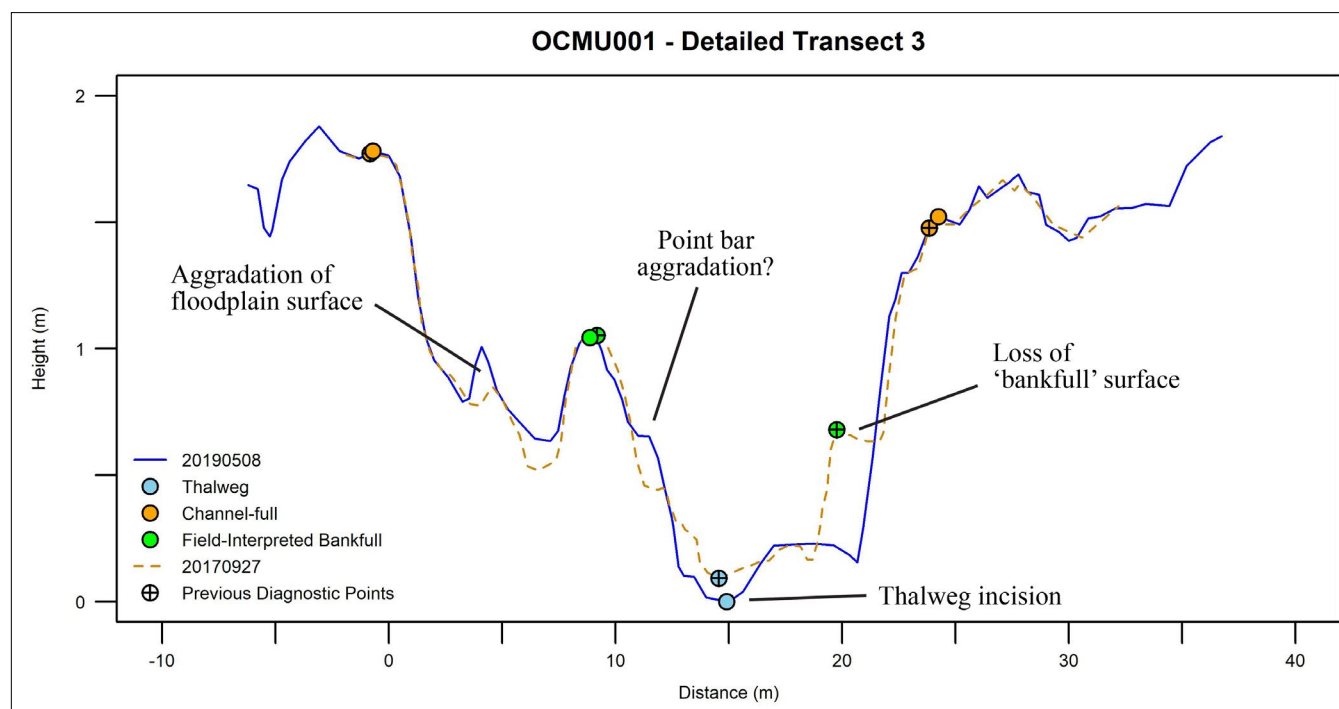


Figure 10. Differences between 2017 and 2019 surveys of detailed transect 3 at OCMU001. View is in the downstream direction (river left is on the left).

Implications and Synthesis of Results

This section describes the processes that were observed at each reach and the potential changes that may occur between surveys (next field surveys are tentatively scheduled for spring or summer 2022). The processes 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

The reach that was surveyed on Walnut Creek (OCMU001) is within 100 meters (328 ft) of a social trail, but visitors are not expected to interact with the stream along the surveyed reach (no obvious trails down to the stream). In-stream habitat changed substantially from 2017 to 2019 (Table 5). In 2019, only a few non-run habitats were identified within the reach (Figure 6). Additionally, thalweg depth was shallower in 2019 compared to 2017. Though the increased homogeneity of the in-stream habitat may be the result of different surveyors identifying geomorphic channel units (GCU) within the reach, the reduction in thalweg position backs up this observed change in habitat (conversion of pools and glides to run habitat). Also, bed material was finer in 2019 compared to 2017 (p -value = 0.012; Table 7). While different riffles were used to conduct the pebble count (a riffle just upstream of the surveyed reach was used in 2017) the fining of the bed is interpreted, along with the homogenizing of habitat and reduction in thalweg depth, as an actual change to the reach. In addition to the changes observed in the type and distribution of GCUs, thalweg depth, and average diameter of bed sediment, an even higher volume of LWD per channel area was observed in 2019 compared to 2017 (Table 8).

