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CBP GIT#12 Stream Health Indicators Project

FINAL Framework

1. Purpose

This project, “Scope of Work 12: Data Review and Development of Multi-Metric Stream Health Indicators,” is a continuation of work developed by the Chesapeake Bay Program (CBP) Stream Health Work Group (SHWG) and the U.S. Geological Survey (USGS) to better understand the drivers and stressors affecting stream health throughout the Chesapeake Bay watershed. Currently, the Chesapeake basin-wide benthic macroinvertebrate index of biotic integrity, or “Chessie BIBI,” is the sole indicator of stream health being used by the SHWG. This project is conducting interviews with experts, reviewing data, creating a framework, providing a data inventory matrix, and making recommendations that may help develop multi-metric stream health indicators for hydraulics and geomorphology. The development of these additional indicators will address the significant science and management need to better understand and communicate how streams respond to management actions.

This framework document and associated data sources spreadsheet were reviewed by the Technical Advisory Group and members of the SHWG and revised by the authors to address their comments.

2. Holistic Approach

The definition of stream health is closely aligned with the Clean Water Act goal “to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." To date, the CBP has relied on a measure of biological integrity, the Chessie BIBI, to assess stream health. Recognizing that stream health reflects a wide range of chemical, physical, and biological elements interacting within a watershed, the SHWG is investigating the possibility of developing indicators for other components of stream health—both physical and chemical.

It is important to recognize that these hydraulics and geomorphology elements, and indeed all the components of stream health, interact within the watershed ecosystem. The practice of stream restoration is focusing more and more on stream functions rather than structure alone. European scientists often prefer the term ***hydromorphology*** to describe the processes of water, sediment, and vegetation that shape the physical integrity of streams. Hydromorphology involves not only the physical processes of stream dynamics, but also the spatial and temporal aspects of these processes. Therefore, comprehensive hydromorphology indicators of stream health ultimately need to incorporate the key processes occurring at the seven scales illustrated in Figure 1 from the European Commission REFORM (REstoring rivers FOR effective catchment Management) project.

