

Appendix C: FluvialGeomorph Reports, Links, and File Names



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Rapid Watershed Assessment Tools Based on High-Resolution Terrain Data

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PURPOSE: The goal of this project was to develop rapid watershed assessment methods to estimate channel stability and sediment transport potential using high resolution terrain data (Light Detection and Ranging-LiDAR) to support US Army Corps of Engineers (USACE) watershed planning. This project developed a suite of tools based on advanced remote sensing technologies (LiDAR) that use off-the-shelf, high-resolution terrain data to rapidly assess watershed condition at the channel, floodplain, valley, and watershed scales. The widespread availability of high-resolution terrain data provides an opportunity to assess watershed conditions in great detail over large spatial extents. Automated geomorphometric tools for extracting key floodplain, valley, and watershed scale metrics are widely developed and available. However, existing toolsets have yet to automate and identify many of the well-established fluvial geomorphological metrics and related empirical relationships at the channel scale. The metrics include width-to-depth and entrenchment ratios, sinuosity, meander wavelength, belt width, and others. For this project, a channel assessment method was developed using a new LiDAR-Hydraulic Geometry Relationships (HGR)-based approach for developing regional curves (Haring et al. 2019). Regional curves relate bankfull channel dimensions and discharge to watershed drainage area and are the basis for analyzing and defining channel metrics at large spatial scales within a watershed for this rapid watershed assessment method. If regional or LiDAR-HGR curves are unavailable for a study area, additional channel assessment methods are in development that use existing hydraulic model depth grids and existing channel surveys for analyzing and defining channel metrics.

The goals and objectives of this project are the following:

Goals

- Provide a rapid watershed assessment method for USACE Planning that identifies high priority restoration and stabilization reaches.
- Develop a USACE Ecological Planning model based on rapid watershed assessment metrics to define restoration and mitigation benefits.

Approach

- Develop a suite of planning analysis tools to rapidly assess and identify sediment sources, pathways, and sinks for watershed analysis.
- Use existing geomorphic principles to develop metrics for analyzing LiDAR-derived channel, floodplain, valley, and watershed characteristics.
- Develop an approach to relate channel, floodplain, valley, and watershed characteristics to Ecosystem Restoration (ER) habitat evaluation and benefits.

This project developed a new toolbox for extracting many common channel, floodplain, valley, and watershed geomorphology metrics. The tools apply to common watershed assessment tasks by developing repeatable data analysis and processing workflows. The study developed and applied these workflows using several test watersheds located throughout the country to determine the applicability to a wide range of hydro-physiographic conditions and input data quality.

The rapid watershed assessment approach was developed to better quantify the benefits of streambank stabilization to protect downstream habitats in the Illinois River impacted by excessive sedimentation. The method allows quantification of the potential stream stabilization requirements in a watershed by mapping fluvial geomorphic channel metrics. The various channel metrics map stream reaches by relative channel stability that is based on high, medium, and low erosion potential for the entire watershed as support to watershed planners. The approach also supports ER habitat evaluations that demonstrate links between fisheries data and high-resolution terrain-derived stream channel characteristics and the quality of aquatic habitat. This framework will use geomorphic channel characteristics as predictor variables of aquatic health measured by fish community metrics. Success with linking ecological indicators to a rapid watershed assessment package will provide a powerful remote sensing RS tool to estimate fisheries potential and test alternative management plans.

In addition, tools created for watershed assessments will support project reconnaissance, regulatory permitting, design, and adaptive management phases with increased spatial coverage and accuracy of geomorphic channel, floodplain, and watershed data. The assessment approach will provide more advanced design information to feasibility alternative evaluation and cost-benefit analysis studies. Maps and data summaries will support USACE engagements and communication of watershed plans across the spectrum of lay and technical audiences.

STUDY NEED: The Illinois River Basin Restoration (IRBR) Program (WRDA 2007, Section 519 (b) and (c)) established the authority to implement watershed restoration studies to reduce sediment transport to Illinois River backwaters, side channels, and wetlands. Early project planning revealed differences in the broad scope of the watershed plan under one policy guidance (USACE watershed policy, EC1105-2-411) and project implementation under a different guidance (USACE 2000). Watershed assessment “may mean including downstream areas that are otherwise technically not in the local watershed or perhaps including a much broader, more regional watershed to adequately capture the full ranges of influence...” (USACE watershed policy, EC1105-2-411). Planning at the project level may consider “...resources that would be directly, indirectly, or cumulatively affected by alternative plans . . . often called the affected area” (USACE 2000). Consequently, it was discovered during early IRBR project planning that USACE methods for stream restoration and ecological benefit analysis were insufficient to document off-site sediment reduction benefits provided by stream stabilization in the watershed. In addition, USACE environmental project cost-benefit analysis (USACE 2000) requires measurable improvement in local habitat conditions (i.e., Habitat Units) that may not be substantial in stream stabilization projects because the projects do not typically capture ecological improvement as much as they stabilize existing conditions to reduce future or off-site impacts.

USACE project planning also includes a host of real estate implications concerning land ownership that precludes taking benefits outside of the project area in federal ownership or easement. As a result, stream restorations evaluate habitat benefits over small stream reaches or

project areas, rather than over decades of sediment transport reduction benefits to the downstream reaches. With hundreds of potential small watershed projects in the Illinois Basin alone (or any USACE watershed study), there is a need to rapidly define sediment management needs with high resolution over large areas. The USACE emphasis on habitat outcomes requires better capacity to evaluate stream habitat over large spatial scales, so there is also a direct need for a planning tool to that provides high-resolution stream habitat indicators.

CONCEPTUAL FRAMEWORK: A landscape approach was used for this study to define an analytical hierarchy of channel, floodplain, valley, and watershed metrics (Figure 1). The information at each level or in various combinations can be used to classify stream condition for watershed assessments. Floodplain, valley, and watershed metrics define the source of overland flow and the external supply of sediment to streams. Channels and floodplains can be sediment sources, pathways, or sinks depending on local physical conditions that can be characterized as Functional Process Zones (FPZ). Thorp et al. (2006) defined FPZs in River Ecosystem Synthesis, which conceptualized the physical-ecological relationships inherent in watersheds, streams, and rivers as catchments driven by climate and geology. The FPZs are shaped as “linked, discontinuous hierarchies of patch dynamics” formed by physicochemical characteristics that affect ecosystem structure and function.

Recent USACE watershed-scale planning initiatives emphasize integration of landscape ecology principles. Hierarchical landscape principles support science, planning, design, implementation, and monitoring of watershed plans by identifying the function and connectivity of habitat patches relevant to natural resource managers and the public. Williams et al. (2013) reported a wide range of geomorphic watershed characteristics to consider, so this study adopted the spatial hydro-geomorphic variables recommended for US databases applicable across the USACE areas of responsibility as a first-level evaluation.

As an example, by evaluating channel slope and width-to-depth ratios, the RS analysis tools can provide insight on distribution of stream power and sediment transport potential within the watershed stream network. These relationships are mapped at the channel, floodplain, valley, or watershed scale, and potential locations of sources, pathways, and sinks can be identified. In combination with additional variables, they directly influence floodplain and watershed characteristics. The development of RS tools that measure channel HGRs in combination with existing landscape ecological principles (Thorp et al. (2006); Williams et al. (2013) provides tools to rapidly assess watersheds.

