National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2026/442
https://doi.org/10.36967/2318455

Wadeable Stream Habitat Monitoring at Horseshoe Bend National Military Park

2023 Change Report



Looking upstream toward transect 6 at the wadeable stream monitoring site on “Claybed Creek” (HOBE001) at Horseshoe Bend National Military Park.

NPS / SECN

Wadeable Stream Habitat Monitoring at Horseshoe Bend National Military Park: 2023 Change Report

Science Report NPS/SR—2026/442

Jacob M. McDonald

University of North Georgia
Lewis F. Rogers Institute for Environmental and Spatial Analysis
Arts & Technology, Room 2022
3820 Mundy Mill Rd.
Oakwood, GA 30566

Please cite this publication as:

McDonald, J.M. 2026. Wadeable Stream Habitat Monitoring at Horseshoe Bend National Military Park: 2023 Change Report. Science Report NPS/SR—2026/442. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2318455

NPS 407/199698, June 2026

The National Park Service Science Report Series disseminates information, analysis, and results of scientific studies and related topics concerning resources and lands managed by the National Park Service. The series supports the advancement of science, informed decisions, and the achievement of the National Park Service mission.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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

This report is available in digital format from the National Park Service DataStore and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Contents

Page

Figures....iv
Tables....vii
Abstract....ix
List of Terms or Acronyms....x
Summary and Key Findings....xii
Introduction....1
Study Area....2
Horseshoe Bend National Military Park....4
Previous Survey and Current Interpretations....6
Methods....8
Basin Characteristics....8
Reach-Scale Measurements....9
Detailed Transect Cross-Sections....12
Statistical Analysis....13
Results....14
Weather Conditions....14
Basin Characteristics....14
Reach Description....16
Habitat Characteristics....18
Channel Morphology....20
Detailed Transects....22
Implications and Synthesis of Results....28
Conclusion....30
Literature Cited....31
Appendix A. Explanation of Variables....35
Appendix B. Survey Results for HOBE001....38

Figures

Page

Figure 1. Generalized channel evolution model. 4

Figure 2. Map showing Horseshoe Bend National Military Park and its wadeable stream site (HOBE001). 5

Figure 3. Spatial hierarchy of stream systems and scales of data collection. 8

Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects. 10

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. 12

Figure 6. Reach-scale map of HOBE001. 17

Figure 7. Differences between the 2019 and 2023 surveys of detailed transect 1 (T1) at HOBE001. 23

Figure 8. Differences between the 2019 and 2023 surveys of detailed transect 2 (T6) at HOBE001. 23

Figure 9. Differences between the 2019 and 2023 surveys of detailed transect 3 (T11) at HOBE001. 24

Figure 10. Longitudinal profile for HOBE001. 26

Figure 11. Map display of watershed size for HOBE001 versus CHAT004, CHAT008, CHAT010, and CHAT014 watersheds. 38

Figure 12. HOBE001 looking upstream from T1 (detailed transect 1). 39

Figure 13. HOBE001 looking downstream from T1 (detailed transect 1). 40

Figure 14. HOBE001 facing the left bank on T1 (detailed transect 1). 41

Figure 15. HOBE001 facing the right bank on T1 (detailed transect 1). 42

Figure 16. HOBE001 looking upstream from T2. 43

Figure 17. HOBE001 looking downstream from T2. 44

Figure 18. HOBE001 facing the left bank on T2. 45

Figure 19. HOBE001 facing the right bank on T2. 46

Figure 20. HOBE001 looking upstream from T3. 47

Figure 21. HOBE001 looking downstream from T3. 48

Figure 22. HOBE001 facing the left bank on T3. 49

Figure 23. HOBE001 facing the right bank on T3. 50

Figures (continued)

Page

Figure 24. HOBE001 looking upstream from T4. 51
Figure 25. HOBE001 looking downstream from T4. 52
Figure 26. HOBE001 facing the left bank on T4. 53
Figure 27. HOBE001 facing the right bank on T4. 54
Figure 28. HOBE001 looking upstream from T5. 55
Figure 29. HOBE001 looking downstream from T5. 56
Figure 30. HOBE001 facing the left bank on T5. 57
Figure 31. HOBE001 facing the right bank on T5. 58
Figure 32. HOBE001 looking upstream from T6 (detailed transect 2). 59
Figure 33. HOBE001 looking downstream from T6 (detailed transect 2). 60
Figure 34. HOBE001 facing the left bank on T6 (detailed transect 2). 61
Figure 35. HOBE001 facing the right bank on T6 (detailed transect 2). 62
Figure 36. HOBE001 looking upstream from T7. 63
Figure 37. HOBE001 looking downstream from T7. 64
Figure 38. HOBE001 facing the left bank on T7. 65
Figure 39. HOBE001 facing the right bank on T7. 66
Figure 40. HOBE001 looking upstream from T8. 67
Figure 41. HOBE001 looking downstream from T8. 68
Figure 42. HOBE001 facing the left bank on T8. 69
Figure 43. HOBE001 facing the right bank on T8. 70
Figure 44. HOBE001 looking upstream from T9. 71
Figure 45. HOBE001 looking downstream from T9. 72
Figure 46. HOBE001 facing the left bank on T9. 73
Figure 47. HOBE001 facing the right bank on T9. 74
Figure 48. HOBE001 looking upstream from T10. 75
Figure 49. HOBE001 looking downstream from T10. 76
Figure 50. HOBE001 facing the left bank on T10. 77
Figure 51. HOBE001 facing the right bank on T10. 78

Figures (continued)

Page

Figure 52. HOBE001 looking upstream from T11 (detailed transect 3).....79
Figure 53. HOBE001 looking downstream from T11 (detailed transect 3).....80
Figure 54. HOBE001 facing the left bank on T11 (detailed transect 3). 81
Figure 55. HOBE001 facing the right bank on T11 (detailed transect 3). 82
Figure 56. Detailed transect 1 at HOBE001.....86
Figure 57. Detailed transect 2 at HOBE001.....87
Figure 58. Detailed transect 3 at HOBE001.....88

Tables

Page

Table 1. Bank Stability Index (BSi) from Fitzpatrick et al. (1998).....11

Table 2. Amount of precipitation and number of precipitation events greater than 1 inch (2.5 cm) during and in the week and month(s) prior to the 2019 and 2023 wadeable stream survey at HOBE. 14

Table 3. Watershed characteristics for HOBE001 compared to four selected reaches from Chattahoochee River NRA (CHAT). 15

Table 4. Land use/land cover characteristics in 2019 and 2023 for the watershed draining to HOBE001.....16

Table 5. Comparison of geomorphic channel units (GCUs) observed in the 2019 and 2023 surveys at HOBE001.....18

Table 6. Particle size distributions of bed sediment (in millimeters) from the pebble counts conducted in 2019 and 2023 at HOBE001. 18

Table 7. Difference in means t-test results comparing the 2019 and 2023 surveys of HOBE001.....19

Table 8. Summary statistics for the large woody debris measured in 2019 and 2023 at HOBE001.....19

Table 9. Comparison of the variability in canopy cover in 2019 and 2023 at HOBE001.....20

Table 10. Comparison of reach-scale averaged thalweg conditions in 2019 and 2023 at HOBE001.....20

Table 11. Comparison of reach-scale averaged width characteristics in 2019 and 2023 at HOBE001.....20

Table 12. Comparison of average reach-scale bank heights in 2019 and 2023 at HOBE001.....21

Table 13. Comparison of average reach-scale bank characteristics in 2019 and 2023 at HOBE001.....22

Table 14. Comparison of the 2019 and 2023 reach-scale and mean detailed transect-scale characteristics on HOBE001 [m = meters]. 25

Table 15. Changes to cross-sectional characteristics on detailed transect 1 (T1) at HOBE001 [m = meters]. 26

Table 16. Changes to cross-sectional characteristics on detailed transect 2 (T6) at HOBE001 [m = meters]. 27

Tables (continued)

Page

Table 17. Changes to cross-sectional characteristics on detailed transect 3 (T11) at HOBE001 [m = meters]. 27

Table 18. Definitions of the variables used in this report. 35

Table 19. Geomorphic channel units (GCUs) observed in the area between transects at HOBE001. 82

Table 20. Characteristics of the large woody debris observed at HOBE001 [m = meters]. 83

Table 21. Variability of canopy cover observed at HOBE001. 84

Table 22. Average reach-scale bank characteristics at HOBE001. 85

Table 23. Cross-sectional characteristics for detailed transect 1 at HOBE001 [m = meters]. 86

Table 24. Cross-sectional characteristics for detailed transect 2 at HOBE001 [m = meters]. 86

Table 25. Cross-sectional characteristics for detailed transect 3 at HOBE001 [m = meters]. 87

Abstract

This report summarizes stream habitat monitoring conducted under the Southeast Coast Network (SECN) protocol, which assesses the status and trends of stream and near-channel conditions to support park management. The study focuses on a permanently monumented reach (HOBE001) along "Claybed Creek," a second-order stream within Horseshoe Bend National Military Park. Surveys were conducted in 2019 (baseline) and 2023 to evaluate geomorphic and habitat changes over time.

Baseline findings from 2019 indicated that HOBE001 exhibited moderate watershed slope and relief, high drainage shape, and predominantly forested and pasture land cover. The channel appeared to be in the widening stage of evolution and featured multiple elevated entrenched surfaces, interpreted as erosional and semi-ephemeral rather than stable floodplains. In-stream habitat was classified as "poor-to-fair," largely due to low geomorphic diversity and limited large woody debris (LWD).

The 2023 resurvey identified several notable changes in watershed and reach-scale conditions. Land cover analysis revealed a 10% decrease in forested area with a corresponding increase in shrubland, likely driven by upstream forestry activities. Within the reach, a significant treefall event introduced substantial LWD between transects T3 and T4, while channel incision in the upper reach was linked to the loss of a large wood step and upstream migration of a resulting knickpoint. Sediment eroded from upstream areas contributed to increased in-channel bar formation and a statistically significant fining of bed material.

Despite finer sediment conditions, habitat quality improved to "fair-to-good" due to increased LWD and greater heterogeneity in geomorphic channel units. These changes suggest enhanced structural complexity and potential for improved habitat stability. However, future conditions remain uncertain and will depend on the persistence of LWD and balance between sediment supply and transport. Stabilization of the large wood may promote further channel adjustment, including possible bifurcation or lateral migration.

No immediate management concerns were identified. Continued monitoring is recommended, particularly near the upstream road crossing, where potential knickpoint migration could pose infrastructure risks. Overall, observed changes highlight the dynamic nature of the system and the importance of repeated monitoring to distinguish between transient adjustments and longer-term trends.

List of Terms or Acronyms

ANOVA: Analysis of variance

B: Sand/gravel bar

Be: Bench

Bf: Bankfull

BM: Benchmark

BSi: Bank stability index

C: Cobble bar

CHAT: Chattahoochee River 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

LT: Low terrace

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

R: Riffle

Ru: Run

SECN: Southeast Coast Network

SOP: Standard operating procedure

T#: Standard transect

Un: Undercut

Summary and Key Findings

The Southeast Coast Network (SECN) stream habitat monitoring protocol collects data to give park resource managers insight into the status of and trends in stream and near-channel habitat conditions (McDonald et al. 2018a). Wadeable stream assessments are implemented at the five SECN inland parks with wadeable streams. These include Horseshoe Bend National Military Park, Kennesaw Mountain National Battlefield Park, Ocmulgee Mounds National Historical Park, Chattahoochee River National Recreation Area, and Congaree National Park. Streams chosen for assessment were specifically targeted for management interest (e.g., trail erosion issues and upstream urban development) or to provide context for similar-sized stream(s) within the park or network (McDonald 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 April 24, 2019, data were collected at Horseshoe Bend National Military Park (HOBE) to characterize the in- and near-channel habitat on a permanently monumented reach on a second Strahler stream order stream (Strahler 1957) nicknamed “Claybed Creek” (HOBE001). These data, along with analysis of remotely-sensed geographic information system (GIS) data, are presented in a baseline report that describes and compares the watershed-, reach-, and transect-scale characteristics of HOBE001 to selected second-order streams at Chattahoochee River National Recreation Area (CHAT004, CHAT008, CHAT010, and CHAT014; McDonald 2020). Though the historic and contemporary land use/land cover in the watersheds draining to HOBE001 and the CHAT streams are different (which is expected), these comparisons were included to provide context for the survey at HOBE001. This baseline report found that compared to the CHAT reaches, HOBE001’s watershed has high drainage shape, moderate slope and relief, and is mostly covered by forests and pasture (with some early succession shrubland). While the high drainage shape and moderate slope/relief likely lead to higher peak flows and shorter times to peak, the high forest cover likely attenuates these peak flows. Like the CHAT streams, HOBE001 appears to be in the third (widening) stage of channel evolution. Multiple “floodplain” surfaces were identified during this baseline survey. Like the CHAT streams, these “floodplain” surfaces have been reinterpreted and renamed elevated entrenched surfaces. This term, elevated entrenched surface, is used instead of floodplain because most of these surfaces are erosional, semi-ephemeral (slump) surfaces and not stable, depositional surfaces the term floodplain represents. Lastly, the baseline report classified habitat as “poor-to-fair”

due to the homogeneity of in-stream habitat (geomorphic channel units) and a general lack of large wood within the channel (providing stability and habitat).

On August 22, 2023, HOBE001 was resurveyed. A new drainage basin analysis of watershed characteristics was not performed because it is assumed the basin has not changed significantly in the geologically short time since the last survey. The land use/land cover analysis found a 10% reduction in Forest and a concomitant increase in Shrub. It is assumed these changes are due to forestry activities taking place in the upper (not managed by NPS) portions of the watershed. The biggest changes were related to a treefall in the lower portions of the reach (between T3 and T4) and channel incision in the upper portions of the reach. The channel incision could have been caused by the loss of the large wood step on T8 and rapid upstream movement of the temporary knickpoint created by the step. The eroded bed sediment from the upper portions of the reach is likely the source of the growth in in-channel bars as well as why bed sediment was statistically significantly finer in 2023 compared to 2019. Though the bed sediment was finer in 2023, the addition of LWD (from the tree fall and from upstream) and a much more heterogeneous distribution of in-stream habitat resulted in habitat being upgraded from “poor-to-fair” to “fair-to-good.” If the LWD in the reach stabilize the bed and the fine sediments can be flushed out of the reach, habitat may upgrade to “good.” Alternatively, if the LWD within the reach are moved out, habitat becomes homogenous (like in 2019), and/or if additional fine sediment is introduced to the reach, the habitat classification may degrade. Lastly, the tree fall between T3 and T4, if it stabilizes, may cause the stream to bifurcate or shift the channel to river left where a secondary, backchannel has developed on the river left side of the large midchannel bar in the reach at least since 2019.

While changes were measured/observed, none of the findings indicate a management concern. It is recommended that the area immediately downstream of the upstream road crossing be inspected to identify any knickpoints that might migrate upstream and undermine the road crossing.