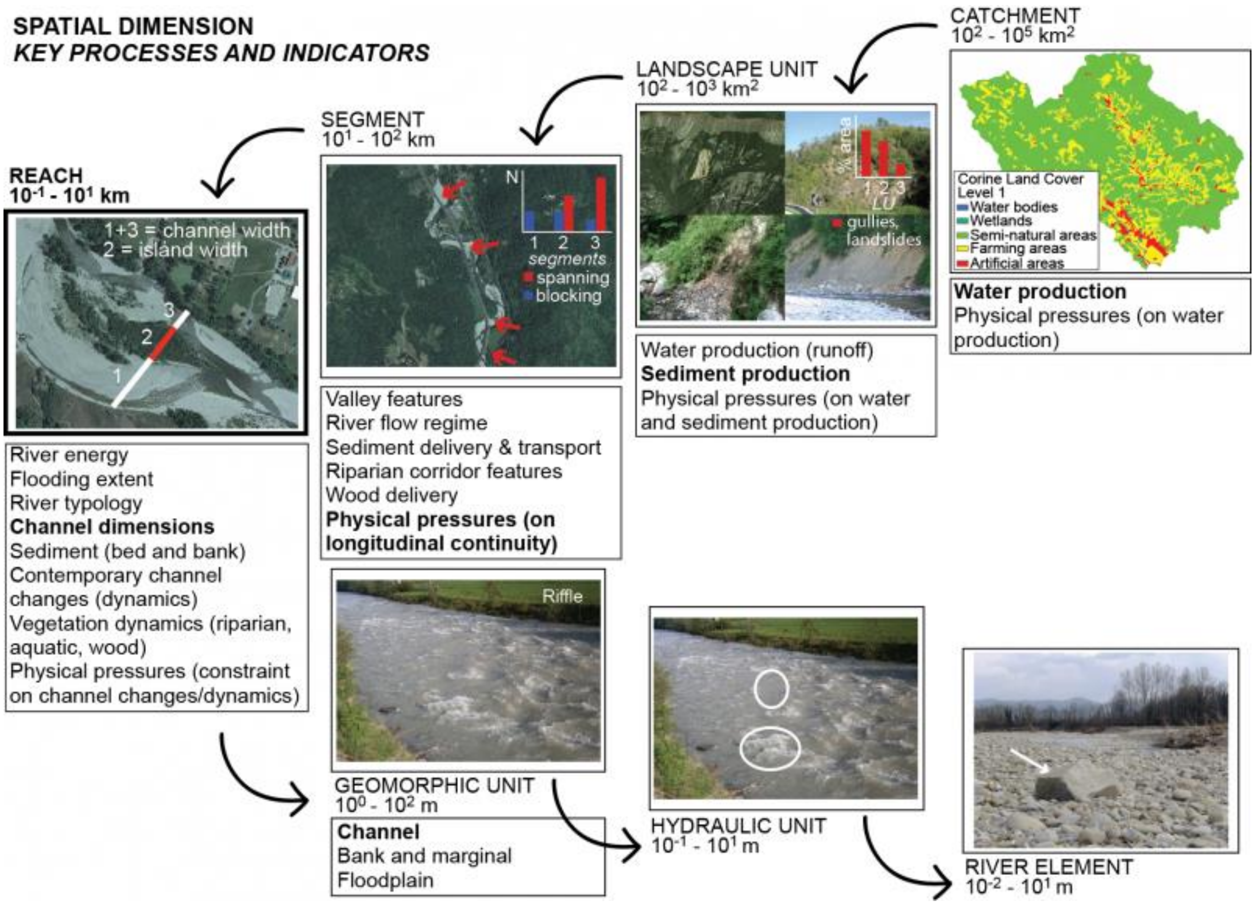

Figure 1. Spatial Dimension with Key Processes and Indicators of River Dynamics from the European Commission REFORM (REstoring rivers FOR effective catchment Management) Project (https://wiki.reformrivers.eu/index.php/Hydromorphology

This holistic approach is also being followed in the current revising of the *Final Draft Function-Based Rapid Stream Assessment Methodology* (FBRSA) by US Environmental Protection Agency (EPA) Region 3, US Army Corps of Engineers (USACE) Baltimore District's Regulatory Program, and Ecosystem Planning & Restoration (EPR) (Starr et al. 2015). The USACE requires the use the FBRSA to document existing and proposed stream conditions for all stream mitigation projects. The FBRSA is being updated to reflect changes in the understanding of stream processes and to include additional floodplain process metrics that reflect the functional uplift associated with floodplain/valley/beaver analog/legacy sediment removal restoration projects.

At the same time, there is a compelling need to develop indicators that are practical and useful in the near term. This project, therefore, is focusing on the reach scale and below, i.e., geomorphic unit, hydraulic unit, and river element, in the REFORM terminology. The REFORM hydromorphology indicators included in Figure 1, are similar to those traditionally used to measure functions illustrated by the Stream Functions Pyramid conceptual model (Harman et al. 2012) comprising hydrology, hydraulics, geomorphology, physiochemical, and biology, on the ultimate foundation of geology and climate (Figure 2). Together these models highlight the potential for indicators of hydraulics and geomorphology to help capture the physical integrity component of stream health.

Our approach in this project will be to focus on the near-term development of reach and smaller-scale indicators of hydraulics and geomorphology within the context of landscape-scale indicators influencing the stream corridor that can be pursued in the future.