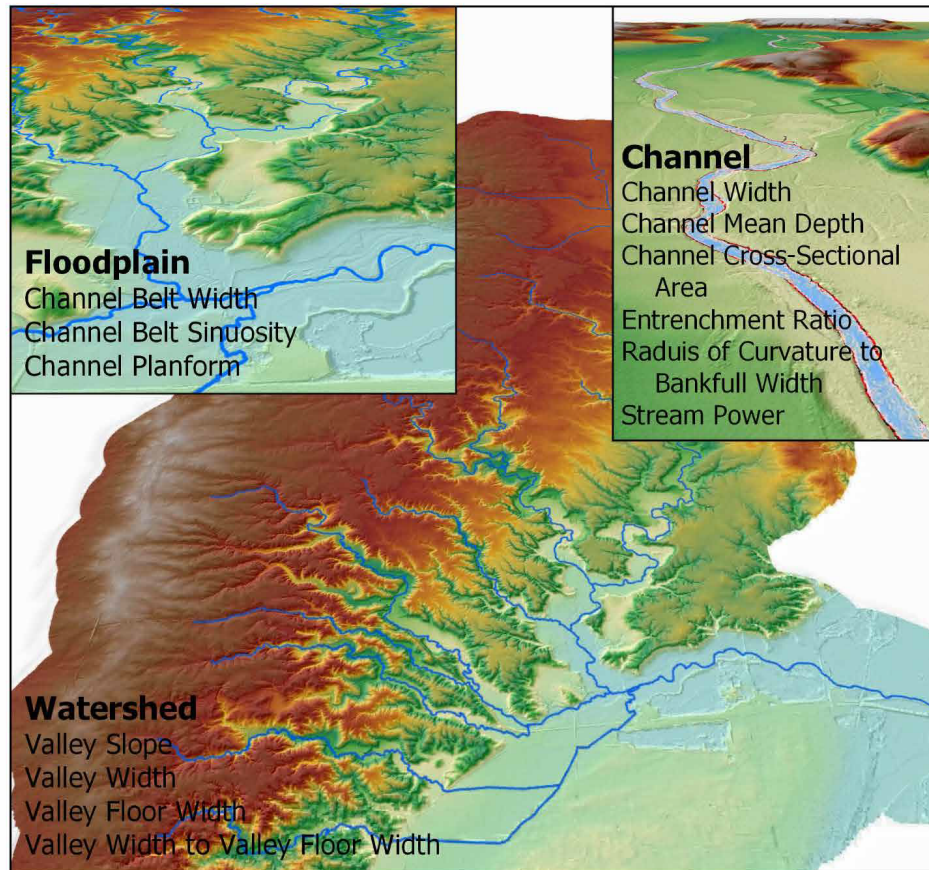


Figure 1. Watershed analysis workflow.

REGIONAL CURVE DEVELOPMENT: Stream systems develop a regular progression of channel form and morphology that naturally balance watershed inputs. Channel forming or bankfull HGR develop from balancing and maintaining a quasi-equilibrium state between sediment supply, slope, channel shape, planform, vegetation, and other factors. In a stable stream, bankfull discharge fills the channel to the active floodplain level providing a delineating morphological feature defining channel forming discharge, sediment transport processes, and depositional features on a floodplain (Dunne and Leopold 1978; FISRWG 1998). Information about bankfull channel geometry and discharge is important to researchers, federal, state, and local governments, and private organizations involved in construction of roadways, bridges, infrastructure projects, stream stabilization and restoration projects, and watershed assessments. Over the past 4 decades, stream analysis, research, and design of restoration and stabilization projects have largely focused on using a natural-channel design approach that is reliant on estimates of bankfull channel geometry and discharge.

A common method for analyzing geomorphic channel stability is to evaluate channel dimensions relative to regional curves that relate bankfull channel dimensions and discharge relative to drainage area through linear regression analysis. The resulting regression models provide morphological channel dimensions that directly relate to channel forming discharge, sediment

transport processes, and depositional channel features. Watershed assessments and stream restoration design techniques suffer from lack of coverage of regional curves for specific hydro-physiographic regions and subregions, which limits the capacity to analyze many ungaged watersheds lacking this data.

LiDAR-HGR based regional curves can be developed by combining existing and discontinued stream gage data, rating curves, and datum conversions with high-resolution terrain data to capture natural geomorphic channel characteristics (Haring et al. 2019). Standard regional curve development is based on traditional geomorphic field surveys capturing bankfull channel dimensions at stable riffle or channel cross-over locations. The LiDAR-HGR methodology also assembles riffle data surveys that provide the least amount of bankfull mean depth error. Similarly, LiDAR-HGR requires an adequate number of gages within a hydro-physiographic region of interest to effectively capture the variation of fluvial geomorphic bankfull conditions. Once the LiDAR-HGR regional curves are assembled, departure analysis comparing channel dimensions from the existing ungaged watershed to the LiDAR-HGR regional curve can be completed. If the channel dimensions at the ungaged watershed location are within the 90% confidence interval, then the channel is considered to be stable. If the channel dimensions fall outside the 90% range, then further analysis is required from other channel and planform matrices. The process for constructing a regional curve is depicted in the flow diagram below (Figure 2).

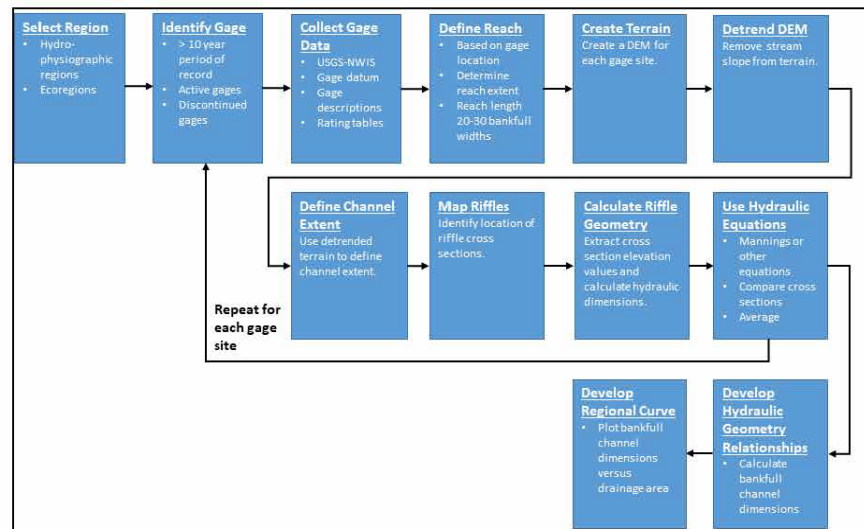


Figure 2. LiDAR-HGR regional curve workflow.

CHANNEL METRICS: This study incorporates open source geospatial tools to support channel, floodplain, valley, and watershed geomorphic analysis. Traditional geomorphic field-based data collection methods, out of necessity, gather and measure channel dimensions and slope using well-established ground survey methods (Harrelson et al. 1994). The traditional field surveys are often limited with constraints on time, funding, and the availability of appropriate survey personnel. In addition, recent literature regarding stream restoration indicates that traditional field survey methods for gathering bankfull channel dimensions may be error prone with reported errors ranging from 5% to 25% (Hammer 1981; Wahl 1977). Conversely, this rapid

watershed assessment method uses existing high-resolution spatial data that can greatly increase the spatial extent and precision of stream assessments thereby reducing time and cost.

An ArcGIS fluvial geomorphology toolbox was developed exclusively for this study to process high-resolution terrain data, extract channel dimensions, and use existing empirical relationships to provide rapid watershed analysis. The toolbox and resulting channel metrics are all based on the concept of bankfull discharge and its effectiveness in shaping the dimension, pattern, and profile of the channel, floodplain, valley, and watershed. Dunne and Leopold (1978) are credited with the commonly accepted and universally applicable definition of bankfull discharge as “the bankfull stage corresponding to the discharge in which the channel maintenance is most effective, that is, the discharge that is moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that result in the average morphological characteristics of channels.” The bankfull discharge and associated channel dimensions are the defining analysis tools that quantify channel metrics relative to empirical relationships known to support stable, intermediate, or unstable stream channel conditions. For example, the sinuosity metric is measured by stream length divided by valley length, and values less than 1.2 may indicate channelization, coupled with a width-to-depth ratio of less than 10 may indicate channel instability in the form of channel bed degradation.

The stream channel metrics are described in Table 1 and are based on bankfull channel dimensions to include width, mean depth, cross-sectional area, discharge, water surface slope, width-to-depth ratios, entrenchment ratios, sinuosity, radius-of-curvature, stream power, and additional planform matrices.

Table 1. Generalized rules for bankfull channel dimension and planform geometry metrics.	
Channel Dimension	
Width, Mean Depth, Cross-sectional Area	Required for Regional Curve Development: Dimensions of bankfull width (ft) and mean depth (ft), cross-sectional area, and discharge (cfs). These are typically plotted against drainage area (square miles).
Width to Depth Ratio	Shape of the channel based at bankfull width (ft) and mean depth (ft) at bankfull discharge.
Entrenchment Ratio	Depicts relative access to the active floodplain. Typically, at two times the maximum bankfull depth, the water surface width should be at least two and one-half times the water surface width at bankfull depth. This ratio may be less depending on channel boundary materials and resistance to erosion.
Planform Geometry	
Sinuosity	Sinuosity is the ratio of stream length to valley length. It can also be described as the ratio of valley slope to channel slope for defined reaches. Less than 1.2 likely means a channelized reach and combined with the width-to-depth ratio less than 10 may indicate incised channel reaches.
Radius of Curvature(R_c)/ Bankfull Width	The ratio value of R_c to bankfull width is commonly used as a diagnostic test for channel planform stability. The ranges that can occur in nature are highly variable, but in general, if the $R_c/Bkfl$ ratio is less than 1.8 (<1.8), then the outside bend-channel banks will likely be eroding very aggressively as the channel bend progresses erosion in a downvalley direction.
Energy	
Stream Power ($S \times Q$)	Stream Power is the slope (S) x discharge (Q) $Q_s Q_{50} \sim S Q$; Lanes-Balance of Dynamic River Forces

FLUVIALGEOMORPH TOOLBOX: The FluvialGeomorph toolbox is designed to provide a comprehensive set of tools for transforming raw terrain data into a set of synthetically derived stream characteristics to derive common fluvial geomorphic metrics (Table 1). The toolbox contains purpose-built Python tools (Table 2) designed to run within ESRI ArcGIS Desktop or ArcPro (ESRI, 2018) to perform geospatial analysis. Some of these Python tools call custom R (R Core Team 2018) functions to perform statistical analysis and graphing. This modular design allows flexibility to support both geospatial analysis and automated report generation. TauDEM (Tarboton 2018) is used for many of the hydro-modification steps. This toolbox was heavily influenced by the currently inactive and closed-source River Bathymetry Toolkit (McKean et al. 2009).