Introduction

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

Wadeable stream monitoring is implemented at the five SECN inland parks with wadeable streams. These include Horseshoe Bend National Military Park (HOBE) in Alabama, Kennesaw Mountain National Battlefield Park (KEMO), Ocmulgee Mounds National Historical Park (OCMU), and Chattahoochee River National Recreation Area (CHAT) in Georgia, and Congaree National Park (CONG) in South Carolina. The streams at HOBE, KEMO, and CHAT are typical Appalachian Piedmont streams that are beginning to re-equilibrate to modern flow and sediment regimes following the poor land use practices of the late 19th and early 20th centuries (McDonald 2019; McDonald and Starkey 2018a, 2018b). The streams at Congaree National Park are typical low gradient, blackwater, Coastal Plain streams (McDonald and Starkey 2018c) while the streams at Ocmulgee Mounds National Historical Park are a mixture of Appalachian Piedmont and Coastal Plain type streams (McDonald and Starkey 2019). Streams chosen for monitoring were specifically targeted due to management interest (e.g., trail erosion issues and upstream urban development) or to provide context for similar-sized streams in the park 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 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 and gullied landscapes like the Appalachian Piedmont.

The objectives of this report are to:

- Present the wadeable stream survey completed at Horseshoe Bend National Military Park during late summer 2023,
- Provide a comparison of the 2023 results to the 2019 "baseline" survey,
- Describe the processes that are likely responsible for differences between the surveys, and
- Explain why HOBE001 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 45.85 inches (1,164.6 millimeters [mm]) 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 25.6°F (−3.55°C) to a high in July of 94.3°F (34.6°C; Wright et al. 2011). Monthly rainfall totals are distributed rather evenly from October through May due to the influence of frontal systems while convective thunderstorms influence the region from late spring through early fall (Lecce 2000). While monthly precipitation tends to be high in the summer, the high levels of evapotranspiration attenuate streamflow during this part of the year (Lins 1997).

The natural condition of rivers draining the southeastern U.S. is generally characterized by meandering channels with densely vegetated banks (Leigh 2008). Contemporary river systems in the southeastern U.S. are in variously altered states that reflect multiple legacies of anthropogenic disturbance (James 2018). Beginning in the late 1800s, deforestation, increased row crop agriculture, and a general lack of soil conservation measures caused widespread erosion of topsoil from steeply sloped upland areas in the Appalachian Piedmont 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 (Bartram 1996) into conduits of turbid water and sand. As row-crop agriculture became less dominant and forest cover increased, sediment delivery to streams was reduced and streambeds began to degrade (Schumm et al. 1984). Today, streambed elevations in many of the region's small streams have returned to historic or near-historic levels though their geomorphic characteristics (width, depth, entrenchment) are quite different from early settlement conditions (Mukundan et al. 2011; Schoonover et al. 2007).

In addition to the legacy effects of agriculture, many Appalachian Piedmont streams have been further subjected to hydrologic alterations caused by urban or suburban development. Increases in impervious surface area associated with development create 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). While these types of changes have not influenced the streams at Horseshoe Bend National Military Park to

the degree that they have affected streams at Chattahoochee River National Recreation Area and Kennesaw Mountain National Battlefield Park, as land gets used and/or developed within the watersheds that drain into Horseshoe Bend National Military Park, hydrologic changes will occur.

As each stream recovers from its unique history of land use and equilibrates to its current flow and sediment regime it will pass through a series of semi-predictable stages of evolution (James 2018; Schumm et al. 1984). These stages include aggradation (receiving more sediment than the flow regime can transport), degradation and narrowing (caused by 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 a stream occupies, at a moment in time, depends on the location of the stream within its network and the unique history and current land use/land cover conditions of the stream's watershed. In general, streams in the Appalachian Piedmont are at the third stage of channel development (further degradation and widening) and their banks are quite unstable and subject to undercutting and slumping (Ruhlman and Nutter 1999).

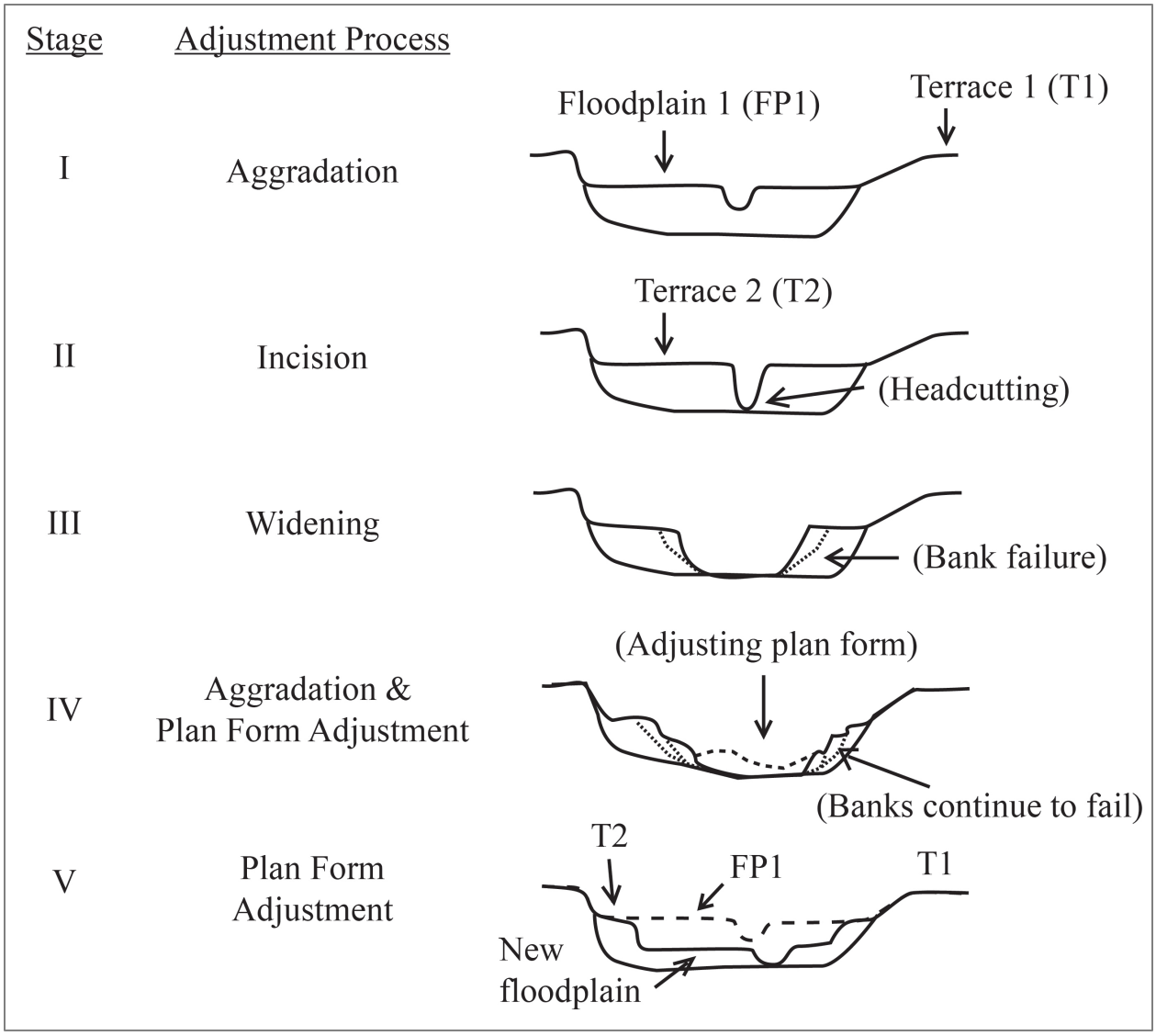


Figure 1. Generalized channel evolution model.
MODIFIED FROM SCHUMM ET AL. (1984)

Horseshoe Bend National Military Park

Horseshoe Bend National Military Park is in eastern Alabama and made up of 2,040 acres (825 hectares [ha]) of mixed hardwood forest (Figure 2). Most of the park is upland forest, and a portion of the area along the southern bank of the Tallapoosa River is covered by successional forest on historical farmland. Approximately 10% of the area (mostly in depressional areas on the floodplain) is classified as wetlands. The remainder of the park is open areas and fields that commemorate historic battlefronts. Surface-water resources at Horseshoe Bend National Military Park include the flow-regulated Tallapoosa River, its relatively narrow flood plain, small intermittent streams along the northern boundary of the Tallapoosa, and a small, unnamed perennial stream on the south side of the Tallapoosa River.

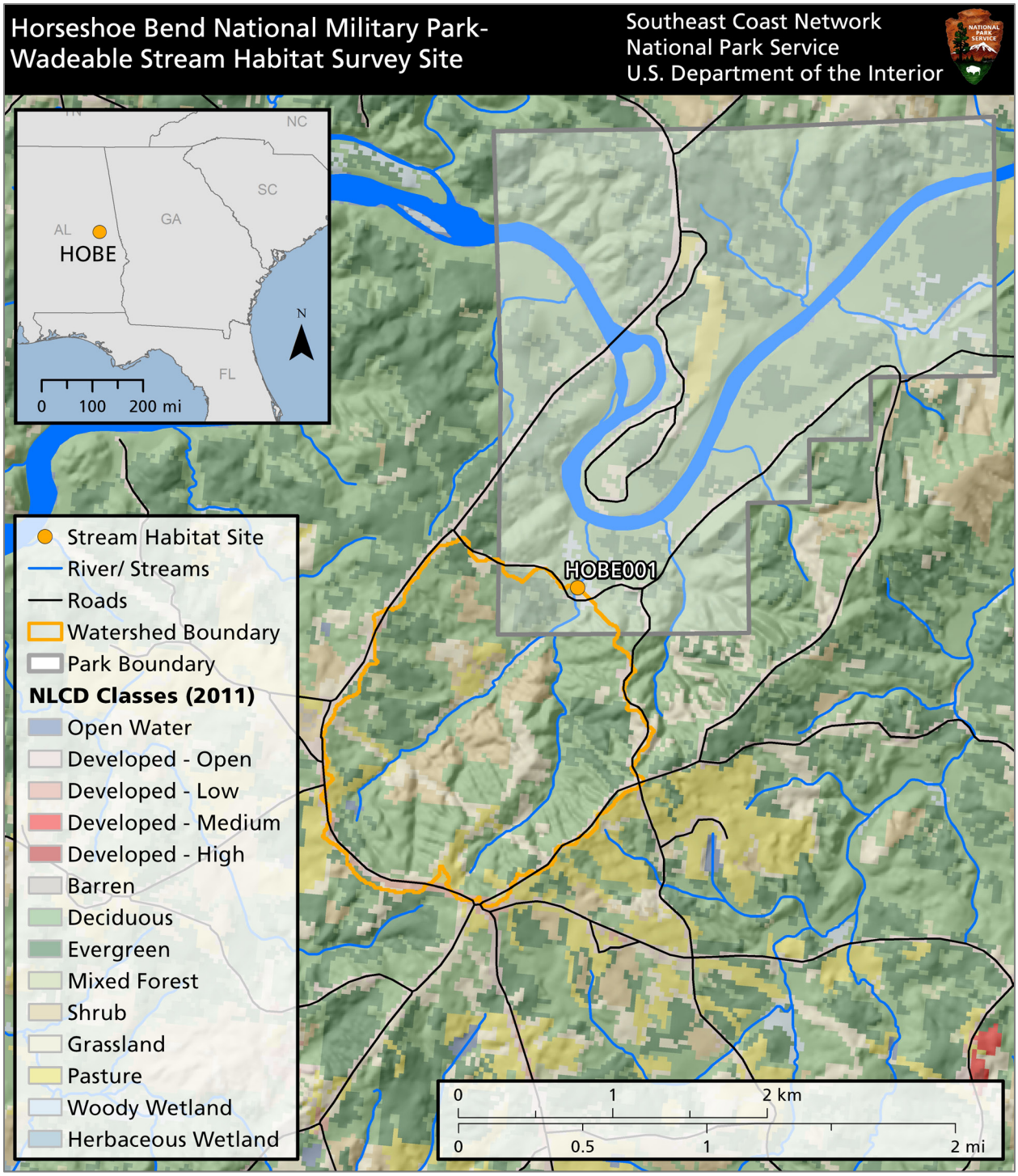


Figure 2. Map showing Horseshoe Bend National Military Park and its wadeable stream site (HOBE001). The watershed draining to the study reach is shown to provide context for the data presented in this report. The land use/land cover (NLCD 2011 in Homer et al. 2015) and perennial streams (derived from 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.

NPS / SECN

Reconnaissance surveys, conducted in 2012, indicated under the drought conditions that existed during fall 2012, most of the park's ephemeral streams ceased to flow (M. B. Gregory, SECN Program Manager, personal observation).

Previous Survey and Current Interpretations

On April 24, 2019, data were collected at Horseshoe Bend National Military Park (HOBE) to characterize the in- and near-channel habitat on a permanently monumented reach on a second Strahler stream order stream (Strahler 1957) nicknamed "Claybed Creek" (HOBE001). These data, along with analysis of remotely-sensed geographic information system (GIS) data, are presented in a baseline report that describes and compares the watershed-, reach-, and transect-scale characteristics of HOBE001 to selected second-order streams at Chattahoochee River National Recreation Area (CHAT004, CHAT008, CHAT010, and CHAT014) (McDonald 2020). Though the historic and contemporary land use/land cover in the watersheds draining to HOBE001 and the CHAT streams are very different (they were expected to be different), these comparisons are included to provide context for the survey at HOBE001.

HOBE001's watershed ("Claybed Creek") has high basin shape and moderate slope/relief and is covered by forest, pasture, and shrubland. The major defining characteristics of the stream were the presence of claybeds in the bed of the stream, a groundwater seep along river left, and elevated entrenched surfaces along both sides of the stream. Based on the different geomorphic surfaces observed within and immediately surrounding the reach, the stream appears to be in channel evolution model (CEM) stage III (Figure 1).

Channel widening was observed to be caused by bank undercutting leading to bank failure (i.e., slumping) and tree falls breaking off chunks of the bank. Slump blocks (e.g., the portions of bank that slumped in the channel) are usually eroded and the sediment is transported downstream. In smaller streams, and lower energy portions of larger streams, these slumps blocks can become sediment sinks if they become stabilized (i.e., by vegetation). During the initial survey of HOBE001, these stabilized blocks were interpreted as representing the bankfull (or sometimes the channel-full) level of the stream.

To account for "bankfull" surfaces being present at multiple heights throughout a reach (or on a transect) interpretation and measurement of these inset surfaces and channel-full changed during this (2023 survey). The lowest longitudinally continuous surface observed on a transect was measured as bankfull and the highest longitudinally continuous surface was measured as channel-full. The term "elevated entrenched surfaces" is introduced to refer to these surfaces inset within channel-full without ascribing a depositional origin to the landform implied by the term bankfull. Elevated entrenched surfaces are further defined later in this report.