The abundance of LWD is a positive habitat attribute for fish and benthic macroinvertebrates, yet the fining of the bed material is likely negatively affecting benthic organisms, and the reach continues to lack habitat heterogeneity thought to promote biodiversity (Allan and Castillo 2007; Palmer et al. 2010). Additionally, Cooper et al. (2019) found that the high amount of sandy and fine bed material suggests the bed sediment is highly mobile, which would put further stress on any benthic organisms. Due to the reduction in the diversity of in-stream habitat, and the increased fining of the bed, OCMU001's in-stream habitat classification was downgraded from 'poor to fair' to 'poor.' As mentioned earlier, 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, the increased fining of the bed and the increased homogeneity in-stream habitat may not be a permanent change. The reduction in the quality of the habitat may be a 'natural' fluctuation within the stream network related more to complex response (Schumm 1973) than a permanent change in the reach. The lack of change in the longitudinal profile supports the interpretation that the reach has not undergone a significant permanent change, and the additional fine sediment that has been deposited within the reach may move through this portion of the stream network by the next survey (tentatively scheduled for spring or summer 2022).

There were very few reach-scale morphologic changes that occurred along OCMU001. The slight differences in channel width (except for wetted width) and bank heights from 2017 to 2019 were likely related to small differences in the interpretation of the location of the diagnostic surfaces used to measure these characteristics. On the other hand, the changes in wetted width that were observed were statistically significant. Wider wetted widths could be related to slightly different flow conditions during the surveys or it could be related to the infilling of the pools and glides. Assuming discharge was approximately equal during each survey, the continuity equation (discharge equals velocity times area) requires that a reduction in thalweg depth (due to infilling of pools and glides) would lead to an increase in width or velocity. The increased wetted width could be related to this need to increase either width or velocity due to the reduction in thalweg depth. Alternatively, the storm that hit Walnut Creek's watershed a week prior to the survey could have contributed to the increase in wetted width observed during the 2019 survey (Table 2). Though, the reduction in thalweg depth suggests the increase in wetted width is related more to the continuity equation than a significant increase in discharge.

The major morphological changes within the reach were observed on the detailed transects. These changes were related to bank slumping, stream bed restructuring, and floodplain aggradation. Channel-full area increased substantially on detailed transects 1 (T1; Table 13) and 2 (T6). These substantial increases were related to the 2017

interpreted channel-full bank top slumping along either river right (T1; Figure 8) or river left (T6; Figure 9) and there no longer being a flat ‘channel-full’ surface on these portions of the bank. Slumping also had a significant impact on detailed transect 3 (T11; Figure 10).

The entire 2017 interpreted ‘floodplain’ bankfull surface was lost between 2017 and 2019. This loss of the floodplain surface on river right is interpreted as the slow, yet progressive, erosion of the toe of a slump block, and the continuance of slumping until the entire block slumped beneath the water surface (Figure 11). This slump block may now become the core of an in-channel bar if the block has become stabilized in the bed of the stream. The stream bed of the other detailed transects has also been restructured. This bed restructuring supports the interpretation that

the bed along OCMU001 is highly mobile which is likely detrimental to benthic organisms within the reach.

Floodplain aggradation on detailed transects 2 (T6) and 3 (T11), along with the overall shallowing of average thalweg depth within the reach, indicates that a substantial amount of sediment is being supplied to the reach. If this increased sediment supply is not a permanent change to the system, the reach will likely re-establish a more diverse assemblage of in-stream habitats and the floodplain and channel will continue to be connected. If this increased sediment supply continues, there could be substantial changes to the reach that could change the relationship between the channel and its out-of-channel areas. Due to the complex hydrologic conditions that characterize the reach (Cooper et al. 2019), the exact changes that could occur are difficult to predict.