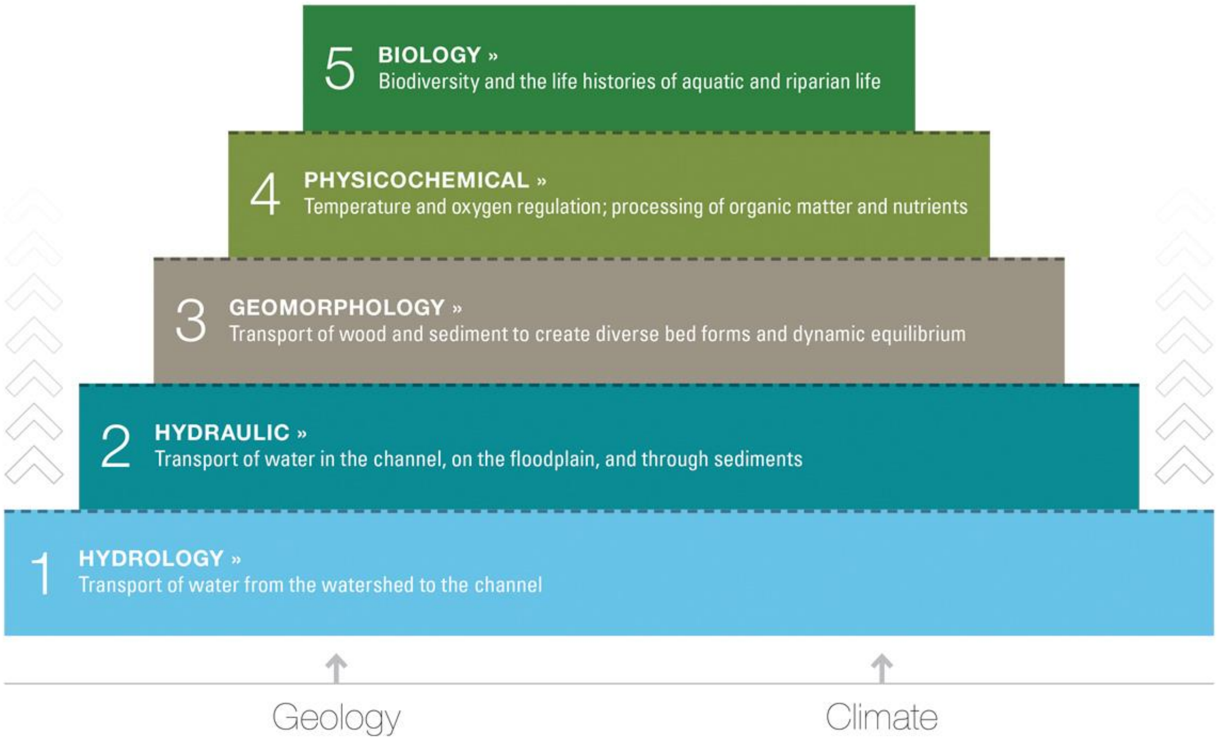

Figure 2. Stream Functions Pyramid (Harman et al. 2012) (https://stream-mechanics.com/Pyramid_factsheet_web%20version.pdf)

3. Potential Indicators

Physical indicators of stream health are challenging because of the dynamic nature of hydraulics and geomorphology in space and time. Specifically, both flow and sediment load change in response to seasons, weather, and both natural biotic and human activities. Nonetheless, robust field methods have been developed for measuring stream channel dimensions that reflect the natural range of stability (both vertical and horizontal), floodplain connectivity, and bedform particle size. New technologies, such as high-resolution land use / land cover (LULC) and hyper-resolution terrain imagery, also provide more detailed data across the landscape that is relevant to hydromorphology. The goal of this project is to identify the most promising indicators of stream stability as a physical complement to the Chessie BIBI and other potential indicators of stream health.

Stream stability is typically defined as a rate of change that is low enough that the stream can respond to changes in flow and sediment, and remain within its original dynamic state. An unstable channel is one where (1) the stream channel or floodplain has eroded or been buried, (2) the width of the channel has overwidened, or (3) the planform (sinuosity) has changed over time. Unstable streams are likely experiencing excessive erosion and sedimentation, which damage aquatic communities. A stable stream retains roughly the same channel characteristics over time and erosion and deposition are in balance.

Previous and current work on stream stability and stream function provides a starting point for identifying potential indicators of hydraulics and geomorphology. As described above the European Commission REFORM project has identified key processes and indicators at the reach and geomorphic unit scales. USEPA and Maryland Environmental Service (MES) undertook research into a Stream Stability Index that has been incorporated into this framework. There is also ongoing work with USEPA and USACE-Baltimore District to revise the function-based Rapid Stream Assessment Protocol and identify key stream and floodplain functions. In addition, the following technical guidance provides a history of physical stream assessment methods and potential indicators:

- Technical Guide for the Development, Evaluation, and Modification of Stream Assessment Methods for the Corps Regulatory Program, USACE and ERDC, 2021
- Stream Mitigation Accounting Metrics: Exploring the Use of Linear-based, Area-based, and Volume Units of Measure to Calculate Impacts and Offsets to Different Stream Archetypes, USEPA, 2021
- A Function-Based Framework for Stream Assessment & Restoration Projects, USEPA, USFWS, and Stream Mechanics, 2012
- Stream Assessment and Mitigation Protocols: A Review of Commonalities and Differences, USEPA, 2010
- Physical Stream Assessment: A Review of Selected Protocols for Use in the Clean Water Act Section 404 Program, USACE and USEPA, 2004

Our preliminary list of potential indicators begins with the following list of functions and measurements that might be developed into metrics to characterize stability using GIS data.