The presence of claybeds within the reach could potentially disrupt progression along the channel evolution continuum due to its high rate of erodibility. Should a knickpoint (large change in slope) migrate upstream into the reach, these exposed claybeds would not provide sufficient protection of the channel bed. This knickpoint could migrate upstream relatively quickly and set the stream back in

its evolutionary stage. The rate this knickpoint migrates upstream is dependent on the sediment composition of the boundary layer (bed sediment), the amount of LWD available to increase bed and bank resistance, and the flow regime that shapes the stream.

Regarding habitat, the distinguishing features of the stream were the homogeneity of geomorphic channel units (predominately run) and lack of large woody debris (LWD). While the reach lacked fine and very fine sediment in its representative riffle (where the pebble count was conducted), the lack of cobble-sized particles within the reach increases the potential for increased bed mobility if a large flood event affects the reach. Due to the lack of coarser sediment, the type or distribution of geomorphic channel units (GCUs), and the lack of LWD, habitat within the reach 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 Horseshoe Bend National Military Park. Habitat within the reach may degrade to a "poor" rating if fine or very fine sediment is added to the reach (potentially from a disturbance upstream). Alternatively, if LWD can become established within the reach, this additional habitat complexity could make the reach more habitable which would result in a "fair" classification of the habitat (Allan and Castillo 2007). The stream does not have immediate management concerns, but there is extensive privet growth in the area 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 (USGS, Fitzpatrick et al. 1998; USEPA, Hughes et al. 2000; and USFS, Harrelson et al. 1994). The physical structure of in- and near-stream habitat has a strong influence on the biological communities and overall ecological integrity of lotic ecosystems (Newson and Newson 2000). Monitoring stream habitat not only provides an understanding of the physical suitability for aquatic species but can also identify stressors that could degrade other park resources and negatively affect visitor experiences.

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

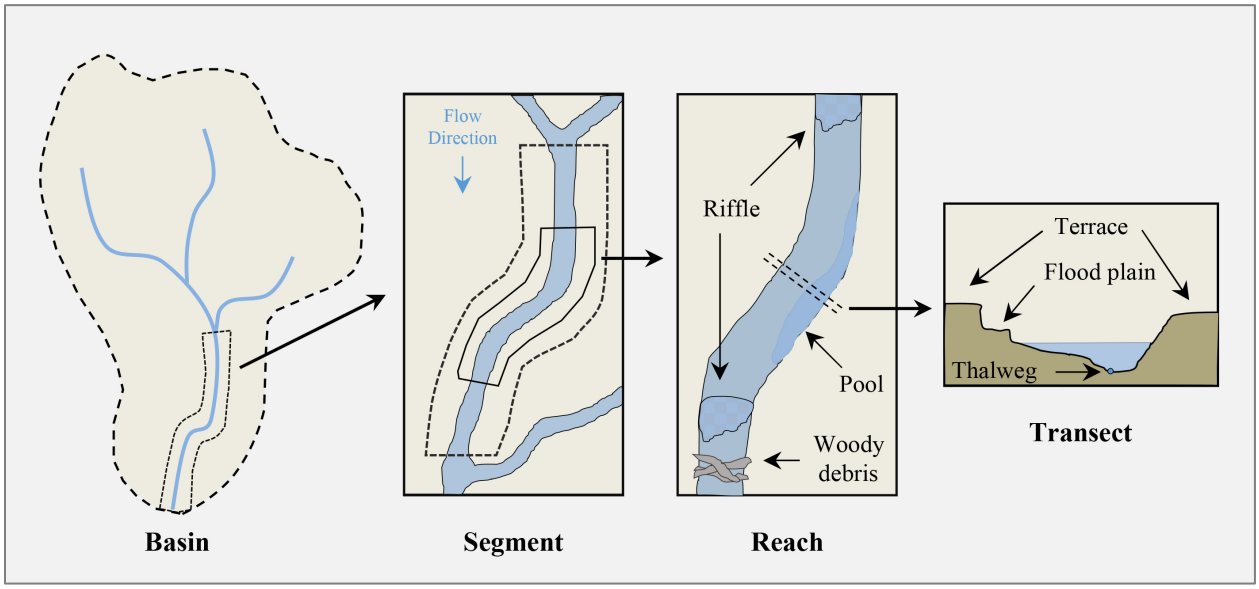


Figure 3. Spatial hierarchy of stream systems and scales of data collection.
MODIFIED FROM FITZPATRICK ET AL. (1998)

Basin Characteristics

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

potential sediment yield (basin relief ratio; Strahler 1957), and the amount of energy available to move sediment through a stream network (entire stream gradient; Craig and Rankl 1978; Fitzpatrick et al. 1998). 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 Habitat Assessment Basin- and Segment-scale Data Summary*—Version 1.0 (McDonald et al. 2018b).

Reach-Scale Measurements

The reach-scale characteristics of each monitored reach are measured at and between 11 equidistant transects (distance between transects is two times average wetted width; Figure 4). Reach length is 20 times average wetted width (as determined during the initial survey of the reach). Data collected at each of these transects includes vegetative bank cover, presence of eroding banks, bed and bank material, channel widths (e.g., wetted, active, bankfull, and channel-full widths), water depth, and bank heights and angles. As described in the "Previous Survey and Current Interpretations" section, the interpretation of bankfull and channel-full were modified to account for the developmental complexity of the stream. Bankfull width was measured from the lowest longitudinally continuous surface on a transect. Bankfull height was measured to the lowest longitudinally continuous surface for each bank. This interpretation can result in different bankfull heights on the same transect. Channel-full width and height were measured from the highest continuous surface on the transect. Additional surfaces inset within the channel-full channel were also measured but are only included in the notes for that reach. 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. This measure helps account for transects with multiple "bankfull" surfaces. Lastly, a quantitative measure of bed sediment is obtained by conducting a Wolman pebble count on a representative riffle within the reach (Wolman 1954).

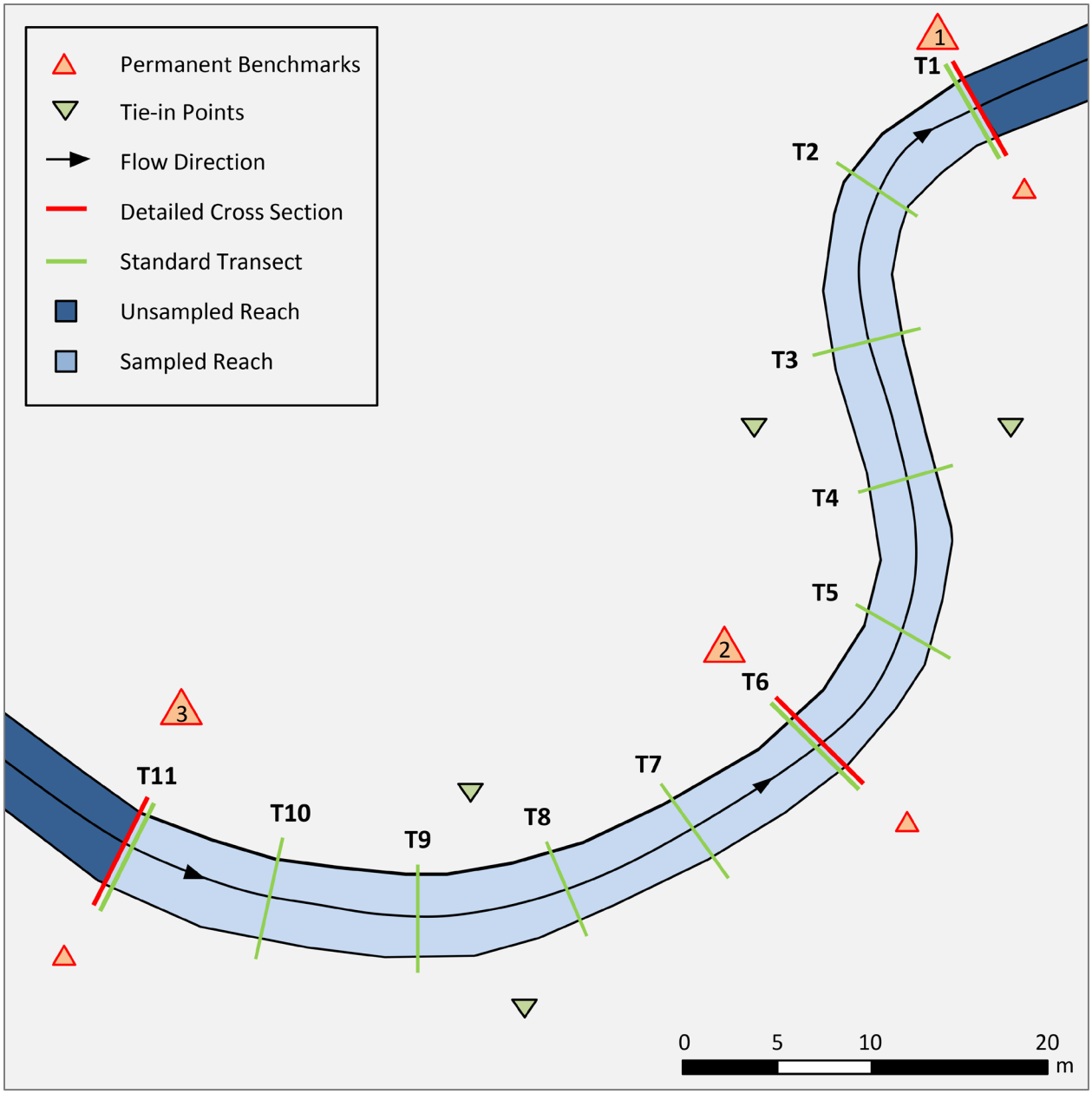


Figure 4. Example layout of stream reach with benchmarks, tie-in points, and transects.
NPS / SECN

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

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

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

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

To understand in-stream and near-channel habitats, measurements are also taken between each transect. These between transect measurements include: canopy cover, the amount and type of in-stream habitat (e.g., high-energy riffles vs. low-energy pools), an inventory of large woody debris (LWD; defined as >1 meter (3.3 ft) in length and >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 based on (1) watershed characteristics (i.e., land use/land cover, slope, and relief); (2) in-stream habitat conditions (i.e., high versus low energy GCUs, bed material, prevalence of LWD); and (3) general channel condition (i.e., bank conditions, degree of entrenchment, presence of knickpoints, or planform changes). 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.

A total station was used to measure the water surface slope at all transects and wherever there was a substantial break in slope (e.g., bottom and top of riffles). Water surface slope was used to

characterize the longitudinal profile as it reflects the hydraulic gradient, captures real-time flow conditions, and is easier to reliably measure compared to channel bed or thalweg elevations.

Detailed Transect Cross-Sections

Three of the eleven 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).

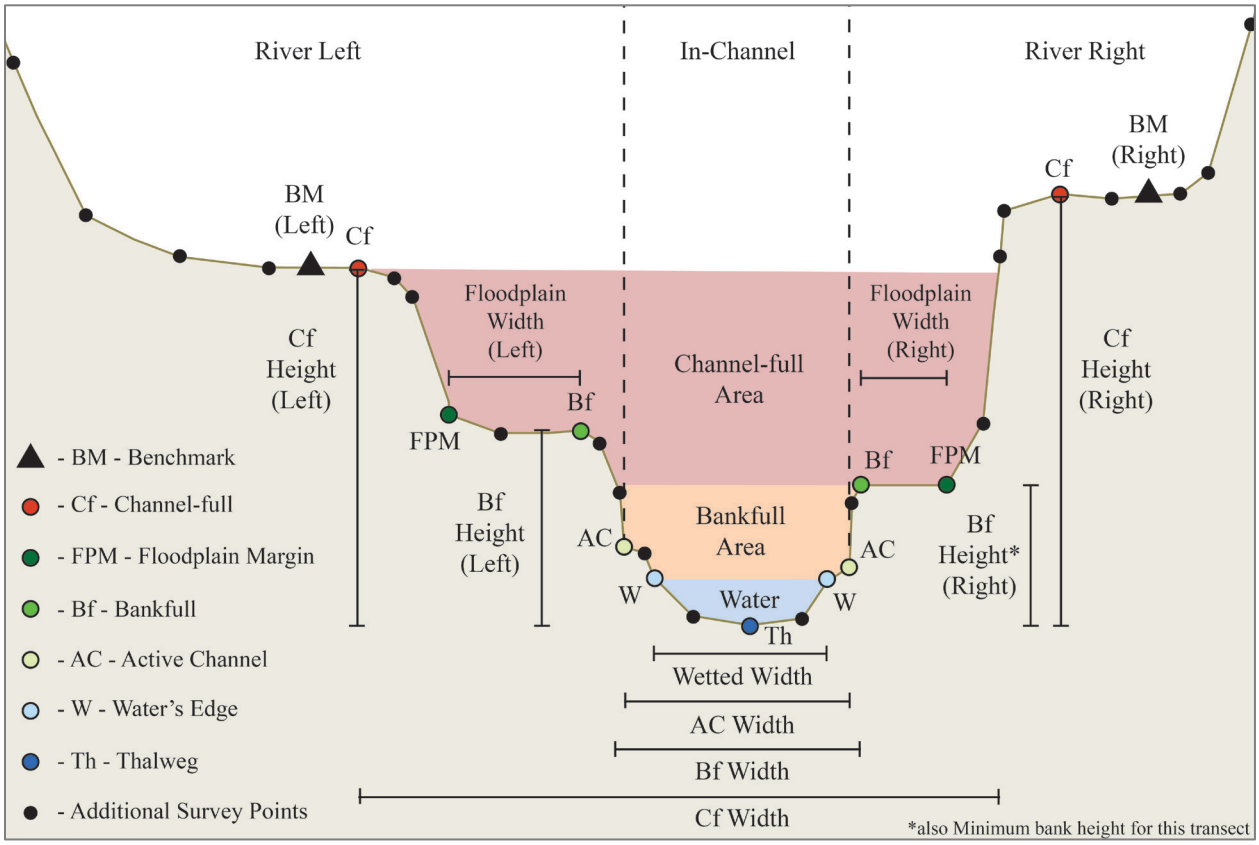


Figure 5. Hypothetical detailed transect cross-sectional survey showing the diagnostic geomorphic surfaces that should be surveyed and the descriptive characteristics that will be derived from the data. Bankfull area includes baseflow area (light blue) and bankfull area (orange). Channel-full area includes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

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 and, along with the bank stability index, to assess the condition and stability of the reach.

Statistical Analysis

Differences in the mean values of nine variables between the 2019 and 2023 surveys were evaluated using two-sample t-tests. These nine variables included:

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

Bankfull width and height are not included in the statistical analysis because bankfull was not measured on each transect (due to lack of elevated entrenched surface) and the number of bankfull measurements between surveys might not be equal.

Results

On August 22, 2023, one stream reach (HOBE001, "Claybed Creek") was surveyed following the methods outlined in SOP 1.2.16 *Wadeable Stream Reach-Scale Field Data Collection*—Version 1.1 (McDonald et al. 2018c) and SOP 1.2.18 *Using a Total Station to Conduct a Stream Survey*—Version 1.1 (McDonald et al. 2018d). Field surveys, in-office analyses, and statistical comparisons between monitoring years (2019 and 2023) are presented in the following sections. Results and data summary tables for the 2023 resurvey of HOBE001 are provided in Appendix B.