Table 2. FluvialGeomorph tools.	
Tool	Description
Burn Cutlines	Burns cutlines into DEM* to ensure water flows across terrain
Contributing Area	Calculates the up-slope area for each DEM pixel
Stream Network	Develops synthetic stream network from hydromodified DEM
Gradient	Calculates stream slope and sinuosity
Create Flowline	Constructs a smooth flowline route
Stream Profile Points	Converts flowline to points and calculates elevation
Detrend DEM	Creates a DEM with valley slope removed
Channel Extent	Creates a channel extent polygon
Channel Slope	Calculates a channel extent slope raster
Centerline	Creates a centerline from channel extent
XS Layout	Creates a set of regularly spaced cross sections
XS Watershed Area	Calculates drainage area for each cross section
XS Assign River Position	Calculates the longitudinal position of each cross section
XS Create Station Points	Converts cross sections to points and calculates elevation
XS Dimensions	Calculates cross section hydraulic dimensions
Reach Bankfull Graph	Graphs sensitivity analysis results for a specified bankfull elevation for selected regions
Reach Geometry Graph	Graphs the hydraulic geometry dimensions for a specified bankfull elevation
XS Plot	Graphs a single cross section for a specified bankfull elevation

*DEM = digital elevation model

FluvialGeomorph tools must be organized into a series of ordered steps, which are referred to as workflows. This project has so far developed two workflows: rapid watershed assessment and regional curve development. For example, Figure 3 is a flow model of the individual steps for the Watershed Analysis workflow described in Table 2. Within each workflow step, one or more FluvialGeomorph tools may be required to accomplish that step. The modular design of the FluvialGeomorph toolbox allows new tools to be created to support a new tasks, modify existing workflows, and move to new watersheds.

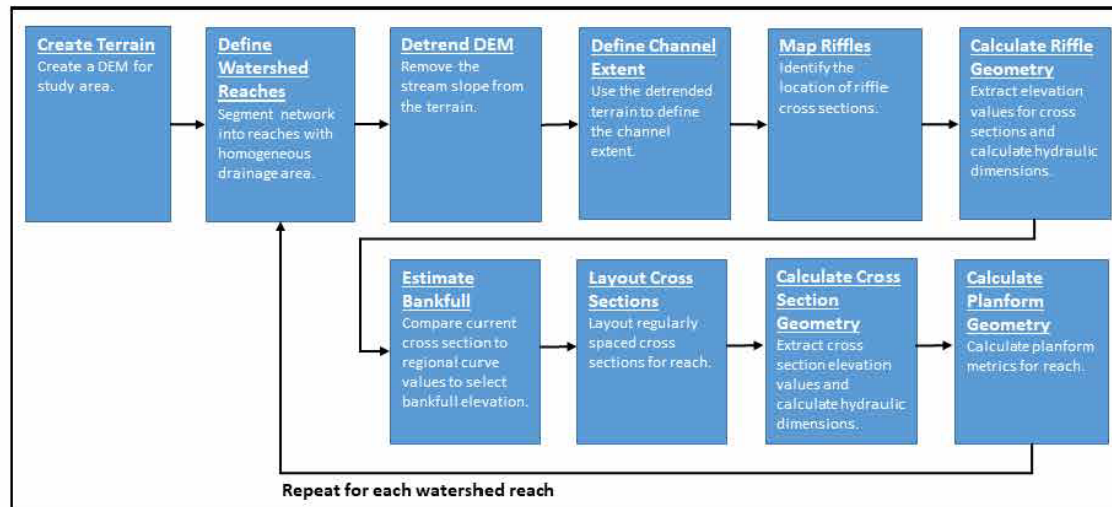


Figure 3. Watershed analysis workflow.

STREAM HABITAT RELATIONSHIPS: Given the fidelity of LiDAR-derived stream metrics described in this study, these stream characteristics should serve as strong predictors of aquatic habitat. To make the link between terrain-derived stream characteristics and the quality of aquatic habitat, this study will use stream metrics as predictor variables of aquatic health measured by such metrics as Index of Biological Integrity (IBI) scores. Machine learning methods will be used to train and test this habitat response model in Minnesota River Basin streams to demonstrate that the watershed, valley, floodplain, and channel metrics can predict fish community characteristics. A subset of available fish sample sites to characterize the Minnesota River Basin across several physiographic regions will be selected. The correlations can be validated against remaining sites to define relationships for extrapolation throughout the basin.

If stream metrics prove to be good predictors of IBI scores for the existing condition, then Future Without Project and project alternatives can be analyzed for habitat impacts using this model. This approach makes the most use of existing LiDAR and state-level IBI data, making it feasible in a rapid assessment framework.

CONCLUSION: HOW DOES THIS HELP THE USACE PLANNING PROCESS? Developing habitat relationships is important for USACE Ecosystem Restoration planning and watershed analysis, and this project provides an efficient rapid watershed assessment methodology. Integrating channel, floodplain, valley, and watershed-wide remote sensing data analysis with existing biological data is more efficient relative to quantitative hydrologic models and can provide high-resolution information during the earliest steps of watershed planning. For this project, existing Minnesota River biological data are used to estimate fisheries potential and to evaluate alternative management plans.

The rapid watershed assessment approach integrates channel metrics and biological data to identify potential benefits of stream restoration alternatives and downstream habitats impacted by excessive sedimentation. The analysis approach uses existing regional curves or develops new curves based on the LiDAR-HGR methodology to analyze geomorphic channel metrics that detect channel stability issues identifying watershed-wide locations (Haring et al. 2019). Once

unstable channel locations or reaches are identified, cumulative steps toward alternative restoration plans and project completion could be conceived and quantitatively evaluated for sediment retention potential and habitat analysis.

The rapid watershed assessment provides efficiency desired for modern USACE district planners and may also be used for disaster and hazard assessment in fire-damaged landscapes. While designed for watershed habitat restoration assessment, the watershed assessments may be used to support regulatory cumulative effects analysis. In conditions where main-stem river backwater sedimentation issues exist or navigation channel dredging is impacted, potential sources and locations of sediment delivery from the watershed can be provided based on the geomorphic watershed analysis. Once the potential sediment sources are located in the tributary streams, then focused watershed and habitat restoration projects can be investigated and implemented.

The approach provides a relatively quick, thorough, geomorphic-based, watershed-wide assessment capability that has not been provided elsewhere, based on current information. This is particularly useful for watersheds that lack biological data to support habitat evaluations as is common in most project sites. The integration of the rapid watershed assessment and biological data will produce a plan that compiles results into a habitat benefits model for nationwide application. The analysis method provides the ability to produce high-resolution, quantitative geomorphic assessments over large spatial ranges.

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Channel Assessment Tools for Rapid Watershed Assessment

by Chris Haring and David Biedenharn

PURPOSE: Existing Delta Headwaters Project (DHP) watershed stabilization studies are focused on restoration and stabilization of degraded stream systems. The original watershed studies formerly under the Demonstration Erosion Control (DEC) Project started in the mid-1980s. The watershed stabilization activities are continuing, and because of the vast number of degraded watersheds and limited amount of yearly funding, there is a need for developing a rapid watershed assessment approach to determine which watersheds to prioritize for further work.

The goal of this project is to test the FluvialGeomorph (FG) toolkit to determine if the Rapid Geomorphic Assessment approach can identify channel stability trends in Campbell Creek and its main tributary. The FG toolkit (Haring et al. 2019; Haring et al. 2020) is a new rapid watershed assessment approach using high-resolution terrain data (Light Detection and Ranging [LiDAR]) to support U.S. Army Corps of Engineers (USACE) watershed planning. One of the principal goals of the USACE SMART (Specific Measureable Attainable Risk-Informed Timely) Planning is to leverage existing data and resources to complete studies. The FG approach uses existing LiDAR to rapidly assess either reach-specific analysis for smaller more focused studies or larger watersheds or ecosystems. The rapid assessment capability can reduce the time and cost of planning by using existing information to complete a preliminary watershed assessment and provide rapid results regarding where to focus more detailed study efforts.