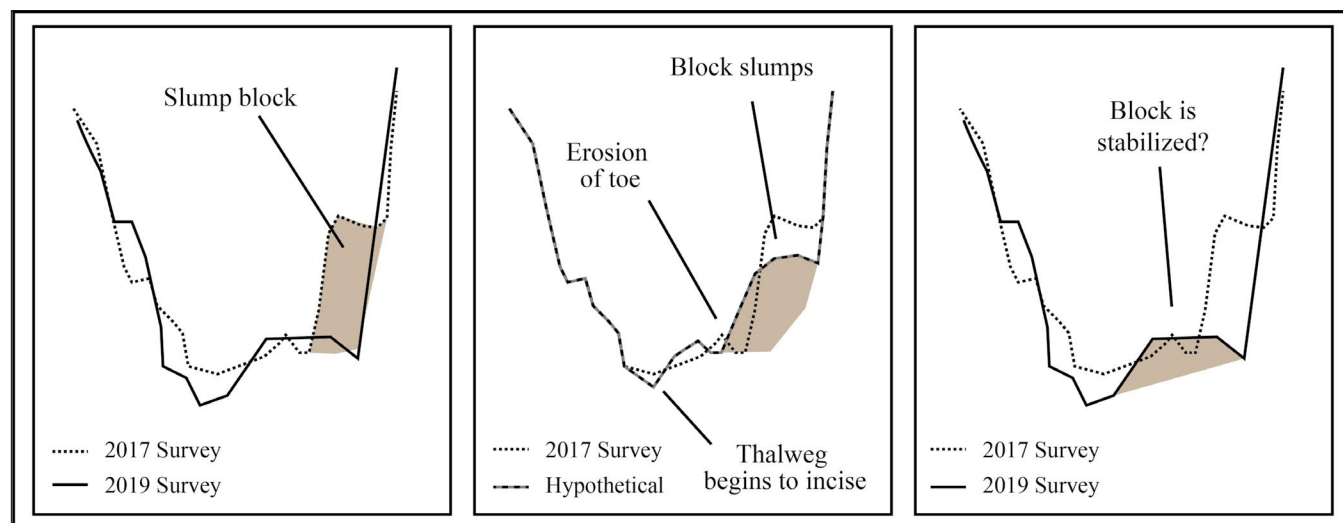


Figure 11. Hypothesized process by which the ‘floodplain’ surface on detailed transect 3 (T11) slumped into the channel and contributed to thalweg incision.

Conclusion

Walnut Creek's watershed at OCMU001 has low slope and relief and is covered mostly by forested lands and agricultural pasture. The major defining characteristics of the stream continue to be the presence of floodplains and natural levees, a lack of riffle habitat, and a homogeneous channel slope throughout the reach. In-stream habitat changed substantially from 2017 to 2019. In 2019, only a few non-run habitats were identified within the reach, while in 2017 there was a mixture of pool and run habitats. Additionally, thalweg depth was shallower, bed material was finer in 2019 compared to 2017, and the floodplain surfaces along detailed transects 2 (T6) and 3 (T11) had a significant amount of aggradation. Floodplain aggradation, along with the overall shallowing of average thalweg depth within the reach, indicates that a substantial amount of sediment is being supplied to the reach. If this increased sediment supply continues, there could be substantial changes to the reach that could change the relationship between the channel and its out-of-channel areas. The exact changes that could occur are difficult to predict due to the complex hydrologic conditions that characterize the reach (Cooper et al. 2019).

The reduction in the diversity of in-stream habitat and the increased fining of the bed contributed to OCMU001's in-stream habitat's classification being downgraded from 'poor to fair' to 'poor'. This classification is a generalized interpretation of in-stream habitat and additional work is needed to determine how flow (e.g., flashiness of flow and baseflow conditions), water quality, and in-stream physical

characteristics affect biodiversity and stream health at Ocmulgee Mounds NHP. The reduction in the quality of the habitat may be a 'natural' fluctuation within the stream network related more to complex response (Schumm 1973) than a permanent change in the reach. The lack of change in the longitudinal profile supports the interpretation that the reach has not undergone a significant permanent change and the additional fine sediment deposited within the reach may move through this portion of the stream network by the next survey (tentatively scheduled for spring or summer 2022).