Weather Conditions

Wadeable stream surveys are conducted as close to baseflow conditions as possible given the time frame available each year (McDonald et al. 2018a). No rain fell on either survey day (Table 2). There was no precipitation recorded in the week prior to the 2023 survey. Prior to the 2019 survey, there was one precipitation event greater than one inch (2.55 inches [6.5 centimeters {cm}], April 19, 2019), which occurred six days before the survey. There was more precipitation recorded in the month prior to the 2023 survey than prior to the 2019 survey. Additionally, more precipitation fell during the three-month period prior to the 2023 survey than prior to the 2019 survey though the same number of greater than 1-inch (2.5 cm) events occurred. Given the similarity of the weather conditions prior to each survey, differences in baseflow conditions are not likely to explain any differences observed between the surveys.

Table 2. Amount of precipitation and number of precipitation events greater than 1 inch (2.5 cm) during and in the week and month(s) prior to the 2019 and 2023 wadeable stream survey at HOBE. Data from weather co-op station Alexander City 3.1 NNE, Alabama, U.S.

Time Frame	Length of Period	Total Precipitation (inches)	Number of Events >1 inch
4/24/2019	Day of Survey	0	0
4/18/2019–4/24/2019	One Week	2.74	1
3/26/2019–4/24/2019	One Month	4.51	2
1/25/2019–4/24/2019	Three Months	13.28	4
8/22/2023	Day of Survey	0	0
8/16/2023–8/22/2023	One Week	0	0
7/24/2023–8/22/2023	One Month	7.72	2
5/26/2023–8/22/2023	Three Months	17.01	4

Basin Characteristics

This section provides a description of the basin characteristics for HOBE001. For a more in-depth look at the basin characteristics and how they compare to selected second-order watersheds at Chattahoochee River National Recreation Area (CHAT), see McDonald (2019). The HOBE001 watershed drains 3.46 square kilometers (1.34 square miles [sq mi]) which makes it bigger than the CHAT streams it was compared to in the baseline report (Table 3). Most of HOBE001's watershed lies south of the park on private land (Figure 2). "Claybed Creek" at HOBE001 is a second-order

stream in its stream network. Compared to the watersheds draining to the selected CHAT reaches, HOBE001's watershed has high drainage shape and moderate slope and relief. In 2019, HOBE001 had very low development (6%) and was mostly covered by forest (85%) and pasture/grassland (8%; Table 4). Since 2019, approximately 10% of the forested area was presumably timbered but is now classified as shrub. While the high drainage shape and moderate slope/relief likely lead to higher peak flows and shorter times to peak, the high forest cover likely attenuates these peak flows. The conversion of forest to shrub likely was not sufficient to create a distinct change in the magnitude or frequency of stormflow events. A more detailed analysis of where land cover changed in relation to the stream network is needed to determine if this change could have influenced the stream network.

Table 3. Watershed characteristics for HOBE001 compared to four selected reaches from Chattahoochee River NRA (CHAT). All variables were calculated using the National Elevation Dataset (NED) 10-meter (32.8-ft) digital elevation model [km = kilometers; m = meters; CV = coefficient of variation].

Basin Characteristic	HOBE001	CHAT004	CHAT008	CHAT010	CHAT014
Drainage Area (km^2)	3.46	1.39	1.65	2.01	2.67
NPS Managed Area (km^2)	0.23	0.01	0.11	0.29	0.01
NPS Managed Area (%)	6.7%	0%	7%	14%	0%
Total Stream Length (km)	4.59	1.64	2.71	2.72	4.22
Drainage Density	1.33	1.18	1.64	1.36	2.00
Strahler Order	2	2	2	2	2
Bifurcation Ratio	2.00	2.00	1.50	1.50	1.25
Entire Stream Gradient [A]	0.0311	0.0232	0.0264	0.0217	0.0167
Segment Gradient [B]	0.0075	0.0135	0.0155	0.0279	0.0145
Slope—Average	8.00	8.30	6.78	5.39	8.05
Slope—Standard Deviation	4.86	5.40	4.64	4.06	4.88
Slope—CV	0.61	0.65	0.68	0.75	0.61
Basin Length (km)	3.08	2.32	2.85	2.86	3.33
Basin Shape [C]	0.36	0.26	0.20	0.25	0.24
Basin Relief (meters)	85.45	74.32	70.33	70.14	80.22
Basin Relief Ratio	0.028	0.032	0.025	0.025	0.024
Elevation—Standard Deviation (m)	17.64	14.41	14.62	12.28	14.45

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

[B] Segment gradient is calculated by dividing the difference in elevations at the top of the stream segment and the bottom of the stream segment by the stream length between those points.

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

Table 4. Land use/land cover characteristics in 2019 and 2023 for the watershed draining to HOBE001. The data included in this table are from the National Land Cover Dataset (NLCD). Δ represents percent change between the 2019 and 2023 datasets.

NLCD Classes	HOBE001	HOBE001	HOBE001
Year	2019	2023	% Δ
Developed Open and Low (%)	6	6	0
Developed Medium and High (%)	0	0	0
Forested (%)	85	73	−11
Shrub (%)	2	11	10
Grassland (%)	8	9	1
Cultivated (%)	0	0	0

Reach Description

HOBE001 is on an unnamed second-order stream that flows from south to north into the Tallapoosa River. The reach surveyed is approximately 520 meters (1,706 ft) upstream of its confluence with the Tallapoosa River and approximately 40 meters (131.2 ft) downstream from an NPS service road (small bridge) crossing. The reach was 50 meters (164 ft) long with 5 meters (16.4 ft) between transects. The stream was nicknamed “Claybed Creek” because of the intermittent exposure of a claybed(s) in the bed of the channel (McDonald 2020). Though no claybeds were recorded during the 2023 survey, during the 2019 survey, two claybeds were observed; one along river left near T6 and T7 and the other on river right near T9 (Figure 6). There are no trails within the vicinity of the reach (besides the service road upstream). A small groundwater seep was observed along river left between T2 and T3 during both surveys. HOBE001 has a moderately coarse bed, and its channel has a moderate degree of entrenchment. Some elevated entrenched surfaces have developed on river left and right inset within the higher valley bottom surface (Figure 6). The detailed transects were surveyed on T1 (BM1), T6 (BM2), and T11 (BM3). The following sections describe the differences between the 2019 and 2023 reach-scale habitat characteristics and channel morphology along HOBE001 as well as the changes that were observed on the detailed transects. Transect-scale survey results for HOBE001 are in Appendix B.

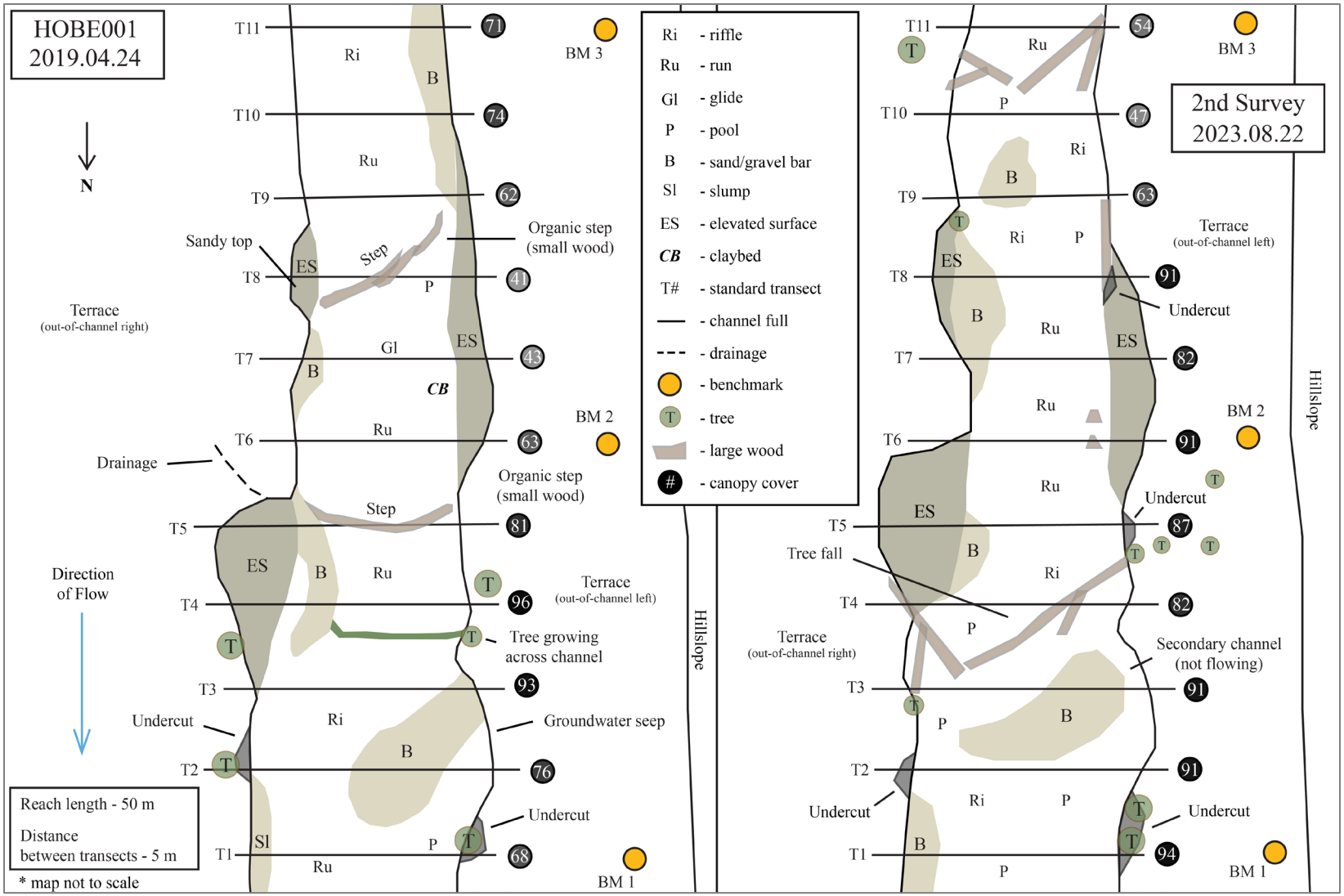


Figure 6. Reach-scale map of HOBE001. Important geomorphic surfaces and in-channel features are labeled to provide context for the standard and detailed transect information provided in this report. The canopy cover circles are varying shades of grey which indicate the amount of canopy cover at each transect.

NPS / SECN

Habitat Characteristics

The frequency and distribution of geomorphic channel units (GCUs) at HOBE001 during the 2019 and 2023 surveys differed substantially (Table 5). During 2019, the GCUs covering "Claybed Creek" were mostly run (present on all but one transect), with a few pools (five transects) and riffles (on three transects). In 2023, run habitat was still found on all but two of the transects but now pools were the most frequently observed (found on ten of the eleven transects). Riffles were also more frequent in 2023, being found on five of the transects. Unlike 2019, no step habitat was observed in 2023.

Table 5. Comparison of geomorphic channel units (GCUs) observed in the 2019 and 2023 surveys at HOBE001. [SD = standard deviation].

GCU Type	Year	Frequency	Max (%)	Mean (%)	SD (%)
Riffle	2019	3	30	20	10
	2023	5	50	32	20
Run	2019	10	100	81	15
	2023	9	95	47	36
Glide	2019	1	50	50	0
	2023	1	5	5	0
Pool	2019	5	25	12	8
	2023	10	100	42	39
Step	2019	2	20	13	11
	2023	0	0	0	0

The result of the pebble counts in 2019 and 2023 show a general fining of the bed sediment between the surveys (Table 6). All classes except for the two largest classes (D_{95} and Max) saw a reduction in size. There was an 18% reduction in the mean size of the pebbles and a 75% reduction in the size of the smallest pebbles. This reduction in mean particle size was statistically significant (Table 7). Though the smallest size classes became finer, there was a 53% increase in the size of the largest pebbles (Table 6).

Table 6. Particle size distributions of bed sediment (in millimeters) from the pebble counts conducted in 2019 and 2023 at HOBE001. The subscripts indicate the percentage of the sample that is smaller than the reported diameter [n = number of measurements taken].

Site	Year	n	Min	D_5	D_{16}	D_{50}	Mean	D_{84}	D_{95}	Max
HOBE001	2019	100	8.00	14.95	22.00	36.00	35.32	49.00	56.05	66.00
	2023	100	2.00	4.85	11.84	21.50	28.96	47.16	71.10	101.00

Table 7. Difference in means t-test results comparing the 2019 and 2023 surveys of HOBE001. [mm = millimeters; m = meters].

Measurement	Difference 2023–2019	P-Value	Significance
Mean Particle Diameter (mm)	−6.36	0.009	p-value < 0.01
Wetted Width (m)	−0.03	0.955	not significant
Active Channel Width (m)	0.43	0.385	not significant
Minimum Bank Width (m)	0.44	0.347	not significant
Channel-full Width (m)	0.05	0.963	not significant
Thalweg Depth (m)	0.03	0.671	not significant
Minimum Bank Height (m)	0.19	0.079	not significant
Channel-full Height (m)	0.15	0.006	p-value < 0.01
Bank Angle (°)	14.57	0.022	p-value < 0.05
Veg. Cover (%)	−1.59	0.821	not significant
Bank Stability Index	0.36	0.446	not significant

The number of pieces of LWD nearly doubled from 2019 (n = 8) to 2023 (n = 15; Table 8). Most of these pieces of LWD were found in the jams between T3 and T4 and between T10 and T11 (Figure 6). In addition to the pieces of LWD increasing substantially, the volume of LWD per channel area increased by over 200% (Table 8). Canopy cover increased from 70% to 80% between the surveys (Table 9) though there was a large reduction in canopy cover in the area upstream of T9 (Figure 6).

Mean thalweg position (relative to the left bank) decreased slightly and the variability in thalweg position increased approximately 43% from 2019 to 2023 (Table 10). The maximum thalweg depth was approximately 23% higher in 2023 (Table 10). Mean thalweg depth only increased by 12% and this change was not statistically significant (Table 7).

Table 8. Summary statistics for the large woody debris measured in 2019 and 2023 at HOBE001. [n = number of measurements taken; m = meters; SD = standard deviation].

Statistic	Year	n	Length (m)	Diameter (m)	Volume (m^3)
Mean	2019	8	1.76	0.23	0.07
	2023	15	3.25	0.20	0.12
Max	2019	8	4.00	0.33	0.20
	2023	15	7.15	0.48	0.43
SD	2019	8	1.22	0.08	0.06
	2023	15	1.93	0.10	0.14
Per Channel Area (m^3/m^2)	2019	8	–	–	0.0014
	2023	15	–	–	0.0046

Table 9. Comparison of the variability in canopy cover in 2019 and 2023 at HOBE001. [n = number of measurements taken; SD = standard deviation; CV = coefficient of variation].