BACKGROUND: The DHP seeks to develop and demonstrate a watershed systems approach to address problems associated with watershed instability: erosion, sedimentation, flooding, and environmental degradation. Initiated by the federal government in 1984, DHP activities targeted 16 watersheds comprising 2,626 mi²* within the Yazoo River Basin in the Lower Mississippi Valley. Primary features that are being utilized to achieve the project goals include grade control structures, floodwater retarding structures, bank-stabilization measures, pipe drop structures, and land-treatment measures. A key component of the DHP is monitoring the system to determine the impact of various features with respect to reductions in sediment delivery. Monitoring also provides for the development of advanced technologies that can be transferred to projects outside of the DHP watersheds.

Integrating and further increasing the USACE knowledge base of DHP watershed and regional sediment management approaches is vital to the successful implementation of the SMART Planning paradigm. Watershed management, in this context, includes the evaluation of sediment sources, pathways, and sinks, and the impacts of various sediment management features on

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

channel stability throughout a watershed. Watershed management also includes the design of equilibrium channels and siting for grade control and bank-stabilization measures. By utilizing findings from geomorphic assessments, in conjunction with selective surveying to obtain general slope and cross-sectional data, watershed plans for flood control, channel stabilization, regional sediment management, and habitat enhancement can be developed more rapidly than existing approaches. Establishing and applying this rapid assessment framework in a DHP watershed through this research and development effort will assist all USACE Districts by providing improved guidance for rapid watershed assessment for river engineering activities while adhering to the SMART Planning Principles.

FLUVIALGEOMORPH (FG) APPROACH: The FG-Rapid Geomorphic Assessment (RGA) approach outlined in Haring and Dougherty* is divided into three primary workflows. The first workflow, which is the subject of this paper, defines Level 1-Channel Stability Analysis (CSA) for stream channel reaches within the study watershed (Figure 1). The Level 1 CSA evaluates both LiDAR-based longitudinal water surface profiles and channel cross-sections. This provides a reconnaissance level method to identify potential areas of concern based on LiDAR water surface or dry channel slope profiles and cross-sectional area comparative analysis. The CSA provides a basis for identifying potential areas of interest where channel degradation, aggradation, or widespread channel changes are observed. This approach is used to qualitatively identify sediment sources, pathways, and sinks based on channel stability analysis within the reach or larger stream network.

If necessary, the second and third levels of the FG-RGA can be used to provide further refinement via Channel Dimensional Analysis and Planform Dimension Analysis, respectively. The final product of the Level 2 and 3 analysis is a reach level report that maps details of the channel and planform metrics. These metrics are a diagnostic rating based on standardized or user-defined geomorphic thresholds. The metrics are then mapped by color-coded signals providing a comprehensive geomorphic assessment at the reach or watershed scale based on empirically derived geomorphic metrics. The FG-RGA Levels 1, 2, and 3 are defined in more detail in the unpublished Haring and Dougherty technical note.

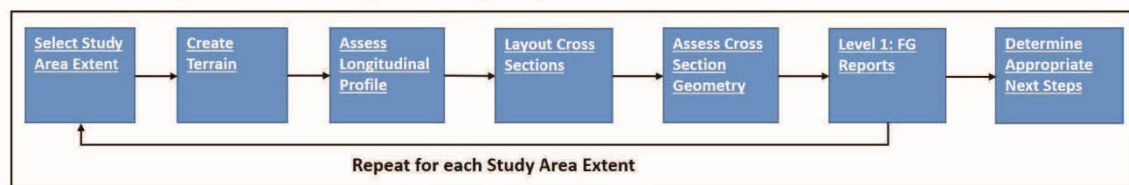


Figure 1. FluvialGeomorph (FG)-Level 1: CSA.

CAMPBELL CREEK CONSTRUCTION HISTORY: Campbell Creek is a small stream in the Batupan Bogue Watershed, which flows into the Yalobusha River just downstream of the Grenada Reservoir (Figure 2). The Campbell Creek watershed is 3.9 mi² with the majority in Grenada County and the downstream section in northeast Montgomery County. Historically,

* Haring, C. H., and M. P. Dougherty. In preparation. *Geomorphic Metrics Used in FluvialGeomorph*. ERDC/CHL Coastal and Hydraulics Engineering Technical Note. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Campbell Creek has experienced channel degradation and widening, primarily as a result of channelization activities in the watershed. In response to this instability, the USACE conducted detailed geomorphic and engineering studies in the mid-1980s aimed at developing stabilization plans for the stream system. As part of these studies, a detailed channel survey was conducted in 1986, which recorded thalweg elevations on a 50 ft interval (Figure 3). Note that the 1986 survey team surveyed the wrong channel downstream at approximately Station 3700. Therefore, this portion of the thalweg survey is invalid. Based on these studies, a stabilization plan was developed for Campbell Creek that included three low drop grade control structures. The proposed location and elevation of these three structures are shown in Figure 4. Further refinements were made to the stabilization plan, and in 1991 another thalweg survey was acquired. A comparison of the 1986 and 1991 surveys (Figure 4) shows that there was significant channel degradation during this time period, with some areas experiencing over 10 ft of channel incision. As a result of these channel changes, the location and elevation of the proposed grade control structures had to be revised. These three structures were constructed in the early 1990s, and the as-built locations and elevations are shown in Figure 4. Recent DHP monitoring of Campbell Creek indicates that portions of the channel were still experiencing channel degradation and bank instabilities, and it was selected as a Regional Sediment Management (RSM) case study to apply the recently developed FG-Level 1 CSA approach.

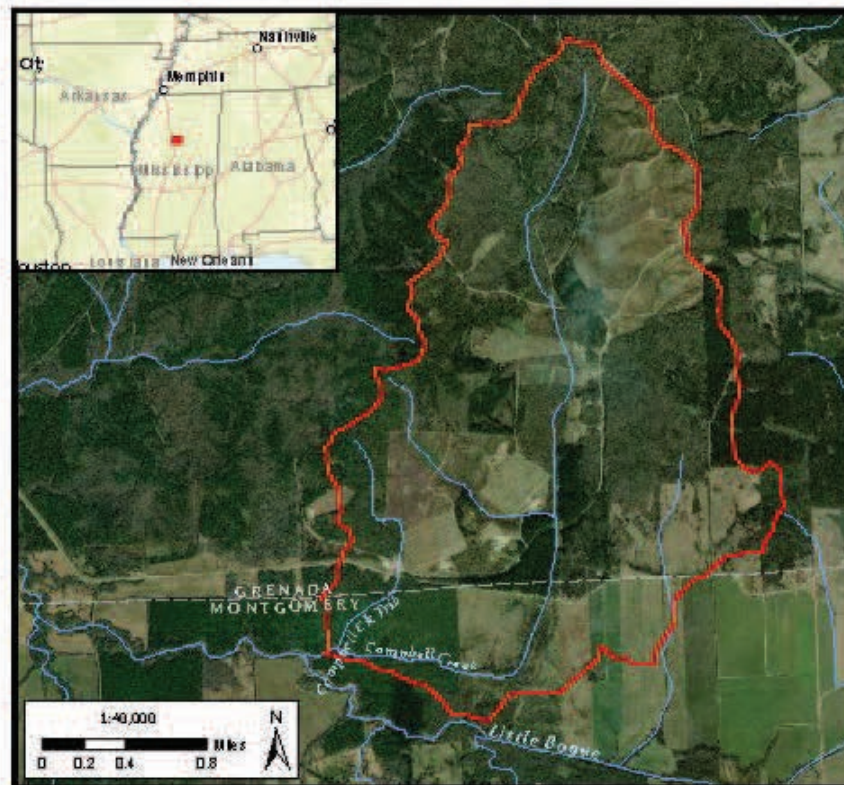


Figure 2. Campbell Creek watershed analysis reaches.