- Floodplain connectivity
- Riparian vegetation
- Lateral stability
- Bedform diversity
- Sediment supply
- Stream energy
- Flow regime

4. Data Sources

This project began with the following series of interview of experts in the field to gain technical insights and identify potentially useful data sources. Additional interviews are planned in the next phase with Tess Thompson of Virginia Tech, Chris Ruck of Fairfax County, and Emily Gentry of USEPA.

- Interstate Commission on the Potomac River Basin (ICPRB)
- University of Maryland, Baltimore County (UMBC) (Matt Baker)
- Maryland Environmental Service (MES)
- Maryland Water Monitoring Conference (MWMC) Stream Monitoring Subcommittee
- USGS/Chesapeake Bay Program (CBP)

Details of these interviews are available in the minutes document. Ten data sources were identified and are detailed in the Excel data sources document. The four most promising data sources are summarized below.

Rapid Habitat Data

Rapid habitat data were collected from jurisdictions across Bay watershed by the Interstate Commission on the Potomac River Basin (ICPRB) as part of the Chessie BIBI development. Twenty-four (24) habitat parameters are reported in the stream macroinvertebrate database. The EPA visual-based Rapid Bioassessment Protocols (Barbour et al. 1999) sought to standardize habitat measures for low and high gradient streams; however, many monitoring programs modified these measures to suit their regulatory needs. Thus, only 9 habitat parameters were measured consistently and frequently (i.e., more than 75% of sampling events) and none of these parameters were collected at all sampling locations. Nonetheless, Matt Cashman (USGS) identified 12 rapid habitat metrics and 2 PCA-derived summary metrics (representing bed and bank/riparian elements) with potential for describing habitat quality.

High-resolution Land Use/Land Cover (LULC)

Using 1-meter imagery, the CBP has recently developed the high-resolution LULC data set representing 2017 ground conditions. Chesapeake Conservancy, USGS, and University of Vermont Spatial Analysis Lab (UVM SAL) collaborated to produce these foundational data for the Chesapeake Bay watershed regional area (206 counties, over 250,000 km^2).

These data are unique in both the spatial and categorical resolution they hold. This project is the largest dataset for open LULC data at a 1-meter resolution, boasting 900 times more detail than the readily available 30-meter resolution National Land Cover Dataset (NLCD). Additionally, the CBP 1-meter LULC data have over 50 unique classes, providing more categorical context than the 13-class CBP land cover data or the 17-class NLCD data. This detailed classification scheme is necessary to ensure these data are widely applicable for supporting data-driven decision-making by the CBP and other regional stakeholders.

Most recently, the 2022 Maryland Healthy Watersheds Assessment analyzed these high-resolution LULC data to reveal numerous metrics (e.g., forest, impervious cover, turf grass, wetlands, and natural land cover) predictive of biological conditions.

USGS Floodplain and Channel Evaluation Tool (FACET)

The Floodplain and Channel Evaluation Tool (FACET) is an open-source python tool that maps the floodplain extent and derives reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). FACET allows the user to hydrologically condition the DEM, generate a stream network, select one of two options for stream bank identification, map the floodplain extent using a Height Above Nearest Drainage (HAND) approach, and calculate stream and floodplain metrics using three approaches.

While the FACET data are available using the 2009 DEM downscaled from 30-meter imagery, USGS/CBP expects to have the new DEM based on 1-meter LiDAR imagery completed by the summer of 2023. The 1-meter DEM will cover 2016-2021. The team will be re-running FACET and other derivatives of the DEM over time. They will work with this project as we identify promising metrics and prioritize the needed analyses.

Relevant work with FACET by USGS includes Matt Cashman comparing FACET results to regional hydraulic curves. Greg Noe has used FACET to calculate a suite of metrics including (1) lateral erosion rate and (2) floodplain deposition rate (vertical cm/yr), providing flux/load of sediment for all Bay catchments. He also has D50 and proportion of sediment type metrics. Mariana Metes is currently using FACET to map headwaters and describe topographic openness.

The 2022 Maryland Healthy Watersheds Assessment has also found that some FACET metrics (e.g., streambank erosion and change, streambank sediment flux, streambed fine sediment) are predictive of biological conditions.