The major morphological changes observed within the reach were seen on the detailed transects. These changes were related to bank slumping, stream bed restructuring, and floodplain aggradation. Bank slumping was interpreted to have contributed to the large observed increase in channel-full area on detailed transects 1 (T1) and 2 (T6), as well as the loss of the 'floodplain' surface along river right on detailed transect 3 (T11). The bed restructuring along the detailed transects supports the interpretation that the bed along OCMU001 is highly mobile. The prevalence of slumping along all three detailed transects also suggests the banks are quite unstable. The highly mobile bed and unstable banks should not be interpreted as a management concern and are expected characteristics for streams in this portion of the Upper Coastal Plain. Except for the high density of exotic invasive vegetation that continues to occupy the area surround the stream, there were no immediate management concerns identified by the survey.

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Appendix A. Explanation of Variables

Table A-1. Explanation of Variables.

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

^a collected at each standard transect (11 measurements)

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

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

Variable	Variable Scale	Description
Bankfull 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
In-channel features	Transect ^a	A description of the in-channel features (e.g., bars or islands) that are present along a transect
Floodplain width	Transect ^a	The width(s) of floodplain(s) present along rivers left and/or right
Bank Undercut	Transect ^a	Where the bank overhangs the channel due to lateral erosion at the base of the bank
Bank Angle	Transect ^a	The dominant bank angle from active channel boundary to the top of the bank
Bank Sediment	Transect ^a	The dominant sediment composition of the channel banks
Bank Erosion	Transect ^a	The presence of and type erosion (e.g., lateral or slump) that is observed on the channel banks
Bank Cover	Transect ^a	A visual estimate of the percent of the channel banks that has vegetative cover

^a collected at each standard transect (11 measurements)

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

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Appendix B. 2019 Survey Results for OCMU001

The following appendix provides transect-scale figures, results, and data summary tables of the 2019 survey of OCMU001. Figures include a watershed map (Figure B-1); photographs taken in the upstream, downstream, left bank, and right bank directions at each detailed transect (T1, T6, and T11; Figures B-2 through B-13); and cross-sectional channel characteristics at each detailed transect (Figures

B-14 through B-16). Tables describe watershed land use characteristics (Table B-1), observed geomorphic channel units (Table B-2), characteristics of large woody debris (Table B-3), canopy cover percentages (Table B-4), channel and bank characteristics (Table B-5), and cross-sectional channel characteristics at each detailed transect (Tables B-6 through B-8).