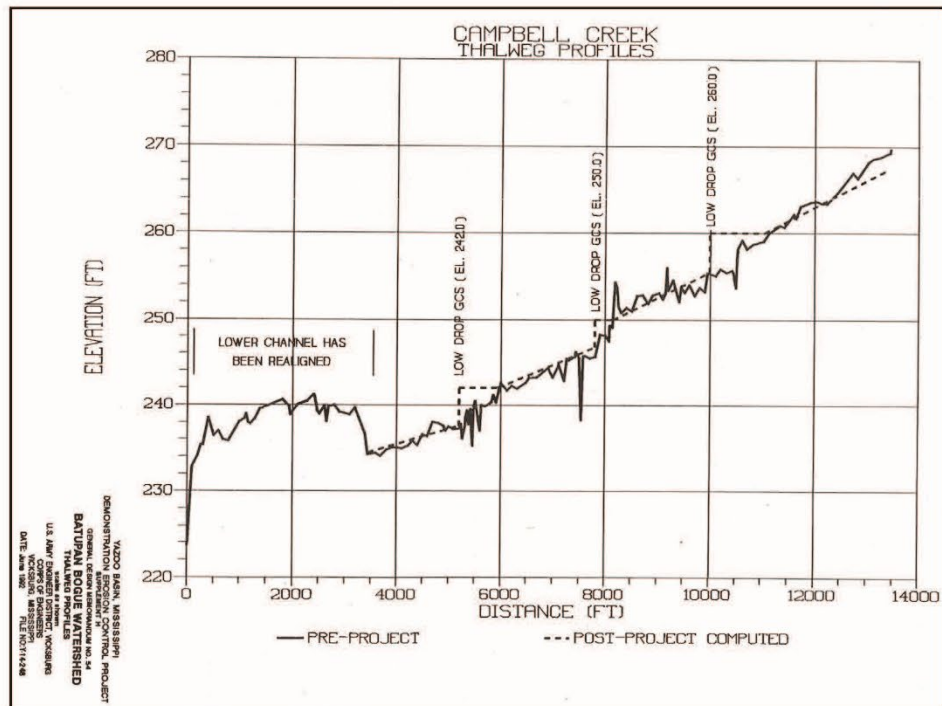


Figure 3. Campbell Creek 1986 channel survey.

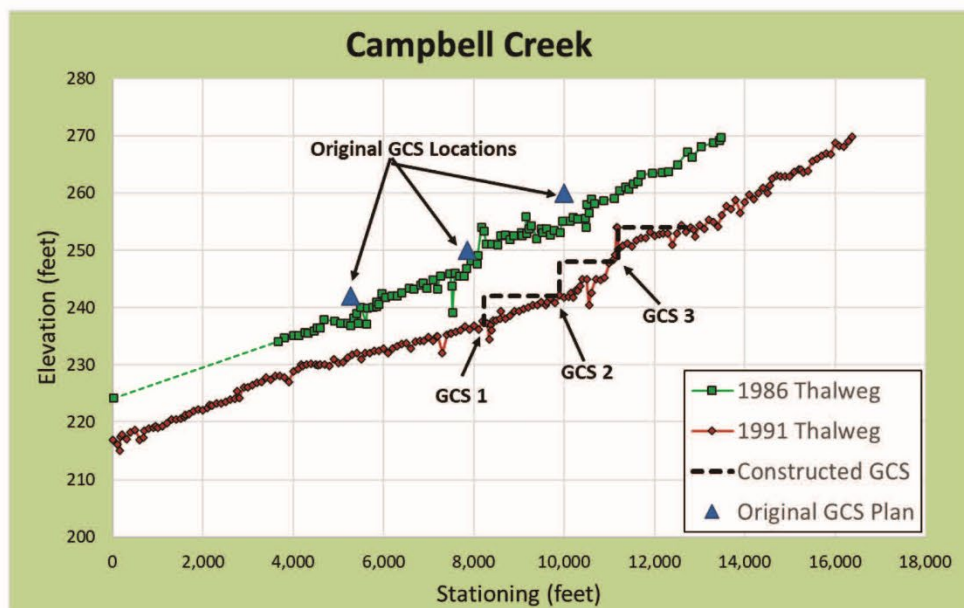


Figure 4. 1986 and 1991 thalweg surveys on Campbell Creek. Note: because of the survey bust in the 1986 survey, the downstream segment was drawn as a straight (dashed) line between approximately Station 3700 and the confluence with Little Bogue, where the elevation was known to be correct.

RSM APPROACH: The Campbell Creek study was divided into four components: (1) field investigations, (2) acquisition and development of LiDAR data, (3) data analysis, and (4) stabilization recommendations.

Field Investigation. The first step was a field investigation of the channel system in October 2019. Figure 5 shows the limits of this field investigation along with pertinent geomorphic features. An ArcGIS Collector app was used via cell phone to take pictures and provide locations along the stream channel transect survey (Figure 5).

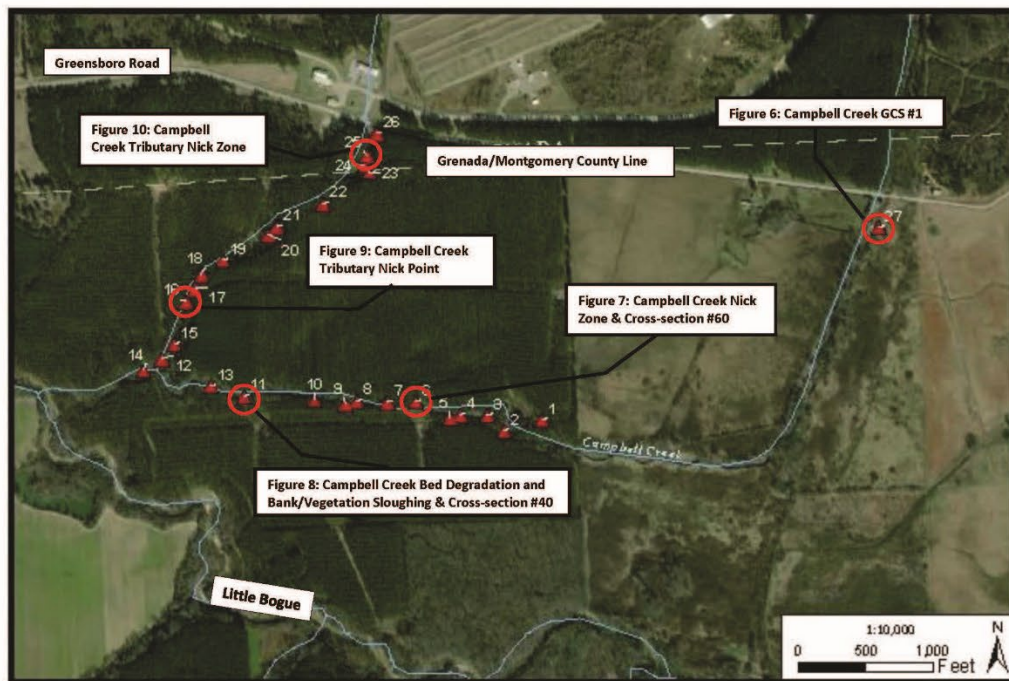


Figure 5. Campbell Creek field investigation with ArcGIS collector point locations.

Photographs of typical channel conditions along Campbell Creek and Campbell Creek Tributary are shown in Figures 6 through 10. These investigations reveal that the channel downstream of the lowermost grade control structure (GCS No. 1; Figure 5) is in a degradational regime, as is most of the entire reach of the Campbell Creek Tributary. In most locations, the bed of the stream had incised into a hard clay material (Figure 10). Although this material is relatively resistant to erosion, there was obvious evidence that the bed was still actively degrading, albeit at a slow rate.



Figure 6. Campbell Creek grade control structure #1.

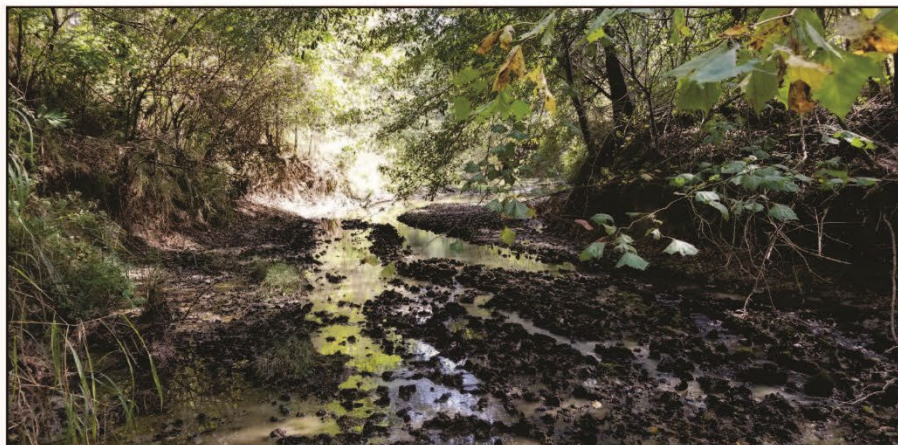


Figure 7. Campbell Creek field identified nick zone in semi-resistant clay bed.



Figure 8. Campbell Creek field identified bed degradation with sloughing bank and vegetation.