Year	n	Min (%)	Mean (%)	Max (%)	SD (%)	CV
2019	11	41	70	96	17	0.25
2023	11	47	80	94	17	0.21

Table 10. Comparison of reach-scale averaged thalweg conditions in 2019 and 2023 at HOBE001. Water depth measurements are in meters and position is the percent distance from the left active channel bank [n = number of measurements taken; SD = standard deviation; CV = coefficient of variation].

Thalweg	Year	n	Min	Mean	Max	SD	CV
Depth (m)	2019	11	0.10	0.26	0.48	0.12	0.45
	2023	11	0.07	0.29	0.59	0.17	0.59
Position [A] (%)	2019	11	10	48	95	30	0.63
	2023	11	10	32	90	28	0.90

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

Channel Morphology

Mean wetted width at HOBE001 was slightly (approximately 1%) narrower and mean active channel width was slightly (approximately 10%) wider in 2023 (Table 11). These differences were not statistically significant (Table 7). Minimum wetted width and minimum active channel width were both narrower in 2023 (−15% and −5%, respectively). Alternatively, maximum wetted width and maximum active channel width were wider in 2023 (+17% and +10%, respectively). Variability (CV) in wetted width increased in 2023 while variability in active channel width did not change substantially (Table 11).

Table 11. Comparison of reach-scale averaged width characteristics in 2019 and 2023 at HOBE001. [n = number of measurements taken; m = meters; SD = standard deviation; CV = coefficient of variation].

Width	Year	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Wetted	2019	11	2.42	3.51	5.13	0.89	0.25
	2023	11	2.06	3.48	6.02	1.19	0.34
Active Channel	2019	11	3.00	4.23	6.02	1.04	0.25
	2023	11	2.84	4.66	6.61	1.24	0.27
Bankfull	2019	6	3.98	5.23	6.00	0.70	0.13
	2023	5	4.33	5.44	6.61	0.89	0.16
Channel-full	2019	11	5.04	8.08	13.70	2.66	0.33
	2023	11	5.05	8.13	12.88	2.48	0.31

Mean bankfull width increased slightly between the two surveys. Five bankfull widths were measured in 2023 as opposed to six in 2019 (Table 11). Mean bankfull width increased by 4%, minimum bankfull width increased by 9%, and maximum bankfull width increased by 10% during the 2023 survey. These changes show the fluctuating nature of "bankfull" in these streams and is further explained in the "Implication and Synthesis of Results" section. Mean channel-full width only increased slightly, and this difference was not statistically significant (Table 7). Variability in channel-full width did not change appreciably between surveys (Table 11).

Mean minimum bank height (lowest bank height on a transect) in 2023 was 17% higher than in 2019 (Table 12). Mean bankfull height was 10% higher in 2023 and less variable (CV = 0.13) than in 2019 (CV = 0.36). Additionally, the minimum bankfull height in 2023 was 58% higher than in 2019. Mean channel-full height was 11% higher and this change was statistically significant (p = 0.006; Table 7). Variability in channel-full height was similar between surveys (Table 12).

Table 12. Comparison of average reach-scale bank heights in 2019 and 2023 at HOBE001. [n = number of measurements taken; m = meters; SD = standard deviation; CV = coefficient of variation].

Height	Year	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Minimum Bank Height [A,B] (m)	2019	22	0.45	1.15	1.64	0.35	0.30
	2023	22	0.71	1.34	1.85	0.37	0.28
Bankfull Height [A,C] (m)	2019	7	0.45	0.74	1.17	0.26	0.36
	2023	6	0.71	0.81	0.95	0.10	0.13
Channel-full Height [A] (m)	2019	22	1.06	1.38	1.78	0.18	0.13
	2023	22	1.25	1.53	1.85	0.17	0.11

[A] Above thalweg.

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

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

There were five fewer bank undercuts in 2023 compared to 2019 (Table 13). The mean horizontal depth of undercuts increased by 60% and the mean vertical height of undercuts increased by 35%. The largest undercut in 2023 (between T1 and T2) increased in depth by over 100% and is 0.90 m higher. Bank angles were on average 31% steeper during 2023 compared to 2019 (Table 13). This difference in mean bank angle was statistically significant (p = 0.022; Table 7). Mean bank vegetation cover did not change substantially from 2023 to 2019 though variability (CV) did increase (Table 13). The difference in mean bank vegetation cover was not statistically significant (Table 7). Bank stability scores were slightly higher (less stable) in 2023 compared to 2019 (Table 13).

Table 13. Comparison of average reach-scale bank characteristics in 2019 and 2023 at HOBE001. [n = number of measurements taken; m = meters; SD = standard deviation; CV = coefficient of variation].

Bank Characteristic	Year	n	Min (m)	Mean (m)	Max (m)	SD (m)	CV
Bank Undercut (horizontal depth [m]) [A]	2019	9	0.06	0.29	0.66	0.18	0.61
	2023	4	0.35	0.48	0.67	0.15	0.32
Bank Undercut (vertical height [m]) [A]	2019	9	0.32	0.52	0.79	0.16	0.31
	2023	4	0.31	0.70	1.05	0.37	0.53
Bank Angle (°)	2019	22	11	48	82	19	0.40
	2023	22	20	63	90	21	0.34
Vegetation Cover (%)	2019	22	30	62	90	21	0.33
	2023	22	10	61	100	26	0.42
Bank Stability [B]	2019	22	9.5	11.6	14.5	1.4	0.12
	2023	22	7.0	12.0	14.5	1.7	0.14

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

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

Detailed Transects

The detailed transects were surveyed on T1 (BM1; Figure 7), T6 (BM2; Figure 8), and T11 (BM3; Figure 9). The mean bankfull cross-sectional area of the three detailed transects did not change substantially between the surveys (Table 14). On average, channel-full area was slightly larger (+15%) in 2023. Water surface slope (longitudinal profile) for this section of "Claybed Creek" was approximately 40% gentler in 2023 (Figure 10; Table 14). This reduction in slope was associated with substantial changes in the morphology of the longitudinal profile. These changes included two areas of channel incision (between T3 and T4 and between T8 and T11) and two areas of aggradation (between T1 and T2 and near T5). The sinuosity of the reach did not change appreciably between the surveys (Table 14).

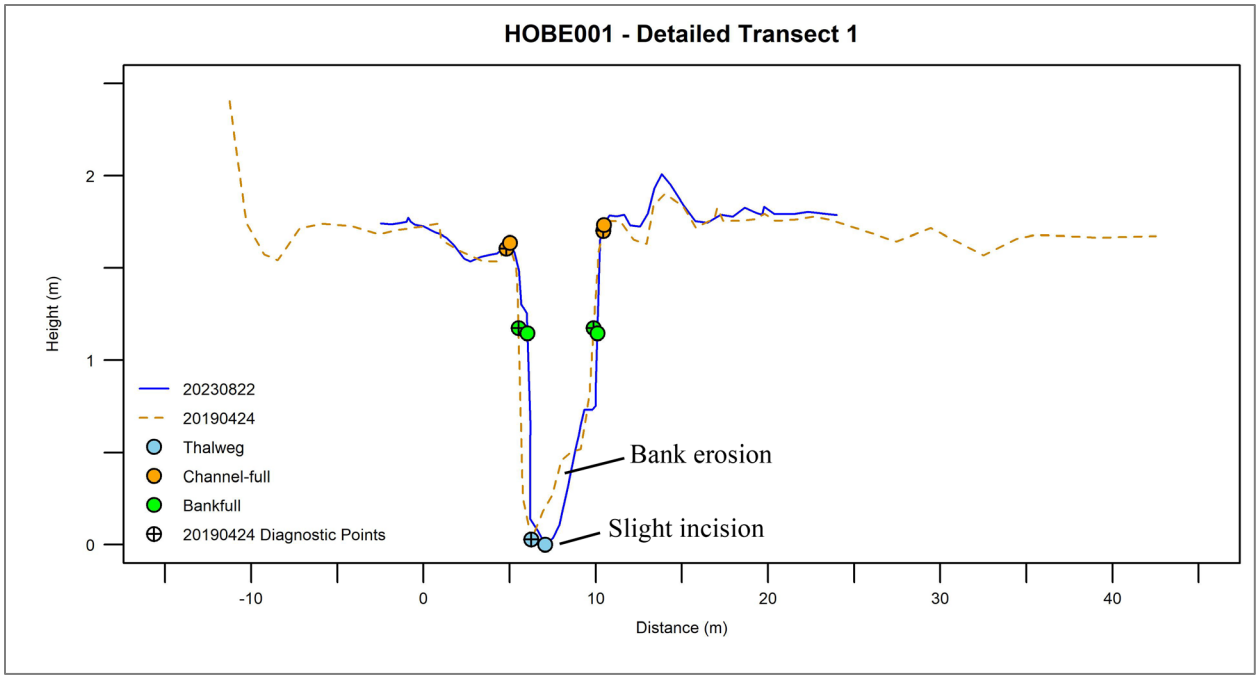


Figure 7. Differences between the 2019 and 2023 surveys of detailed transect 1 (T1) at HOBE001. The view is in the downstream direction.

NPS / SECN

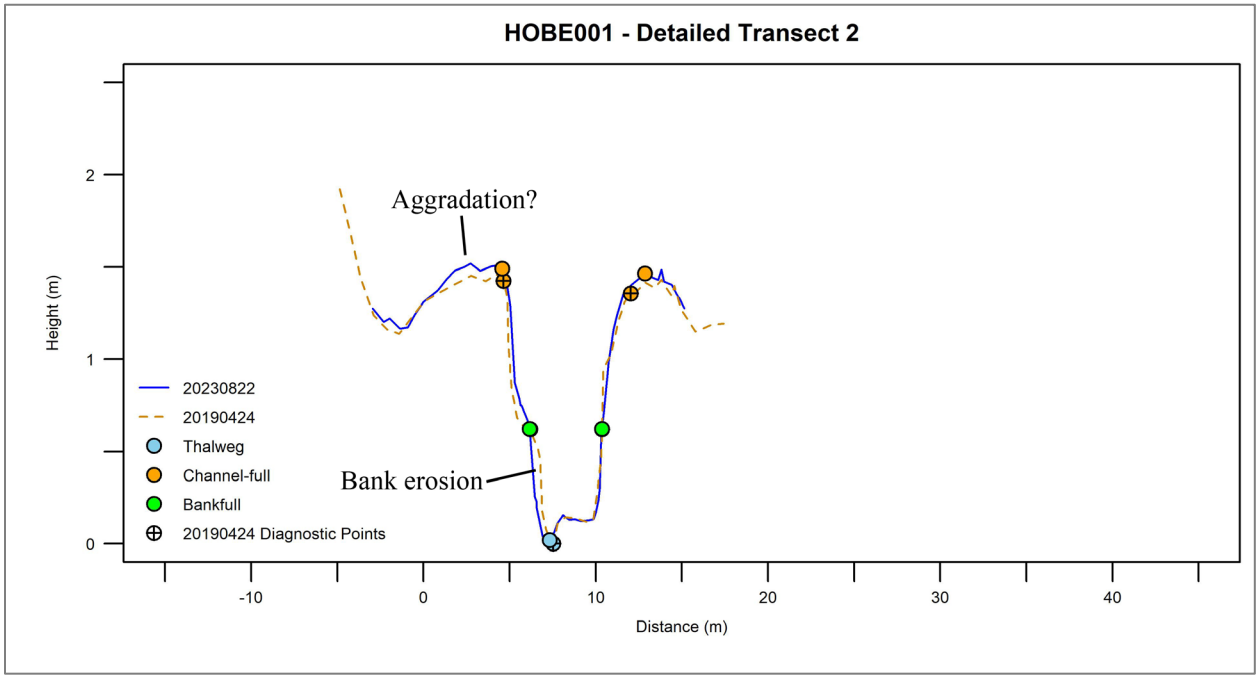


Figure 8. Differences between the 2019 and 2023 surveys of detailed transect 2 (T6) at HOBE001. The view is in the downstream direction.

NPS / SECN

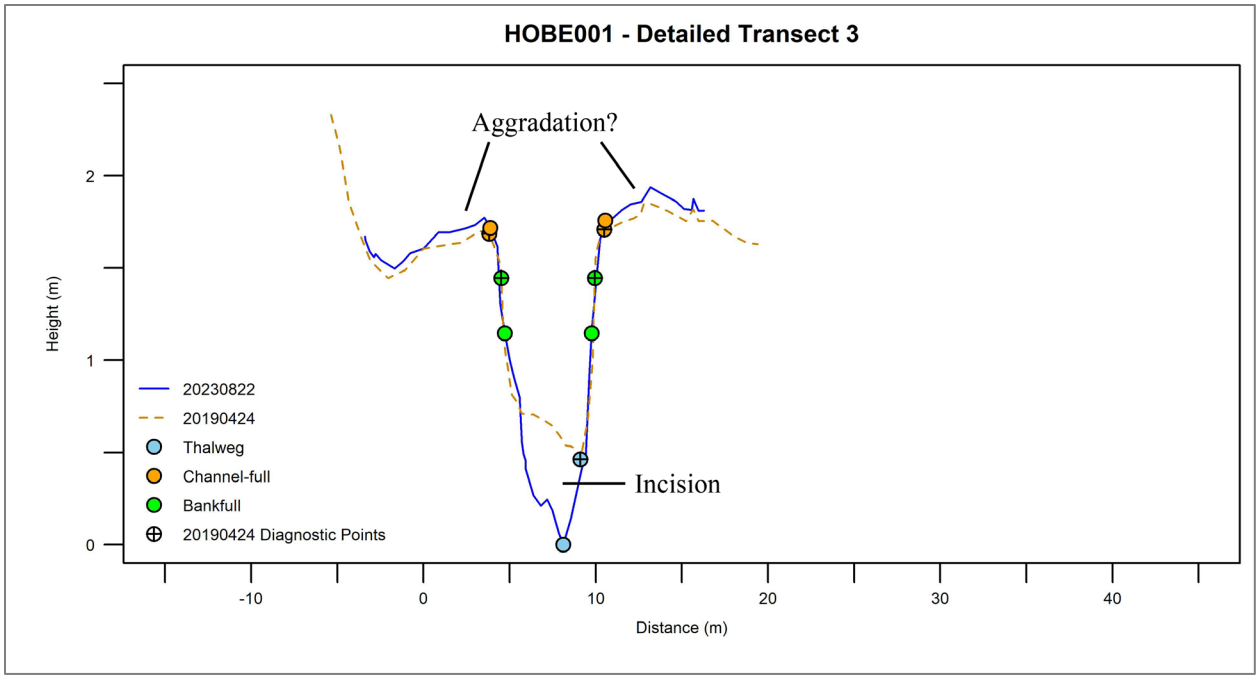


Figure 9. Differences between the 2019 and 2023 surveys of detailed transect 3 (T11) at HOBE001. The view is in the downstream direction.

NPS / SECN

Table 14. Comparison of the 2019 and 2023 reach-scale and mean detailed transect-scale characteristics on HOBE001 [m = meters].