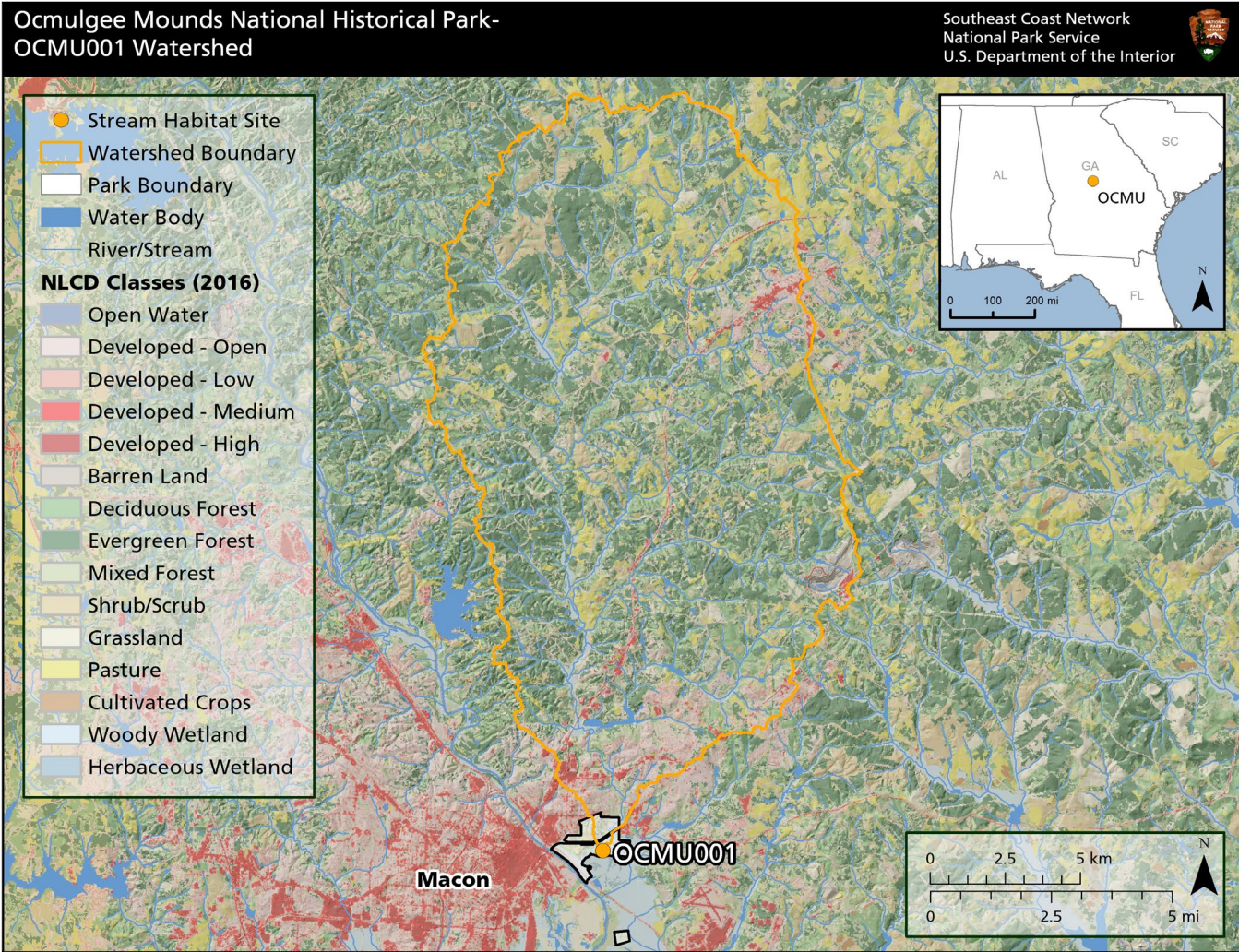


Figure B-1. Map showing the watershed draining to OCMU001 at Ocmulgee Mounds National Historical Park. The land use/land cover (NLCD 2016, Homer et al. 2020) and perennial streams (derived from a 10-meter (32.8-foot [ft]) digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.



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



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



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



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



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



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



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



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



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



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



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



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

Table B-1. Land use land cover characteristics for 2001, 2006, 2011, and 2016 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; 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 ¹	8	8	9	8
Developed—Low ¹	2	3	2	3
Developed—Medium ¹	1	1	1	1
Developed—High ¹	0	0	0	0
Barren	1	1	1	1
Deciduous	31	31	28	20
Evergreen	25	24	22	29
Mixed Forest	7	7	6	15
Shrub	0	2	3	4
Grassland	11	10	14	4
Pasture	10	9	9	10
Cultivated	0	0	0	0
Woody Wetland	3	3	3	3
Herbaceous Wetland	0	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 GCU.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	0	90	0	0	10
2–3	5	90	0	5	0
3–4	0	70	30	0	0
4–5	0	70	30	0	0
5–6	0	100	0	0	0
6–7	0	70	20	10	0
7–8	0	100	0	0	0
8–9	0	100	0	0	0
9–10	0	90	0	10	0
10–11	0	100	0	0	0
Frequency	1	10	3	3	1
Max (%)	5	100	30	10	10
Mean (%)	1	88	8	3	1
Median (%)	0	90	0	0	0
SD (%)	2	13	13	4	3

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

LWD ID	Length (m)	Diameter (m)	Volume (m ³)	Transect Interval	Function	Position
1	1.25	0.53	0.28	1	Sediment Trap	Buried
2	2.58	0.16	0.05	1	Sediment Trap, Organic Trap	Buried
3	2.27	0.21	0.08	1	Sediment Trap, Organic Trap	Jam
4	2.54	0.13	0.03	1	Organic Trap	Jam
5	1.02	0.10	0.01	1	None	Free
6	2.33	0.20	0.07	2	Jam	Jam