Figure 9. Campbell Creek Tributary nick point with channel widening and sloughing bank and vegetation immediately downstream.



Figure 10. Campbell Creek Tributary nick zone downstream of James H. Bidy Road culverts.

Acquisition and Development of LiDAR Data. The next step in the process was the acquisition of LiDAR survey data to assist in the geomorphic assessment. The Grenada County, Mississippi, LiDAR data were downloaded from the MARIS (Mississippi Automated Resource Information System) site:

<https://www.maris.state.ms.us/HTM/DownloadData/LIDAR.html>

Based on the Mississippi LiDAR collection map, the COE Delta Phase II – 2010 data cover Grenada County. The LASer (LAS) was downloaded by flightline but was unprocessed. Each point was not classified. The ArcPro automated classification ground tool was used, taking approximately 4 days to classify the ground points from the flightlines. An LAS Dataset was created and then a 1 ft digital elevation model (DEM). The flightlines from Grenada County crossed into Montgomery County allowing a visual comparison of the two DEMs, which were

visually similar. MXDs (Map Exchange Documents) for Campbell Creek are available at the following link:

\\mvrdfs\egis\Work\Office\Regional\ERDC\EMRRP_Sediment\CampbellsCreek

The 2014 LiDAR data for Montgomery County, Mississippi, was discovered on the U.S. Geological Survey (USGS) Rocky FTP site:

ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/NED/LPC/projects/USGS_LPC_MS_Laurel_2014_LAS_2015/

The LAS tiles were downloaded, and a LAS dataset was created. The dataset was filtered for ground, water, and rail; then, a 1 ft DEM was created.

Data Analysis. For comparison purposes, the 2014 LiDAR data were initially analyzed using the RGA-Level 2 protocols which located cross sections based on DEM-identified narrow-riffle locations. This profile is shown in Figure 11. This profile appeared to provide a reasonable representation of the overall channel profile. However, several key features such as grade control structures, culverts, and other major breaks in grade were not captured. The RGA-Level 2 approach is focused on the development of hydraulic geometry parameters, and therefore cross-section locations are selected at identified riffle locations, which may be spaced too far apart to capture many of the local breaks in the channel grade. For this reason, the LiDAR data were re-analyzed using the RGA-Level 1 approach, selecting cross sections every 50 ft. As shown in Figure 11, this survey using the 50 ft spacing captured the three grade control structures as well as other significant breaks in grade. Similar profiles were developed for Campbell Creek Tributary (Figure 12). As shown in Figure 12, the profile developed using the 50 ft (RGA-Level 1) cross-section spacing provided a much more detailed view of the channel grade than the RGA-Level 2 approach.

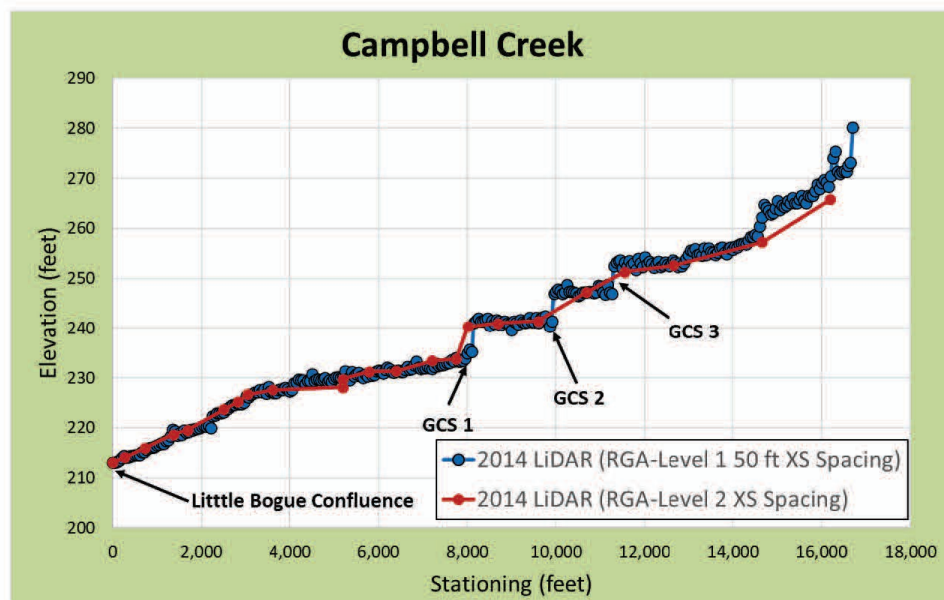


Figure 11. Campbell Creek 2014 LiDAR-RGA Level 1 and 2 profile plot comparison.

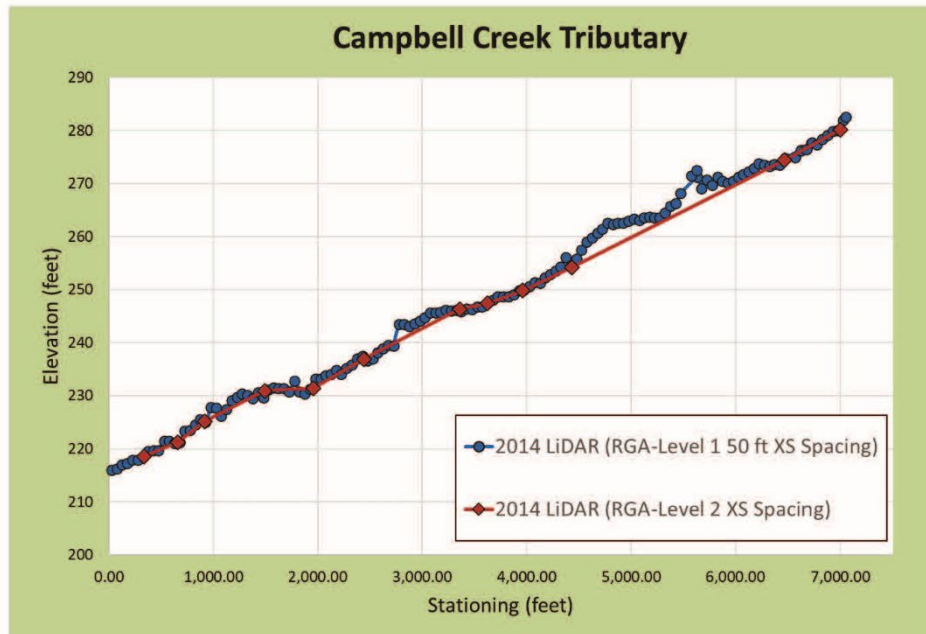


Figure 12. Campbell Creek Tributary 2014 LiDAR-RGA Level 1 and 2 profile plot comparison.

As second part of the FG Level-1 CSA analysis, cross-section comparisons from Figures 7 and 8 are analyzed to identify potential channel degradational and aggradational trends within the reach or watershed. During the field site visit, visual field observations were easy to make based on the presence of resistant bed materials and assessing channel dimensions. As an example, Figures 13 and 14 (locations in Figure 5; photos in Figures 7 and 8) illustrate stream channel changes to cross-sectional dimensions and terrace elevation connections. The data in each figure provides the channel dimension comparisons for each cross section. Between the two sites there is an insignificant increase in the watershed size of 0.08 mi² and increase of 10 cfs (USGS StreamStats 2-year discharge increase from 1260 to 1270 cfs), but large increases in all hydraulic channel characteristics such as channel depth, cross-sectional area, and others illustrated in the cross-sectional summary tables. Mapping the cross-sectional area increases and decreases provide locations for identifying potential channel instability and localized nick points or zones. Those locations can then be assessed using detailed survey methods. Geomorphic comparisons of the terrace levels and hydraulic geometry relationships provide further understanding into channel evolution within the watershed. Additional analysis can be completed to compare specific reach relationships such as stream power, shear stress, entrenchment ratios, and other geomorphic indicators in RGA Level 2 and 3.

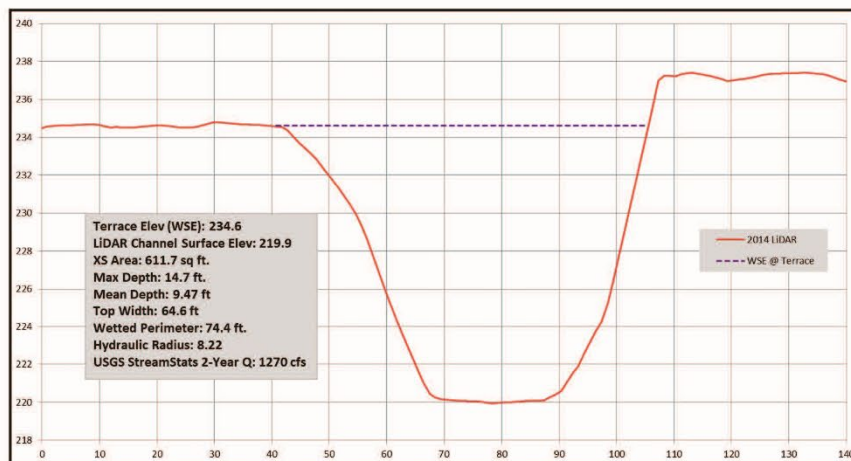


Figure 13. Campbell Creek cross section #40 associated with Figure 8.