Hyper-Resolution Terrain-based Hydrography Mapping

Matt Baker of UMBC, in partnership with the Chesapeake Conservancy, has produced new streamlines using hyper-resolution DEMs in each of 75 HUC-8 watersheds in Chesapeake Bay watershed (stream density is 2x that in NHD). The method is scalable and can be applied wherever adequate LiDAR coverage exists. Location and morphometry of streams and other channel-like features are mapped directly from the DEM; streams are not estimated based on thresholds of derivative layers e.g., flow accumulation, slope, curvature. The method uses algorithms to classify terrain into ten most common landforms: flat, summit, ridge, shoulder, spur, slope, hollow, footslope, valley, and depression. Streams and channels are extracted using a combination of valley and depression forms calculated at two different scales.

The map includes channel features such as height of bank above bottom and slope. These data can be used to develop a landform classification, e.g., what is the probability of a reach being a ditch, gully, or rill? Indicators can also be based on "how anomalous is the bank height for the catchment," or whether it is narrowing or widening going downstream. Also, the more variable the sinuosity, the more likely the reach is not anthropogenic. This work includes an algorithm to connect across bridges and roads and produce connector length. These hyper-resolution data may be useful for refining riparian modeling for the Bay.

Gridded Soil Survey Geographic Database (gSSURGO)

The gSSURGO Database is generally the most detailed level of soil geographic data developed by the National Cooperative Soil Survey (NCSS) in accordance with NCSS mapping standards. The tabular data represent the soil attributes, and are derived from properties and characteristics stored in the National Soil Information System (NASIS). The gSSURGO data were prepared by merging traditional SSURGO digital vector map and tabular data into State-wide extents, and adding a State-wide gridded map layer derived from the vector, plus a new value added look up (valu) table containing "ready to map" attributes. The gridded map layer is offered in an ArcGIS file geodatabase raster format. The value added look up (valu) table contains attribute data summarized to the map unit level using best practice generalization methods intended to meet the needs of most users.

Peter Claggett's USGS/CBP team is working on which soil variables in gSSURGO are most important. They are also using 800-meter Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Oregon State University) data to help map erosion potential related to rainfall and orographic effects. Identifying highly erodible soils will be helpful for the project.

5. Evaluation of Indicators

The next step of the project is to evaluate the potential indicators and data sources identified above to determine their likely value and practicality for producing indicators of hydraulics and geomorphology to better assess stream health. Specifically, are there GIS data available that can be used to capture the important processes and lead to one or more metrics that can be applied across the Chesapeake Bay watershed? Below we provide some examples of previous work and discuss our plans to evaluate potential indicators for incorporating thresholds of health and testing to validate candidate indicators.

<u>Examples</u>. Illustrative examples of using GIS data include the work done by Rich Starr and Ted Weber for Maryland State Highway Administration (SHA) in 2009 that used LULC data to evaluate 200 sites and make reasonable predictions of stream stability using the following metrics. The sites were in 4 watersheds in Coastal Plain of Maryland and therefore the thresholds for expected indicator condition were based on those more erodible soils and not applicable to other regions.

- Erodible soils
- Slope
- Riparian vegetation
- Impervious surface

The Stream Stability Index project by MES and USEPA to develop a tool for the Water Resources Registry (WRR) tested preliminary models of incision and entrenchment in Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. A white paper is forthcoming. The model used FACET combined with regional curves to estimate the following bankfull characteristics:

- Bank Height Ratio (including Elevation at Top of Stream Bank and Bankfull Depth)
- Floodplain Area Ratio
- Stream Power

Matt Cashman's work with ICPRB to create a multi-jurisdictional rapid habitat assessment database identified the following 12 original metrics, plus two summary habitat metrics developed through Principal Component Analysis. These metrics vary by jurisdiction, with some being observed and others modeled, therefore only a subset of metrics provides complete Bay watershed coverage.

- Bank Stability
- Bank Vegetation
- Channel Alteration
- Embeddedness
- Epifaunal Substrate
- FLOW
- Pool Substrate
- Pool Variability Quality
- Riffle/Pool/Run Ratio
- Riparian Vegetation Score
- Sedimentation

- Sinuosity
- Velocity/Depth Combination
- Habitat Component 1 (embeddedness, riffle frequency velocity/dept combination)
- Habitat Component 2 (riparian condition score, bank stability, bank vegetation, sediment deposition)

Kelly Maloney et al. (2021) of USGS recently developed a suite of flow alteration metrics for stream reaches throughout the Chesapeake Bay watershed and demonstrated linkages between flow alteration intensity and degraded biological condition of streams. Using separate random-forest models, they developed predictions of flow status for 12 hydrologic metrics. An overall flow alteration intensity indicator provides combined information from the individual metrics.