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

Transect	Canopy Cover (%)
1	87
2	91
3	85
4	100
5	82
6	54
7	40
8	15
9	6
10	6
11	63
Min (%)	6
Max (%)	100
Mean (%)	57
Median (%)	63
SD (%)	36
CV	0.62

Table B-5. Comparison of 2017 and 2019 reach scale and average detailed transect characteristics at OCMU001 [m—meters; L—left; R—right; DS—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	0.72	0.98	1.91	1.60	1.28	1.30	1.21	1.35	0.46	0.26	0.36	0.20
Bankfull Height ^{1,2} (m)	6	6	0.72	0.98	1.21	1.35	0.91	1.09	0.82	1.05	0.21	0.14	0.23	0.13
Channel-full Height ^{1,2} (m)	11	11	1.42	1.47	1.91	1.71	1.66	1.58	1.65	1.58	0.12	0.09	0.07	0.06
Water Depth at Base ³ (m)	11	11	-0.10	-0.11	-0.06	-0.06	-0.08	-0.08	-0.07	-0.08	0.01	0.01	–	–
Bank Undercut ² (m)	2	0	0.08	0.00	0.95	0.00	0.52	–	0.52	–	0.62	–	1.19	–
Bank Angle (°)	11	11	17	12	56	61	39	34	43	37	13	13	0.33	0.38
Vegetation Cover (%)	11	11	20	30	80	90	53	61	50	60	21	20	0.40	0.32
Bank Stability ⁴	11	11	At-Risk	At-Risk	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.38	0.99	0.12	0.09

¹ above thalweg

² statistics are based on the transects where feature is present

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

⁴ See Table 1 for explanation of scores

Table B-6. Cross-sectional characteristics for detailed transect 1 at OCMU001 in 2019 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	8.43	10.84	0.78	10.01	1.04	9.63
Channel-full	15.67	15.15	1.03	13.89	1.68	8.24
Ratio	1.86	1.40	1.33	1.39	1.62	0.86