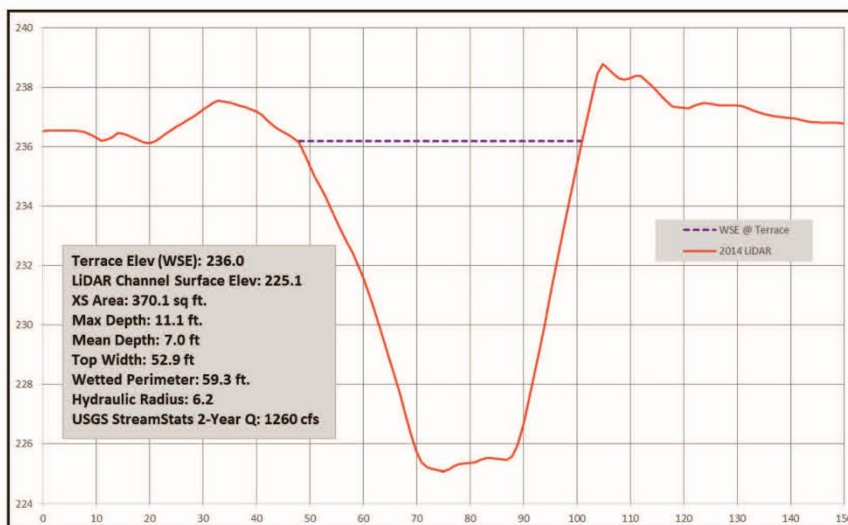


Figure 14. Campbell Creek cross section #60 immediately upstream of Figure 7.

One criticism of using LiDAR to represent bed profiles is the limitation with respect to penetrating the water surface. Consequently, the elevations shown may be the water surface rather than the true bed of the channel. While this is a real issue that must be considered, it is often not a significant problem in many small streams where the water depths at base flow conditions may be only a few inches to a foot. Obviously, this depends on the stream and the flow at the time the LiDAR was flown, but for Campbell Creek the LiDAR-depicted elevations were believed to be within half a foot or less of the actual channel bed. Obvious exceptions occur upstream of the grade control structures or at other localized areas where ponded water existed.

Through the DHP monitoring program, empirical relationships between channel slope and drainage area were developed. These curves were developed by calculating the channel slope and drainage for stream reaches that were identified as being in a Channel Evolution Model (CEM)

Type IV or V (Schumm et al. 1984). CEM Type IV and V reaches represent reaches that have attained or are approaching dynamic equilibrium. The slope-drainage area relationship for CEM Type IV and V reaches is shown in Figure 15. The Campbell Creek study area, with a drainage area of approximately 3.9 mi², has an equilibrium slope of approximately 0.0019.

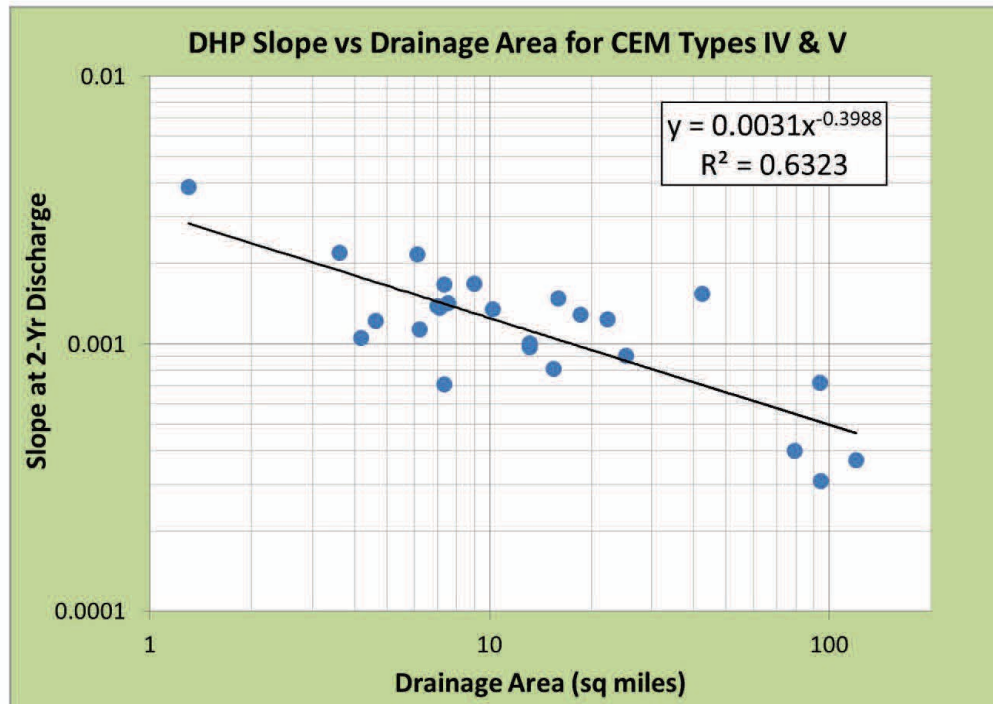


Figure 15. Channel slope vs. drainage area for CEM Types IV and V reaches within the DHP watersheds.

The channel slope based on the 2014 LiDAR was determined for three reaches along Campbell Creek (Figure 16). As shown, the lower and upper reaches have bed slopes that are considerably greater than the equilibrium slope of 0.0019. These two reaches are expected to be degradational based on this comparison. The middle reach, which extends downstream from GCS 1 to approximately Station 4000, had a slope of only approximately 0.0012, which was slightly less than the equilibrium slope. This reach is expected to be in equilibrium or slightly aggradational based on the empirical analysis.

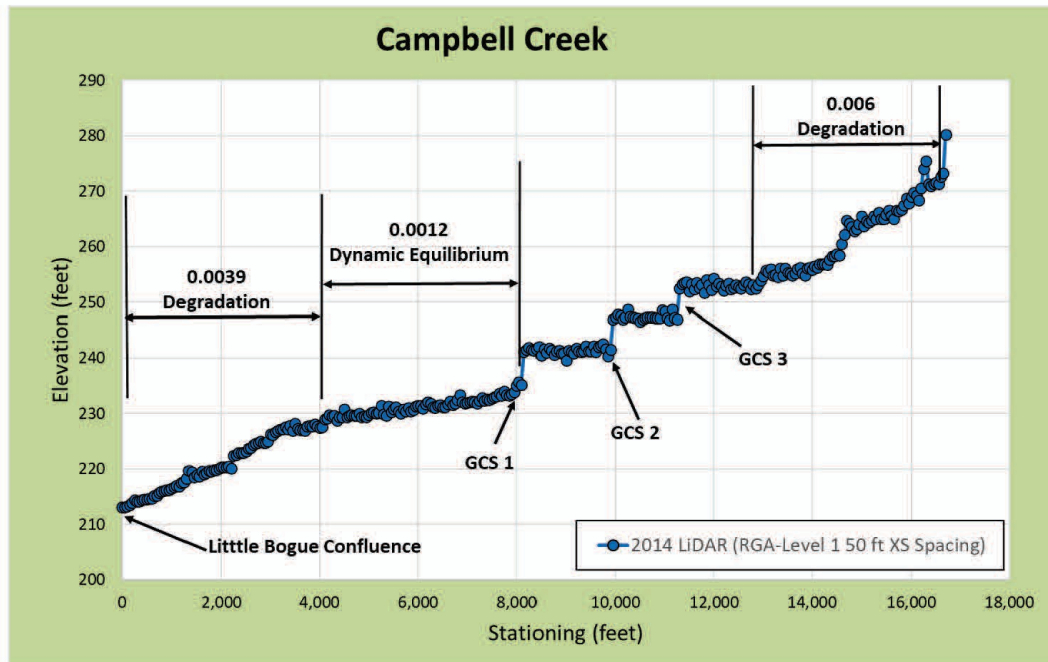


Figure 16. Channel Slope for reaches of Campbell Creek equilibrium slope is approximately 0.0019.