In 2022, Tetra Tech (Roth et al. 2022) tested GIS metrics related to hydrology and geomorphology for the Maryland Healthy Watersheds Assessment and found that many of the following metrics from CBP LULC (2017), StreamCat (2016), Kelly Maloney et al. (2021), and FACET (USGS 2019) and FACET-derived work by Greg Noe were important in explaining biological condition in Maryland streams. Recently, CBP has rerun the Healthy Watersheds models with new riparian metrics, which may change the importance of the hydrology and geomorphology metrics listed. Kelly Maloney has also cautioned that decoupling FACET metrics might not be advisable.

Hydrology	% Forest in Catchment	CBP high-resolution land use/land cover data, 2017
	Density Road-Stream Crossings in Watershed	StreamCat, 2010 data
	% Wetlands in Catchment	CBP high-resolution land use/land cover data, 2017
	Flow Alteration Score	USGS, Kelly Maloney research
Geomorphology	Dam Density in Watershed	StreamCat, 2013 data
	Road Density in Riparian Zone, in Watershed	StreamCat, 2010 data
	Streambank Lateral Erosion	USGS, Greg Noe and others' research; derived from FACET and other inputs
	Streambank Change (m2)	USGS, Greg Noe and others' research; derived from FACET and other inputs
	Streambank sediment flux – incorporates bank height, lateral erosion, and bulk density	USGS, Greg Noe and others' research; derived from FACET and other inputs
	Streambed D50	USGS, Greg Noe and others' research; derived from FACET and other inputs
	Streambed Fine Sediment Cover	USGS, Greg Noe and others' research; derived from FACET and other inputs
	Streambed Fine Sediment + Sand Cover	USGS, Greg Noe and others' research; derived from FACET and other inputs
	% Impervious in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017

Thresholds. These and other examples of potential metrics drawn from GIS data sources will be reviewed for their utility as hydraulic and geomorphic "performance standards" of stream health. The critical aspect of this review is determining what the expected (natural) state of the metrics or multi-metric indicator is to assign thresholds of stream health. Deviations from expectations hold the most promise for indicators that can be compared across large areas, such as the Chesapeake Bay watershed. Regression relationships (regional curves) that estimate bankfull discharge and related channel dimensions based on drainage area (using empirical stream gage data) may be able to serve as the expectation for potential hydromorphology indicators such a floodplain connectivity.

Another aspect to be reviewed is the ability of the GIS data to provide change over time and, therefore, determine if a stream has recently become unstable, is continuing to be unstable, or is nearing stability again. Recent work by Matt Cashman of USGS and Matt Baker of UMBC has identified signals of channel change in USGS gage data in the Patapsco Valley and elsewhere. To date, they have identified mostly longer term signals, but also some shorter term signals of change.

Testing. Ultimately, any prospective indicators need to be tested against empirical data collected in the field and/or modeling results using independent information. Brock Reggi of Virginia DEQ has offered to provide sites for testing once criteria for selection are developed. Recent work by USGS (Matt Cashman, Mariana Metes, Greg Noe, Peter Claggett, and Labeed Ahmed) includes comparing physical parameters in FACET with regional hydraulic curves to be completed once FACET is rerun with the 1-m LiDAR DEM. In addition, UMBC is comparing 100 hyper-resolution (1-m DEM) cross sections (proportional to stream order) in the Gunpower-Patapsco basin with (1) manual renderings from LiDAR and (2) field measurements. These results should be available in Spring 2023 and can be used to validate prospective indicators. Another important effort currently underway is the USGS Stream Team, which is measuring the following empirical field data (among others) that can be used to validate potential indicators. The Shenandoah and Eastern Shore regions have been completed, with two more regions to be done.

- Longitudinal profile (depth variation, roughness, and sinuosity)
- Reach channel and bankfull widths (average and variability)
- Full cross sections (topographic roughness and variability)
- Total bank height and bankfull heights (and variability)
- Ratio of bankfull to total bank height
- Modified BEHI scores utilizing above bank components
- Average lateral stream retreat determined by dendrochronology

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