Site	Year	n [A]	Slope	Sinuosity	n [B]	Bankfull Area (m^2)	Bankfull Width (m)	Bankfull Height (m)	Channel-full Area (m^2)	Channel-full Width (m)	Channel-full Height (m)
HOBE001	2019	13	0.0068	1.02	3	3.04	4.65	0.92	5.58	6.39	1.39
	2023	12	0.0041	1.03	3	2.97	4.43	0.96	6.41	6.66	1.6
Difference	2019–2023	–	−0.0027	0.02	–	−0.06	−0.22	0.05	0.84	0.27	0.21

[A] Number of measurements taken for slope and sinuosity.

[B] Number of measurements taken for bankfull and channel-full area, width, and height.

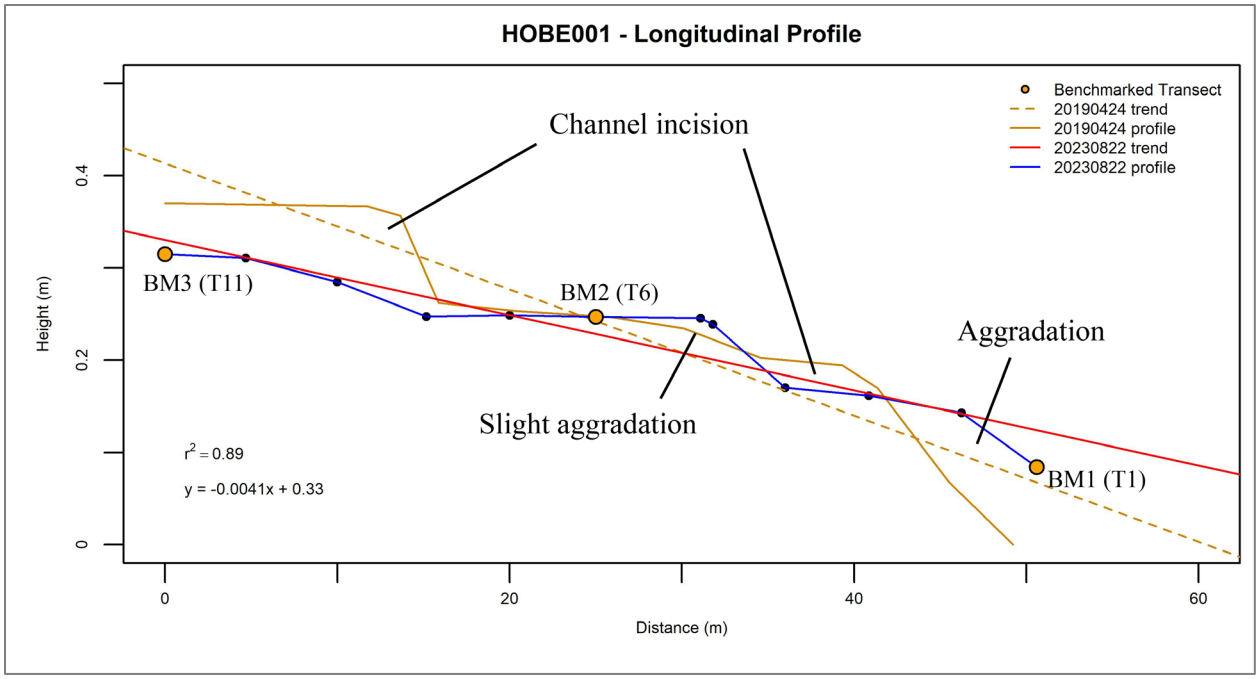


Figure 10. Longitudinal profile for HOBE001. The red line on the graph corresponds to the slope of the reach in 2023 (0.0041 m/m). The r^2 value describes the strength of the 2023 trend line (interpreted slope). The "T#" in parentheses indicates the standard transect number on which the detailed transects were surveyed.

NPS / SECN

The geomorphic changes observed on detailed transect 1 (T1) include some slight incision of the channel and erosion of the river right bank (Figure 7). No bankfull surfaces were identified in the field on this detailed transect. Using the reach-scale mean bankfull height to calculate the bankfull measurements, bankfull cross-sectional area decreased by approximately 2% (Table 15). Though channel-full width decreased by approximately 3%, the small amount of incision increased channel-full height by approximately 4% which caused channel-full area to increase by approximately 3%.

Table 15. Changes to cross-sectional characteristics on detailed transect 1 (T1) at HOBE001 [m = meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2019	3.34	4.35	1.15
	2023	3.26	4.07	1.15
Change	2019–2023	−0.08	−0.28	0.00
Channel-full	2019	5.34	5.38	1.58
	2023	5.52	5.23	1.64
Change	2019–2023	0.18	−0.15	0.06

Only a small amount of change occurred on detailed transect 2 (Figure 8). The river left bank eroded and there appears to have been some aggradation of the out-of-channel area immediately adjacent to the channel on river left. This apparent aggradation may be real change or the result of a slightly different survey line. Future surveys will determine if this change continues. The small amount of change caused bankfull cross-sectional area to increase by 12% (Table 16). The slightly higher banks and the wider channel caused channel-full area to increase by 14%.

Table 16. Changes to cross-sectional characteristics on detailed transect 2 (T6) at HOBE001 [m = meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2019	1.75	4.17	0.62
	2023	1.96	4.19	0.60
Change	2019–2023	0.22	0.02	−0.02
Channel-full	2019	5.98	7.22	1.36
	2023	6.80	8.20	1.44
Change	2019–2023	0.82	0.98	0.09

Detailed transect 3 (T11) also had some aggradation of the out-of-channel area (on both sides of the channel) as well as substantial channel incision (Figure 9). No bankfull surfaces were identified in the field on this detailed transect. Using the reach-scale mean bankfull height to calculate the bankfull measurements, bankfull cross-sectional area decreased by 8% (Table 17). However, channel-full area increased by 28% due to the incision of the channel and the slightly higher banks caused by the apparent aggradation of the out-of-channel area.

Table 17. Changes to cross-sectional characteristics on detailed transect 3 (T11) at HOBE001 [m = meters].

Type	Year	Area (m^2)	Width (m)	Height (m)
Bankfull	2019	4.02	5.43	0.98
	2023	3.70	5.04	1.15
Change	2019–2023	−0.32	−0.40	0.16
Channel-full	2019	5.41	6.57	1.22
	2023	6.93	6.55	1.72
Change	2019–2023	1.52	−0.02	0.49

Implications and Synthesis of Results

This section describes the processes observed at HOBE001 and the potential changes that may occur between surveys (next round of surveys in summer or fall 2026). The processes described will be explained within the context of the objectives of the protocol (i.e., basin characteristics that affect channel morphology and habitat, and the status of channel morphology and habitat characteristics).

HOBE001's watershed is relatively large for a second-order stream (3.46 square kilometers [1.34 sq mi], Table 3) and covered by forested areas (73%), shrubland (11%), and grassland/pasture (9%; Table 4). Approximately 6% of "Claybed Creek's" watershed is developed and with no areas classified as medium- or high-intensity development. Though HOBE001's watershed has a low percentage of developed land cover (and associated impervious surfaces), the high percentage of the watershed covered by pasture and shrub lands along the stream network may contribute to flashier stormflows than expected based on the high forest cover (Price et al. 2011). HOBE001's watershed has a high entire stream gradient (0.0311 m/m), a low segment gradient (0.0075 m/m), and a low reach gradient (0.0068 m/m, Tables 3 and 14). HOBE001's watershed has an intermediate average slope (8.0°), moderately low drainage density (1.33 km/km^2), a high basin shape (0.36; more circular watershed), and a moderately high basin relief ratio (0.028; Table 3). Based on the basin/watershed characteristics (i.e., entire stream gradient, watershed slope, basin shape, basin relief ratio, and land use/land cover), the stream likely has a moderately flashy flow regime. The low segment and channel slopes may attenuate the energy available to erode the reach during periods of flooding, but remaining watershed characteristics indicate that the basin is likely influenced by moderately flashy flow conditions. Gage data are needed to confirm these interpretations. Due to its location on the south side of the Tallapoosa River, visitors are not expected to interact with "Claybed Creek."

Since the 2019 survey, geomorphic channel unit (GCU) diversity increased as the predominantly run covered reach had converted to a more diverse assortment of runs, riffles, and pools. Riffle habitat increased by 12%, run decreased 34%, and pools increased 30% (Table 5). There was a statistically significant change (reduction) in the mean diameter of bed material as measured by a pebble count (Table 7). Additionally, all but the two largest size fractions from the pebble count decreased in size. This addition of finer sediment is likely due to the influx of sediment from the incision that occurred in the upper portions of the reach. Loss of the step on T8 may have contributed to the observed incision.

The monitored reach at "Claybed Creek" had a large increase in the number (nearly twice as many pieces) and volume of LWD (>225% increase) within the reach (Table 8). High volumes of LWD, coarse bed material, and a mix of GCUs is indicative of relatively good habitat for benthic macroinvertebrates, if these features are stable and not frequently altered or shifted by flashy flows (Allan and Castillo 2007). Though there was an influx of fine sediment, based on the greater diversity of GCUs and the large increase in the volume of LWD per channel area, HOBE001's in-stream habitat was upgraded from "poor-to-fair" to "fair-to-good." 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 HOBE001. Habitat at HOBE001 will continue to upgrade to "good" if the fine bed material moves out of the reach, LWD stays within the reach, and/or if habitat (GCU) diversity continues to increase (Allan and Castillo 2007). Alternatively, habitat could downgrade to "fair" or worse if GCU homogenize, additional fine sediment is added to the reach, and/or if LWD passes out of the reach and is not replaced by upstream wood.

The major defining characteristics of "Claybed Creek" were the incision of the bed in the upper portions of the reach, the presence of multiple elevated entrenched surfaces, and the development of a secondary channel along river left in the downstream portion of the reach (Figure 6). The gravel bar between T1 and T3 observed in 2019 has grown towards river right developing a "secondary channel" on the river left side. This secondary channel is where a groundwater seep was observed in 2019. This secondary channel may overtake the main flow path if conditions cause further downcutting in this portion of the stream. Alternatively, this whole bar system could get washed out and additional changes may not occur. The elevated entrenched surfaces between T4 and T6 on river right and between T5 and T8 on river left appear to be relatively stable and may represent an incipient floodplain surface if they continue to be stabilized by vegetation. On the other hand, the elevated entrenched surface on river right between T7 and T9 appears to be eroding away and serving as the core of the bar observed in this area. This process is like what was observed on Noses and Ward Creeks at Kennesaw Mountain National Battlefield Park (Bateman McDonald 2025a). This degradation of elevated entrenched surfaces is natural and how this highly disturbed stream (due to its history of upstream deforestation) is equilibrating to its current sediment and flow regime. Lastly, the channel incision in the upper portions of the reach is likely related to the loss of the organic step that was between T8 and T9 in 2019. Again, this common process was also observed on multiple reaches at Chattahoochee River National Recreation Area during the 2021 surveys (Bateman McDonald 2025b).

There are no management concerns related to this reach. The changes observed are not creating conditions that are unsafe to visitors. It is recommended the area immediately downstream of the upstream road crossing be inspected to identify any knickpoints that might migrate upstream and undermine the road crossing. Additional work related to understanding the flow regime, water quality, and in-stream biota is needed to determine how upstream conditions are influencing the water moving through this reach.

Conclusion

HOBE001's watershed ("Claybed Creek") has high basin shape and moderate slope/relief and is covered by forest, pasture, and shrubland. The major defining characteristics were the channel incision observed in the upper portions of the reach, the elevated entrenched surfaces observed along both sides of creek, and the small secondary channel developing on the river left side of the lower portion of the reach. The stream continues to develop based on the stream channel evolution model presented earlier (Figure 1). As stated in the 2019 baseline report, based on the different geomorphic surfaces observed within and immediately surrounding the reach, the stream appears to be in channel evolution model stage III. The elevated entrenched surfaces are evidence the stream is widening through progressive slumping of the stream banks. The large amount of sediment which moved through the channel as the result of the LWD step blowing out around T8 shows how quickly the sediment within the reach can move. Additionally, while this process of erosion, storage, and transport is natural, if the watershed upstream of this reach (and the park) is developed, the hydrology of the stream may change in a way that causes further degradation of the stream channel potentially influencing the road crossing just upstream of the reach.

For habitat, the distinguishing features of the stream during this survey were the heterogeneity of in-stream habitat (mixture of run, riffle, and pool) and the large increase in LWD (compared to 2019). While there was an influx of fine sediment in its representative riffle (location of pebble count), due to the increased heterogeneity of habitat, and the influx of LWD, the classification of habitat within the reach was upgraded from "poor-to-fair" to "fair-to-good." 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 Horseshoe Bend National Military Park. Habitat within the reach may degrade back to a "poor-to-fair" rating if additional fine and/or very fine sediment is added to the reach (potentially from a disturbance upstream), if the GCUs lose their heterogeneity, and/or the reach loses LWD without gaining more pieces from upstream. Alternatively, if LWD can become established within the reach, this additional habitat complexity could make it more habitable resulting in an upgrade to a "good" classification (Allan and Castillo 2007). The stream does not have immediate management concerns, but there is extensive privet growth in the area outside the channel.

Literature Cited

Allan, J.D., and M.M. Castillo. 2007. Stream ecology: structure and function of running waters. Springer, Dordrecht, Netherlands.

Bartram, W. 1996. William Bartram: Travels and Other Writings. Slaughter, T. P. (ed.), Library of Congress, Washington, D.C.

Bateman McDonald, J.M. 2025a. Wadeable stream habitat monitoring at Kennesaw Mountain National Battlefield Park: 2023 change report. National Resources Report. NPS/SR—2025/329. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2313926

Bateman McDonald, J.M. 2025b. Wadeable stream habitat monitoring at Chattahoochee River National Recreation Area: 2021 change report. National Resources Report. NPS/SR—2025/263. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2308213

Craig, G.S., and J.G. Rankl. 1978. Analysis of runoff from small drainage basins in Wyoming. U.S. Geological Survey Water-Supply Paper 2056.

Fitzpatrick, F.A., I.R. Waite, P.J. D'Arconte, M.R. Meador, M.A. Maupin, and M.E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water Quality Assessment Program: U.S. Geological Survey Water Resources Investigations Report 98-4052. https://pubs.usgs.gov/publication/wri984052

Gregory, K.J., and D.E. Walling. 1973. Drainage basins form and processes: A geomorphological approach. Huddersfield, West Yorkshire, United Kingdom.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream channel reference site: an illustrated guide to field techniques. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hewlett, J.D., and A.R. Hibbert. 1967. Factors affecting the response of small watersheds to precipitation in humid areas: Forest Hydrology 1:275–290.

Homer, C.G., J.A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N.D. Herold, J.D. Wickham, and K. Megown. 2015. Completion of the 2011 national land cover database for the conterminous United States—representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing. 81:345–354.

Hughes, R.M., S.G. Paulsen, and J.L. Stoddard. 2000. EMAP-Surface waters: a multiassemblage, probability survey of ecological integrity in the USA. Hydrobiologia. 422/423:429–443.

James, L.A. 2018. Ten conceptual models of large-scale legacy sedimentation – a review: Geomorphology 317: 199–217.

Knighton, D. 1998. Fluvial forms and processes. Edward Arnold, London.