Note that these stability assessments are based solely on the empirical relationships. Therefore, these assessments must be field verified before making a final judgement about the stability of the reaches. As mentioned previously, the field investigations indicate that the channel downstream of GCS 1 was primarily in a degradational regime. Therefore, there is considerable uncertainty about the middle reach being in an equilibrium or slightly aggradational regime, and the general consensus is that this reach is likely to be degradational.

The Campbell Creek Tributary only has a drainage area of approximately 0.4 mi², and the equilibrium slope is approximately 0.0047. However, because this drainage area is beyond the lower limits of the data in Figure 15, there is considerable uncertainty with this slope estimate. This tributary is extremely steep with an overall slope of approximately 0.0091, which is twice the calculated equilibrium slope. This slope comparison coupled with the field indicators suggests that the Campbell Creek Tributary is in a degradational regime.

Stabilization Recommendations. A primary goal of this RSM effort is to demonstrate how the FG RGA-Level 1 approach can be used in a planning study to layout stabilization features along a stream. Using the 2014 LiDAR survey coupled with a preliminary field and geomorphic assessment, a series of grade control structures were developed for Campbell Creek. Although the 2014 survey is 6 years old and therefore does not represent the present-day condition, it will be used herein to demonstrate the design approach. In an actual study, an existing condition survey should be obtained.

To aid in the development of a grade control plan, Campbell Creek was divided into four reaches as shown in Figure 17. For this effort, all structures are sloping rock riffle type of grade control structures that have drop heights ranging from 3 to 4 ft (Newbury and Gaboury 1993). Reach 1 is

the downstream-most reach, and as discussed previously, was identified as a severely degradational reach. For this reach, four grade control structures are planned (Figure 17). The next upstream reach is Reach 2. The channel slopes in Reach 2 are much less than in Reach 1, but according to the geomorphic assessment, this reach was still considered to be degradational, and therefore grade control are needed. As shown in Figure 17, two grade control structures would be required for this reach. Reach 3 is the reach that is currently stabilized with three existing low drop grade control structures, and analysis of the profile data indicates that no additional grade control is needed in this reach. The most upstream reach is Reach 4, which is a severely degrading. Five grade control structures are planned for this reach. Because of the extremely steep slopes in this reach, several of the structures are spaced very close to each other.

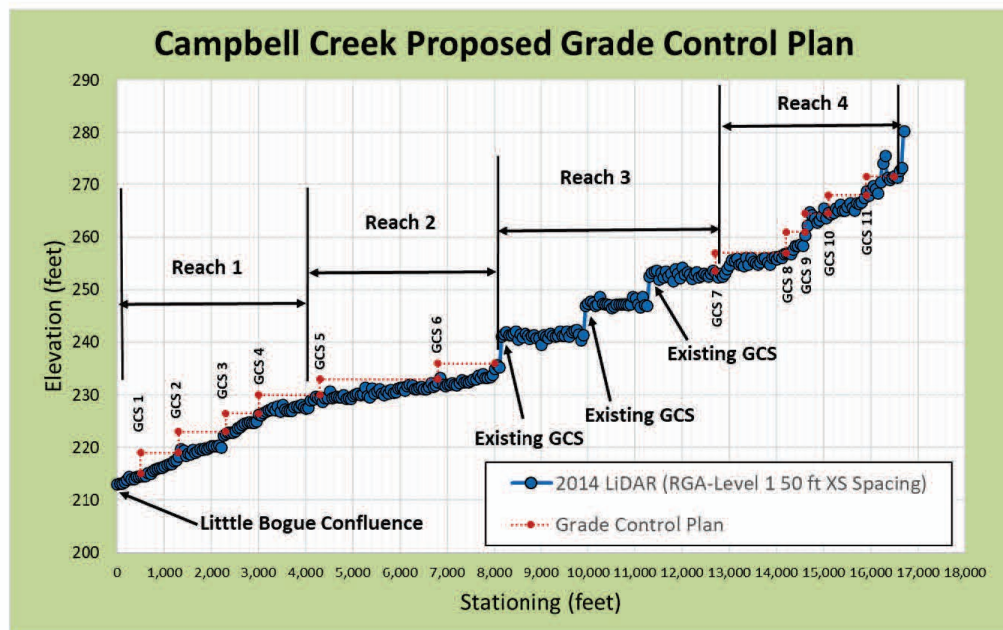


Figure 17. Grade Control Plan for Campbell Creek.

DISCUSSION: Traditionally, developing a stream stabilization plan begins with acquiring a detailed survey of the channels, involving both thalweg elevations and cross sections. This type of detailed survey can be extremely expensive, particularly when an entire watershed is being analyzed. In fact, surveying costs are often one of the largest engineering efforts, and in many studies these costs are far beyond the allowed budget. Therefore, developing more cost effective methods for obtaining channel surveys, particularly in the early planning stages, should be a high priority.

This RSM study of Campbell Creek clearly shows that LiDAR surveys provide sufficient profile and cross-sectional information to assist in a geomorphic assessment of the channel system, and the layout of a system of grade control structures. As discussed herein, the original grade control plan for Campbell Creek was developed using a detailed thalweg and cross-section survey obtained in 1986. In this case, the thalweg was surveyed approximately every 50 ft, and cross sections were taken approximately every 1,500 ft. Another detailed survey was acquired in 1991,

which required the structure locations and crest elevations to be modified. This is often the case when planning grade control and bank stabilization structures. Therefore, using simplified, more cost-effective survey techniques such as LiDAR may be more appropriate in these situations. For this study, an existing LiDAR survey from 2014 was used, but if this were a real project, a new LiDAR survey should be obtained cost effectively with unmanned aerial vehicles/drones. Although no cost comparisons were conducted as part of this study, the collection of a LiDAR survey from a fixed wing aircraft focused only on the channel and floodplain areas has the possibility of being considerably more economical than a traditional ground survey. LiDAR resolution and cost comparisons are further discussed in *Geomorphic Riverine Data Collection Methods* *.

The grade control plan discussed above is just one of a number of possible grade control alternatives that could be developed. This design was developed primarily considering the channel profile data. The actual locations and elevations of the structures could be adjusted due to various other design considerations such as tributary locations, geotechnical considerations, flood control issues, environmental concerns, landowner issues, local drainage issues, and access issues. It is also important to recognize that it may be years between the initial planning and the actual construction, and that the channel morphology may have changed considerably during that time period. At that point a more detailed survey would need to be obtained in order to develop the final layout of structures. All these issues support the concept discussed herein that the use of relatively cheap and easily obtainable LiDAR surveys are more than adequate for the initial planning of grade control structures.

CONCLUSION: The application of the FG-RGA Level 1 CSA approach to the Campbell Creek Watershed clearly demonstrated its utility as a reconnaissance-level watershed assessment approach. LiDAR data was used to identify channel dimensions and profile as well as potential channel instability locations within the watershed. Grade control structures were laid out based on this preliminary assessment. It is also noted that the Level 1 approach should be initiated prior to the field site visits to identify areas of concern especially when time and funding resources limit the ability to field validate sites. The FG-Level 1 CSA approach provides an essential level of geomorphic detail for initial watershed assessment and meets the needs of the DHP and USACE SMART Planning watershed study initiatives.

ADDITIONAL INFORMATION: This Coastal and Hydraulic Engineering Technical Note (CHETN) was prepared as part of the Ecosystem Management and Restoration Research Program and the RSM Program.

The report was written by Chris Haring (Christopher.P.Haring@usace.army.mil) and David Biedenham (David.S.Biedenham@usace.army.mil) of the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Deputy Program Manager for the RSM Program (RSM) is David May; Program Manager for the RSM Program, is Dr. Katherine E. Brutsché.

* Haring, C. H. In preparation. *Geomorphic Data Collection Methods: LiDAR Surveys Versus Traditional Field Survey*. ERDC/CHL Coastal and Hydraulic Engineering Technical Note. Vicksburg, MS: U.S. Army Engineer Research and Development Center

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<http://dx.doi.org/10.21079/11681/40379>

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Weblinks to Reports:

<https://github.com/FluvialGeomorph/FG-User-Manual>
<https://www.techmanual.fluvialgeomorph.org/>

File Name and Description of FG Input and Outputs:

A USB drive of all the Fluvial Geomorph files used in this analysis was provided to the Papio Missouri River NRD in early 2024 and made available to all members of the Partnership.

The Analysis file structure is as follows:

- Creek or Stream Name
 - Reach Number (1 to XX)
 - FG terrain input file
 - FG parameter file
 - FG output files (multiple extensions)

For additional information about the use of the files and applications, please contact the Technical Point-of-Contact for this analysis, Paul Boyd, Omaha District, paul.m.boyd@usace.army.mil, or Chris Haring, Engineering Research and Development Center, Christopher.P.Haring@usace.army.mil