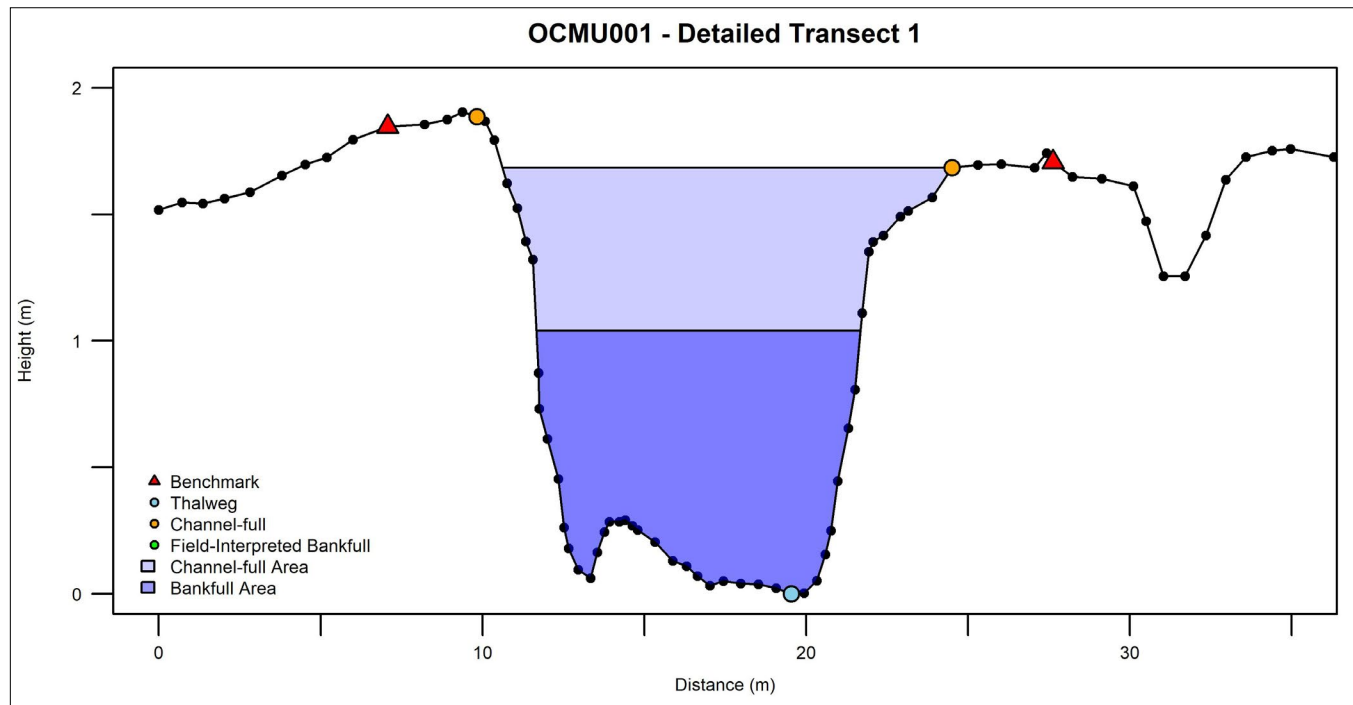


Figure B-14. Detailed transect 1 at OCMU001 in 2019. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

Table B-7. Cross-sectional characteristics for detailed transect 2 at OCMU002 in 2019 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	3.73	7.41	0.50	6.89	0.70	9.79
Channel-full	21.98	22.54	0.98	21.56	1.79	12.04
Ratio	5.89	3.04	1.94	3.13	2.55	1.23

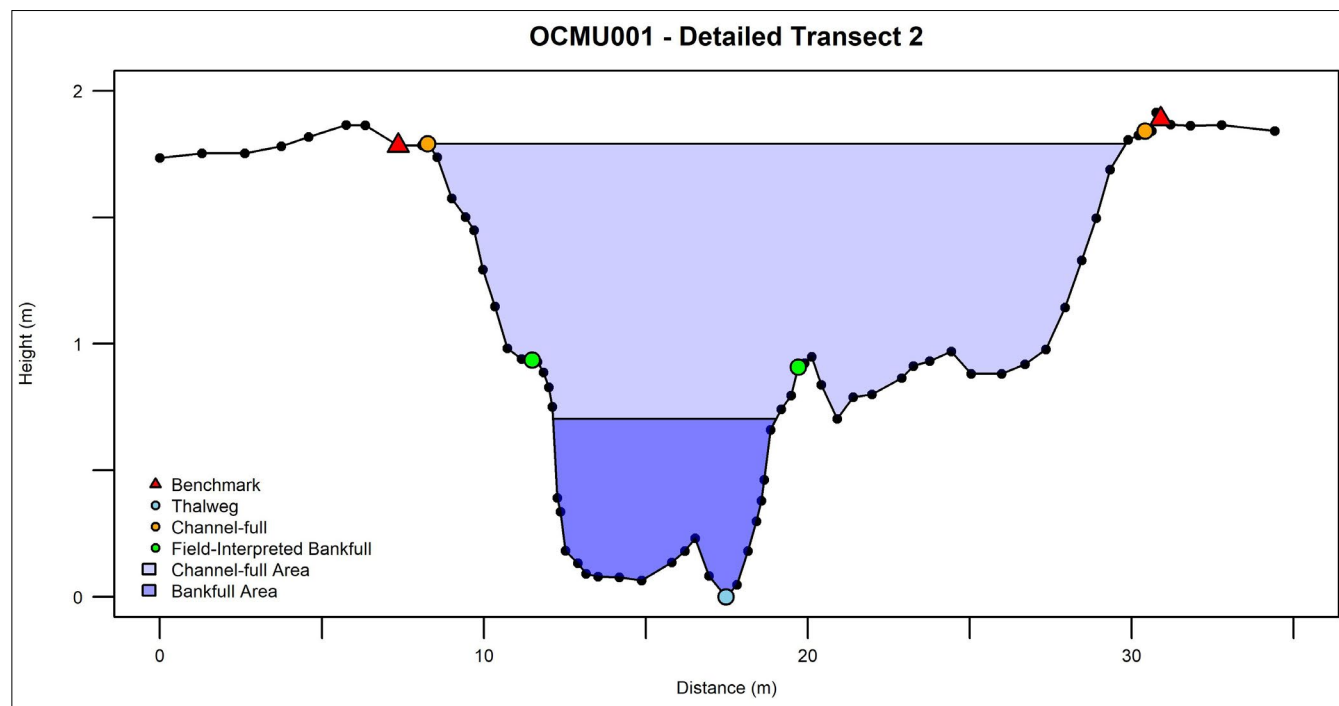


Figure B-15. Detailed transect 2 at OCMU001 in 2019. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

Table B-8. Cross-sectional characteristics for detailed transect 3 at OCMU001 in 2019 [m—meters].

Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	4.34	10.13	0.43	9.86	0.64	15.51
Channel-full	20.97	24.28	0.86	23.45	1.52	15.40
Ratio	4.83	2.40	2.01	2.38	2.39	0.99

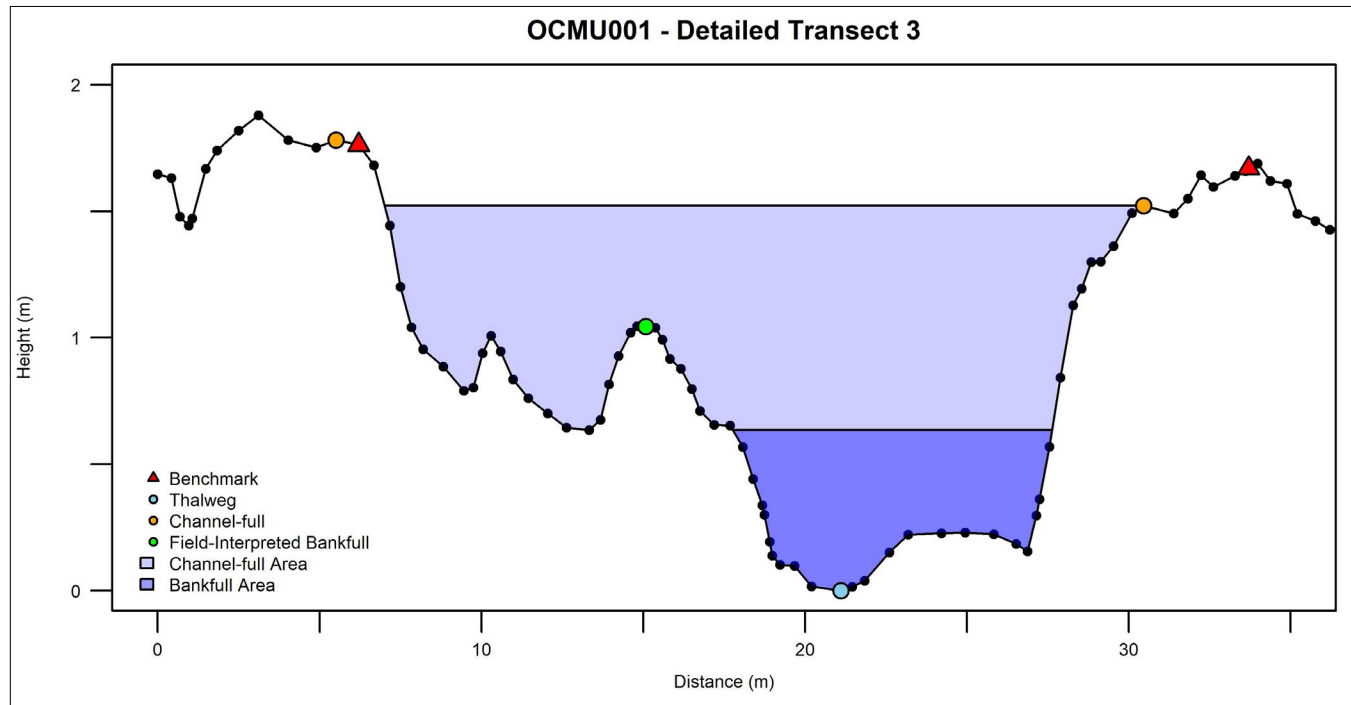


Figure B-16. Detailed transect 3 at OCMU001 in 2019. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals light blue plus dark blue). View is in the downstream direction.

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