Lecce, S. A. 2000. Spatial variations in the timing of annual floods in the southeastern United States. Journal of Hydrology 235:151–69.

Leigh, D.S. 2008. Late Quaternary climates and river channels of the Atlantic Coastal Plain, Southeastern USA. Geomorphology 101:90–108.

Lins, H.F. 1997. Regional streamflow regimes and hydroclimatology of the United States. Water Resources Research 33 (7):1665–1667.

McDonald, J.M. 2019. Wadeable stream suitability assessment for long-term monitoring: Horseshoe Bend National Military Park. Natural Resource Data Series NPS/SECN/NRDS—2019/1234. National Park Service. Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2265988

McDonald, J.M. 2020. Wadeable stream habitat monitoring at Horseshoe Bend National Military Park: 2019 baseline report. Natural Resource Report NPS/SECN/NRR—2020/2067. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2271740

McDonald, J.M., and E.N. Starkey. 2018a. Wadeable stream suitability assessment for long-term monitoring: Kennesaw Mountain National Battlefield Park. Natural Resource Data Series NPS/SECN/NRDS—2018/1185. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2256953

McDonald, J.M., and E.N. Starkey. 2018b. Wadeable stream suitability assessment for long-term monitoring: Chattahoochee River National Recreation Area. Natural Resource Data Series NPS/SECN/NRDS—2018/1186. National Park Service. Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2256954

McDonald, J.M., and E.N. Starkey. 2018c. Wadeable stream suitability assessment for long-term monitoring: Congaree National Park. Natural Resource Data Series. NPS/SECN/NRDS—2018/1184. National Park Service. Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2256949

McDonald, J.M., and E.N. Starkey. 2019. Wadeable stream suitability assessment for long-term monitoring: Ocmulgee National Monument. Natural Resource Data Series NPS/SECN/NRDS—2019/1221. National Park Service. Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2259872

McDonald, J.M., M.B. Gregory, J.W. Riley, and E.N. Starkey. 2018a. Monitoring wadeable stream habitat conditions in Southeast Coast Network Parks: Protocol narrative. Natural Resource Report NPS/SECN/NRR—2018/1715. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2254874

McDonald, J.M., M.B. Gregory, and J. Riley. 2018b. Stream habitat assessment basin and segment scale data summary—Version 1.0: Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—1.2.15. Southeast Coast Network, Athens, Georgia. https://irma.nps.gov/DataStore/Reference/Profile/2254012

McDonald, J.M., E.N. Starkey, M.B. Gregory, and J. Riley. 2018c. Wadeable stream reach-scale field data collection—Version 1.1. Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—1.2.16. Southeast Coast Network, Athens, Georgia. https://irma.nps.gov/DataStore/Reference/Profile/2293668

McDonald, J.M., E.N. Starkey, M.B. Gregory, and J. Riley. 2018d. Using a total station to conduct a stream survey—Version 1.1. Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—1.2.18. Southeast Coast Network, Athens, Georgia. https://irma.nps.gov/DataStore/Reference/Profile/2293670

Mukundan, R., D.E. Radcliffe, and J.C. Ritchie. 2011. Channel stability and sediment source assessment in streams draining a Piedmont watershed in Georgia, USA. Hydrological Processes 25:1243–1253.

Newson, M.D., and C.L. Newson. 2000. Geomorphology, ecology and river channel habitat: Mesoscale approaches to basin-scale challenges. Progress in Physical Geography 24(2):195–217.

Paul, M.J., and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics, 32(1):333–365.

Price, K., C.R. Jackson, A.J. Parker, T. Reitan, J. Dowd, and M. Cyterski. 2011. Effects of watershed land use and geomorphology on stream low flows during severe drought conditions in the southern Blue Ridge Mountains, Georgia and North Carolina, United States. Water Resources Research 47:1–19.

Rose, S., and N.E. Peters. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): A comparative hydrological approach. Hydrological Processes 15:1441–1445.

Ruhlman, M.B., and W.L. Nutter. 1999. Channel morphology evolution and overbank flow in the Georgia Piedmont. Journal of the American Water Resources Association 35(2):277–290.

Schoonover, J.E., B.G. Lockaby, and J.N. Shaw. 2007. Channel morphology and sediment origin in streams draining the Georgia Piedmont. Journal of Hydrology 342:110–123.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. Incised channels: morphology, dynamics and control. Water Resources Publications, Littleton, Colorado.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38(6):913–920.

Trimble, S.W. 1969. Culturally Accelerated Sedimentation on the Middle Georgia Piedmont. U.S. Soil Conservation Service, Fort Worth, Texas.

Wenger, S.J., J.T. Peterson, M.C. Freeman, B.J. Freeman, and D.D. Homans. 2008. Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors. Canadian Journal of Fisheries and Aquatic Sciences 65:1250–1264.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35(6):951–956.

Wright, C.J., E. Thompson, B.A. Blankley, M.W. Byrne, T. Curtis, and M.B. Gregory. 2011. Summary of weather and climate monitoring in Southeast Coast Network parks, 2010. Natural Resource Data Series NPS/SECN/NRDS—2011/309. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2176354

Appendix A. Explanation of Variables

Table 18 contains information about the variables collected using the SECN Wadeable Stream Habitat Monitoring Protocol.

Table 18. Definitions of the variables used in this report.

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

[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 18 (continued). Definitions of the variables used in this report.

Variable	Variable Scale	Description
Pebble Count	Reach	The size and distribution of 100 particles (pebble count) from a representative riffle (Wolman 1954).
Canopy Cover	Reach [A]	The average of four measurements (looking upstream, downstream, and at each bank) taken using a spherical densiometer.
Reach Sinuosity	Reach	Sinuosity is calculated by dividing reach length by valley length.
Longitudinal Profile	Reach	The gradient of the line that connects the tops of the steps and riffles within a reach (channel slope)
Wetted Width	Transect [A]	Wetted channel width is measured where water is flowing (including undercuts)
Active Channel Width	Transect [A]	Active channel width is measured to the beginning of vegetation within the stream channel
Bankfull Width	Transect [A,B]	Bankfull widths should only be measured if there is a floodplain (or incipient floodplain) present
Bankfull Height	Transect [A,B]	The height of the channel bank where a floodplain is present
Bankfull Area	Transect [B]	The cross-sectional area of a stream channel at bankfull stage (height) measured perpendicular to flow
Bankfull Perimeter	Transect [B]	The length of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at bankfull discharge
Bankfull Hydraulic Radius	Transect [B]	A measure of hydraulic efficiency defined by the ratio between bankfull area and bankfull perimeter
Channel-full Width	Transect [A,B]	Channel-full widths are measured from the top of the lowest bank that is not a floodplain.
Channel-full Height	Transect [A,B]	The height of the channel bank where a floodplain is not present (channel-full height is also measured where a floodplain is inset within an entrenched channel)
Channel-full Area	Transect [B]	The cross-sectional area of a stream channel at bankfull stage measured perpendicular to flow
Channel-full Perimeter	Transect [B]	The length of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at channel-full discharge
Channel-full Hydraulic Radius	Transect [B]	A measure of hydraulic efficiency defined by the ratio between channel-full area and channel-full perimeter
Thalweg Position	Transect [A]	The position of the thalweg as a percent distance of the wetted width from left water's edge
Thalweg Depth	Transect [A]	The greatest depth of water along a transect
Dominant Particle Size	Transect [A]	A visual estimate of the dominant sediment size along a transect
Dominant Habitat	Transect [A]	A visual estimate of the dominant geomorphic channel unit along a transect

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

[B] Calculated at each detailed transect (3 per reach) using survey data collected using a total station.

Table 18 (continued). Definitions of the variables used in this report.

Variable	Variable Scale	Description
In-channel Features	Transect [A]	A description of the in-channel features (e.g., bars or islands) that are present along a transect
Floodplain Width	Transect [A]	The width(s) of floodplain(s) present along river 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 of 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.

Literature Cited

Dunne, T., and L.B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman, San Francisco, California.

Fitzpatrick, F.A., I.R. Waite, P.J. D'Arconte, M.R. Meador, M.A. Maupin, and M.E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water Quality Assessment Program. U.S. Geological Survey Water Resources Investigations Report 98-4052. https://pubs.usgs.gov/publication/wri984052

Horton, R.E. 1932. Drainage basin characteristics. Transactions, American Geophysical Union 13: 350–361.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions American Geophysical Union 35(6):951–956.

Appendix B. Survey Results for HOBE001

Figures 11 through 58 and Tables 19 through 25 show survey sites and results.

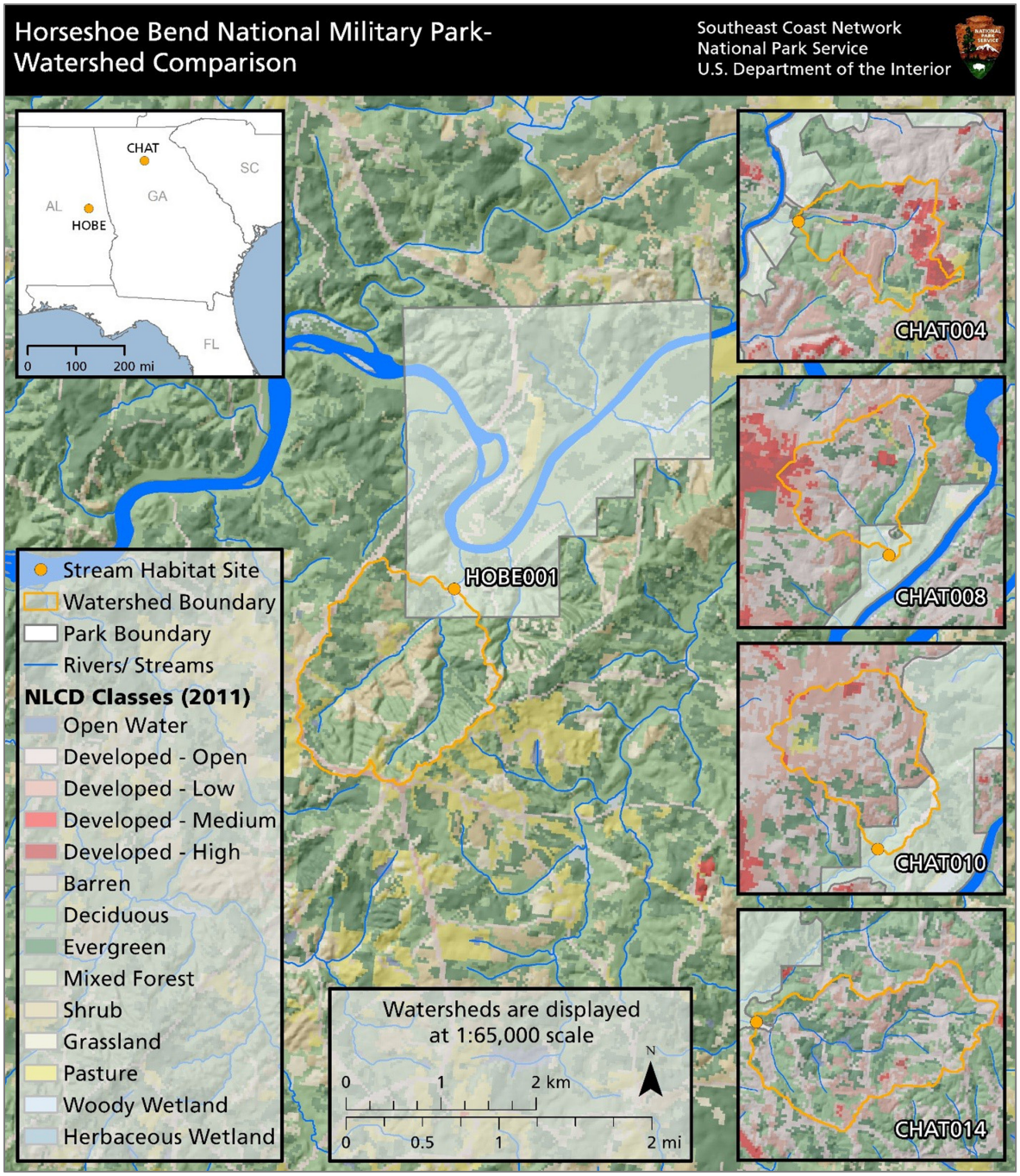


Figure 11. Map display of watershed size for HOBE001 versus CHAT004, CHAT008, CHAT010, and CHAT014 watersheds. The land use/land cover (NLCD 2011 in Homer et al. 2015) and perennial streams (derived from a 10-meter (32.8-ft) digital elevation model; data available from the U.S. Geological Survey) in the vicinity of the park are also shown.

NPS / SECN



Figure 12. HOBE001 looking upstream from T1 (detailed transect 1).
NPS / SECN



Figure 13. HOBE001 looking downstream from T1 (detailed transect 1).
NPS / SECN



Figure 14. HOBE001 facing the left bank on T1 (detailed transect 1).
NPS / SECN



Figure 15. HOBE001 facing the right bank on T1 (detailed transect 1).
NPS / SECN



Figure 16. HOBE001 looking upstream from T2.
NPS / SECN



Figure 17. HOBE001 looking downstream from T2.
NPS / SECN



Figure 18. HOBE001 facing the left bank on T2.
NPS / SECN



Figure 19. HOBE001 facing the right bank on T2.
NPS / SECN



Figure 20. HOBE001 looking upstream from T3.
NPS / SECN



Figure 21. HOBE001 looking downstream from T3.
NPS / SECN



Figure 22. HOBE001 facing the left bank on T3.
NPS / SECN



Figure 23. HOBE001 facing the right bank on T3.
NPS / SECN



Figure 24. HOBE001 looking upstream from T4.
NPS / SECN



Figure 25. HOBE001 looking downstream from T4.
NPS / SECN



Figure 26. HOBE001 facing the left bank on T4.
NPS / SECN



Figure 27. HOBE001 facing the right bank on T4.
NPS / SECN



Figure 28. HOBE001 looking upstream from T5.
NPS / SECN



Figure 29. HOBE001 looking downstream from T5.
NPS / SECN



Figure 30. HOBE001 facing the left bank on T5.
NPS / SECN



Figure 31. HOBE001 facing the right bank on T5.
NPS / SECN



Figure 32. HOBE001 looking upstream from T6 (detailed transect 2).
NPS / SECN



Figure 33. HOBE001 looking downstream from T6 (detailed transect 2).
NPS / SECN



Figure 34. HOBE001 facing the left bank on T6 (detailed transect 2).
NPS / SECN



Figure 35. HOBE001 facing the right bank on T6 (detailed transect 2).
NPS / SECN



Figure 36. HOBE001 looking upstream from T7.
NPS / SECN



Figure 37. HOBE001 looking downstream from T7.
NPS / SECN



Figure 38. HOBE001 facing the left bank on T7.
NPS / SECN



Figure 39. HOBE001 facing the right bank on T7.
NPS / SECN



Figure 40. HOBE001 looking upstream from T8.
NPS / SECN



Figure 41. HOBE001 looking downstream from T8.
NPS / SECN



Figure 42. HOBE001 facing the left bank on T8.
NPS / SECN



Figure 43. HOBE001 facing the right bank on T8.
NPS / SECN



Figure 44. HOBE001 looking upstream from T9.
NPS / SECN



Figure 45. HOBE001 looking downstream from T9.
NPS / SECN



Figure 46. HOBE001 facing the left bank on T9.
NPS / SECN



Figure 47. HOBE001 facing the right bank on T9.
NPS / SECN



Figure 48. HOBE001 looking upstream from T10.
NPS / SECN



Figure 49. HOBE001 looking downstream from T10.
NPS / SECN



Figure 50. HOBE001 facing the left bank on T10.
NPS / SECN



Figure 51. HOBE001 facing the right bank on T10.
NPS / SECN



Figure 52. HOBE001 looking upstream from T11 (detailed transect 3).
NPS / SECN



Figure 53. HOBE001 looking downstream from T11 (detailed transect 3).
NPS / SECN



Figure 54. HOBE001 facing the left bank on T11 (detailed transect 3).
NPS / SECN



Figure 55. HOBE001 facing the right bank on T11 (detailed transect 3).
NPS / SECN

Table 19. Geomorphic channel units (GCUs) observed in the area between transects at HOBE001. The data describe the percent coverage of each type of GCU [SD = standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1–2	20	5	0	75	0
2–3	0	0	0	100	0
3–4	0	20	0	80	0
4–5	50	40	0	10	0
5–6	0	95	0	5	0
6–7	0	90	0	10	0
7–8	0	90	0	10	0
8–9	50	40	0	10	0
9–10	35	30	5	30	0
10–11	5	10	0	85	0

Table 19 (continued). Geomorphic channel units (GCUs) observed in the area between transects at HOBE001. The data describe the percent coverage of each type of GCU [SD = standard deviation].

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
Frequency	5	9	1	10	0
Max (%)	50	95	5	100	0
Mean (%)	16	42	1	42	0
Median (%)	3	35	0	20	0
SD (%)	21	37	2	39	0

Table 20. Characteristics of the large woody debris observed at HOBE001 [m = meters].

LWD ID	Length (m)	Diameter (m)	Volume (m^3)	Transect Interval	Function	Position
1	4.74	0.18	0.12	10	None	Jam
2	7.15	0.10	0.06	10	Organic Trap	Jam
3	1.02	0.12	0.01	10	Bank Protection, Organic Trap	Buried
4	2.38	0.48	0.43	9	Bank Protection	Buried
5	2.25	0.12	0.03	8	Sediment Trap, Organic Trap	Buried
6	1.64	0.23	0.07	5	Sediment Trap	Buried
7	2.78	0.21	0.10	4	Bank Protection, Organic Trap, Jam	Ramp, Jam
8	3.28	0.16	0.07	4	Organic Trap, Jam	Ramp, Jam
9	2.16	0.13	0.03	4	Jam, Organic Trap	Jam
10	5.67	0.11	0.05	4	Organic Trap, Jam	Ramp, Jam
11	1.57	0.25	0.08	4	Sediment Trap	Buried
12	4.19	0.30	0.30	3	Bank Protection, Organic Trap	Jam
13	6.31	0.28	0.39	3	Jam, Organic Trap	Ramp
14	1.10	0.12	0.01	2	Jam, Organic Trap	Jam
15	2.47	0.27	0.14	2	Jam, Organic Trap	Jam

Table 21. Variability of canopy cover observed at HOBE001. [CV = coefficient of variation; SD = standard deviation].

Transect	Canopy Cover (%)
1	94
2	91
3	91
4	82
5	87
6	91
7	82
8	91
9	63
10	47
11	54
Min (%)	47
Max (%)	94
Mean (%)	80
Median (%)	87
SD (%)	17
CV	0.21

Table 22. Average reach-scale bank characteristics at HOBE001. [m = meters; L = left bank; R = right bank; 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 [A] (m)	11	11	0.72	0.71	1.73	1.85	1.29	1.39	1.36	1.48	0.36	0.39	0.28	0.28
Bankfull Height [A,B] (m)	3	3	0.72	0.71	0.90	0.95	0.78	0.83	0.72	0.84	0.10	0.12	0.13	0.14
Channel-full Height [A,B] (m)	11	11	1.25	1.30	1.73	1.85	1.48	1.57	1.48	1.49	0.14	0.19	0.09	0.12
Water Depth at Base [C] (m)	11	11	−0.03	−0.40	0.45	0.09	0.14	−0.07	0.12	−0.02	0.15	0.14	–	–
Bank Undercut [B] (m)	3	1	0.36	0.35	0.67	0.35	0.52	0.35	0.52	0.35	0.16	–	0.30	–
Bank Angle (°)	11	11	26	20	90	90	67	59	73	57	22	21	0.33	0.36
Vegetation Cover (%)	11	11	20	10	100	80	75	46	80	50	22	20	0.29	0.44
Bank Stability [D]	11	11	Stable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable	1.99	1.38	0.17	0.11

[A] Above thalweg.

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

[C] A negative number indicates base of bank is above the water surface.

[D] See Table 18 for explanation of scores.

Table 23. Cross-sectional characteristics for detailed transect 1 at HOBE001 [m = meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.80	4.63	0.39	3.84	0.78	4.92
Channel-full	5.52	7.11	0.78	5.23	1.64	3.20
Ratio	3.07	1.54	2.00	1.36	2.10	0.65

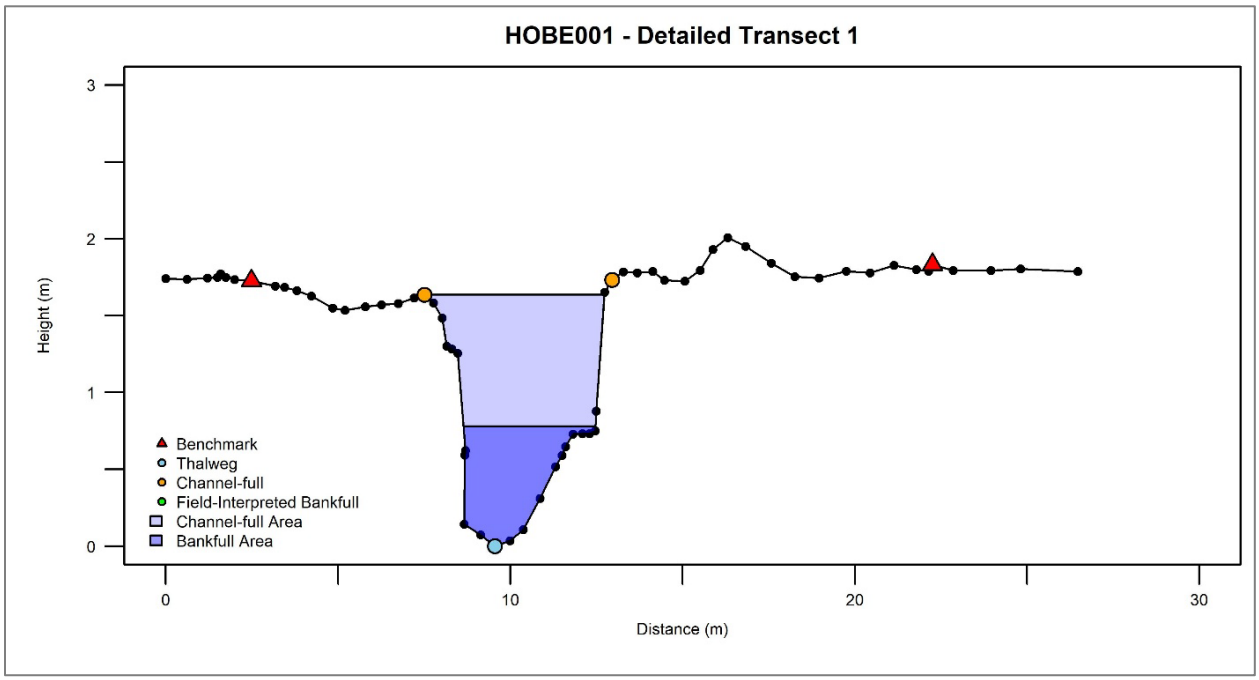


Figure 56. Detailed transect 1 at HOBE001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Additionally, the channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full 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.

NPS / SECN

Table 24. Cross-sectional characteristics for detailed transect 2 at HOBE001 [m = meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	1.96	4.70	0.42	4.19	0.60	6.97
Channel-full	6.80	9.26	0.73	8.20	1.44	5.68
Ratio	3.46	1.97	1.76	1.96	2.40	0.82

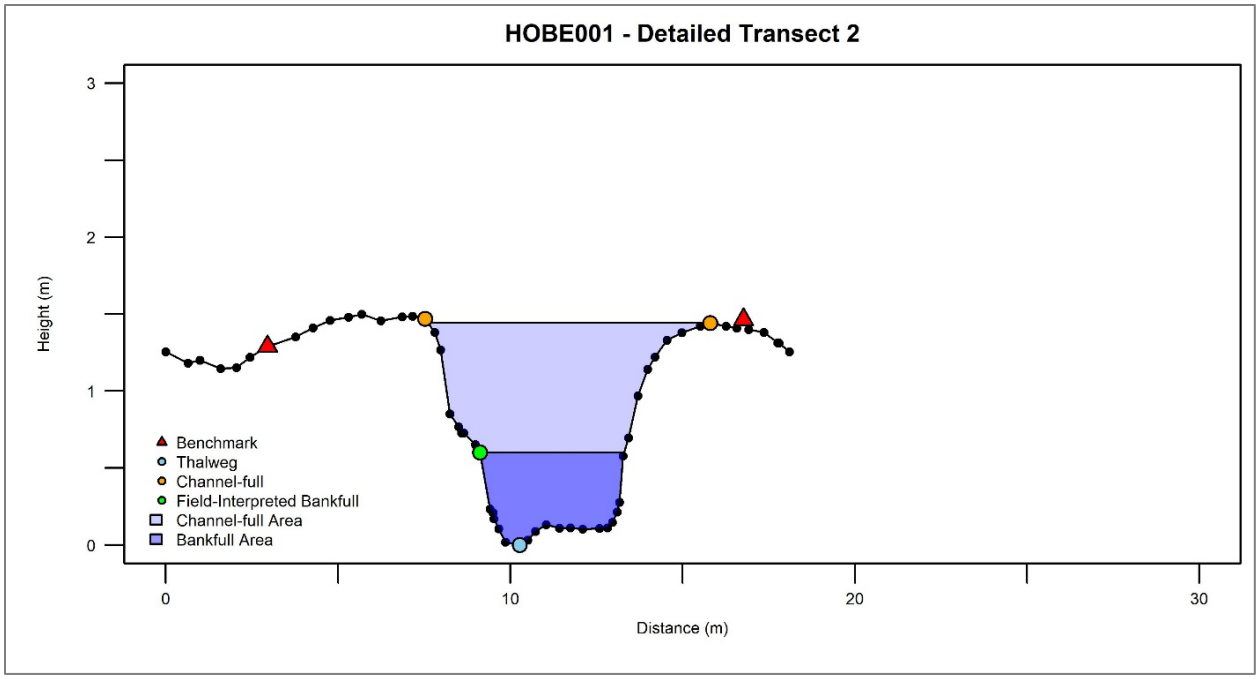


Figure 57. Detailed transect 2 at HOBE001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional area equals 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.

NPS / SECN

Table 25. Cross-sectional characteristics for detailed transect 3 at HOBE001 [m = meters].

Type	Area (m^2)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
Bankfull	2.05	4.51	0.45	3.97	0.78	5.09
Channel-full	6.93	7.87	0.88	6.55	1.72	3.81
Ratio	3.38	1.74	1.94	1.65	2.20	0.75

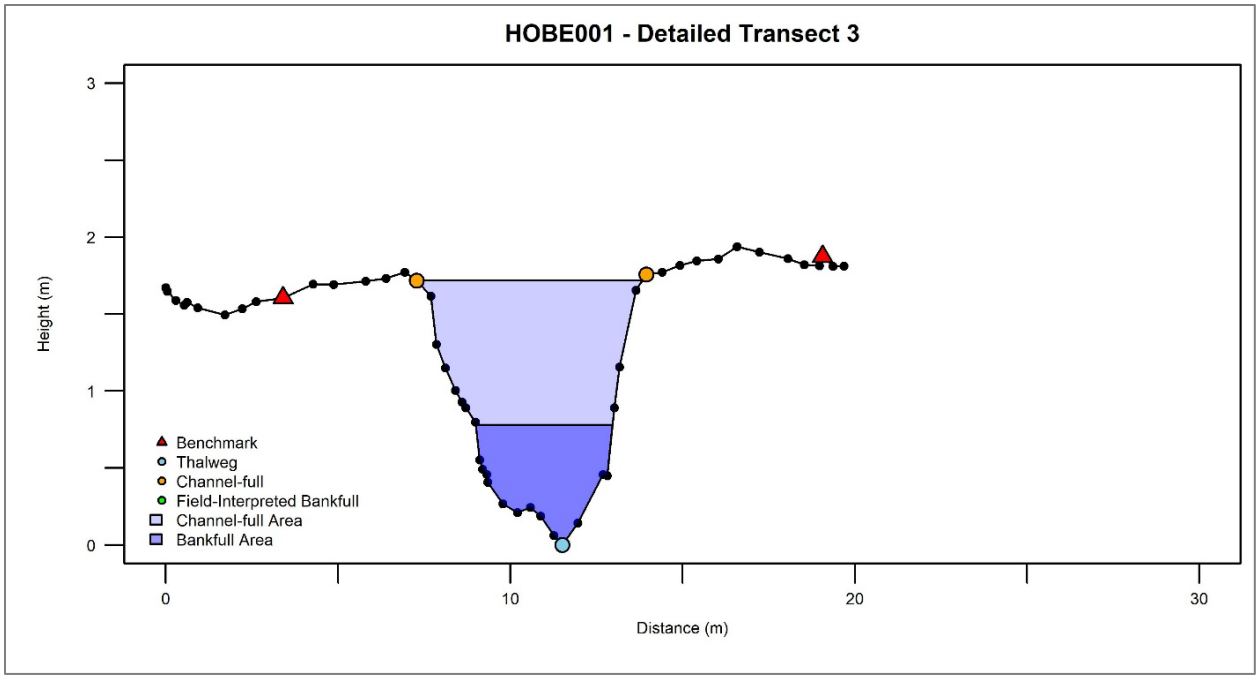


Figure 58. Detailed transect 3 at HOBE001. The surveyed locations of the left and right benchmarks, channel-full bank-tops, and interpreted bankfull bank height are shown on the figure. Channel-full (light blue) and bankfull (dark blue) cross-sectional areas are also included (channel-full cross-sectional 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.

NPS / SECN

Literature Cited

Homer, C.G., J.A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N.D. Herold, J.D. Wickham, and K. Megown. 2015. Completion of the 2011 national land cover database for the conterminous United States—representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing 81:345–354.

National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2026/442
https://doi.org/10.36967/2318455



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

NPS 407/199698, June 2026