CBP GIT#12 Stream Health Indicators Project: Recommendations for Developing Hydromorphology Indicators with GIS Data
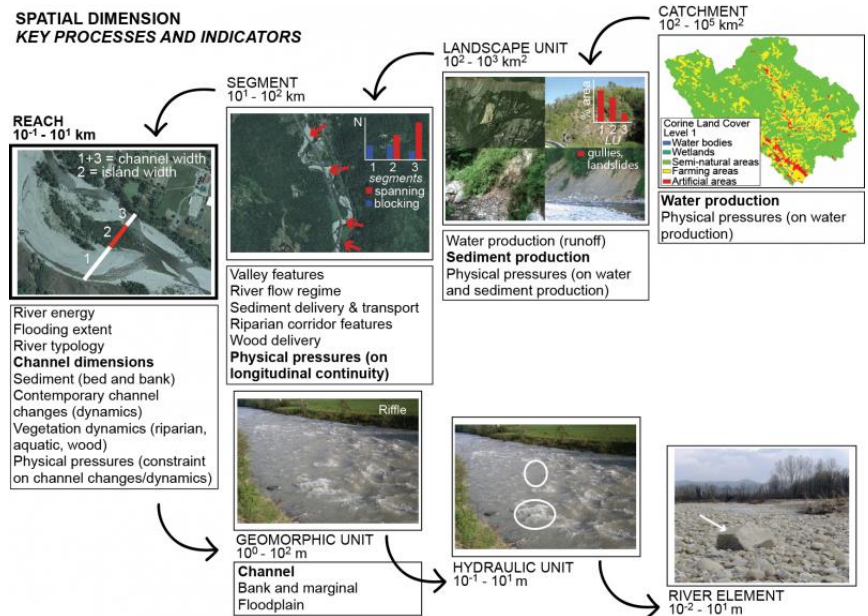
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FINAL REPORT

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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.

The Stream Health Workgroup's (SHWG) 2019 Work Plan includes action items to identify additional parameters or metrics to describe and quantify stream health to complement existing biological indicators, as described in Action #1.3 and #4.1 of the Logic and Action Plan:

https://www.chesapeakebay.net/documents/22039/2021.10.28_-_shwg_-_2022-2024_logic__action_plan_final_draft_to_srs.pdf

To complete these action items, the SHWG developed three Phases (1, 2, and 3) in collaboration with the USGS. Phase 1 was completed by USGS and identified the most significant stressors to stream health in the Bay. Phase 2 was initiated in 2020 and examined research to quantify the effects of selected water quality Best Management Practices (BMPs) on these stressors, linking how stressors are impacted by BMPs, and will help guide jurisdictions in the selection of BMPs to improve stream health beyond nutrient and sediment reductions. This project is part one of the final phase (Phase 3A) and will begin to address the question outlined in the SHWG's Logic and Action Plan: "Following the implementation of management efforts, how is stream health changing, and how can we better characterize the response through non-biological metrics?"

Millions of dollars are invested in management actions annually to address the Bay's TMDL, yet studies often find limited biological or ecological lift in local streams. Many BMPs currently being implemented throughout the watershed may not improve in-stream health. For example, stormwater BMPs and other projects intended to reduce nutrient and sediment loads into local streams are generally designed to regulate runoff during and after precipitation events, but don't necessarily improve in-stream habitat. Stream restoration BMPs can improve in-stream habitat but may not improve water quality stressors such as toxic contaminants or high salinity. More needs to be done to understand and communicate how streams respond to management actions once priority stressors are mitigated or removed. This remains a significant science and management need.

Currently, the Chesapeake Basin-wide Indicator of Biological Integrity (Chessie BIBI) is the sole indicator of stream health utilized by the Stream Health Workgroup. While it is an excellent indicator of the overall biotic community, it does not necessarily reflect BMP-driven improvements in hydraulics, geomorphology, and physicochemical qualities which are also components of stream health. The main outcome of the full Phase 3 plan is the identification of additional non-biological metrics that may complement the Chessie BIBI. These additional metrics will help us better understand the trajectory of stream health (e.g., improving or declining) by expanding the SHWG assessment of stream health to include factors beyond the biological stream community throughout the Chesapeake Bay watershed.

This project conducted interviews with experts, reviewed data, created a framework, provided a data inventory matrix, and makes recommendations that may help develop multi-metric stream health indicators for hydraulics and geomorphology (hydromorphology). This draft report incorporates (1) the framework document and associated data sources spreadsheet (submitted by this team on December 16, 2022) and (2) recommendations for further indicator development and associated data inventory matrix (submitted April 14, 2023), which were revised based on comments from the Technical Advisory Group and members of the SHWG. Additional expert interviews, data discovery, comparison of GIS data

with field case studies, and an example overlay of relevant GIS layers were also conducted to produce this report.

2. Interviews with Experts

We conducted a series of interviews with experts in the field to gain technical insights into potential indicators and to identify potentially useful data sources. Interviews were conducted with the following organizations and individuals:

- Interstate Commission on the Potomac River Basin (ICPRB) (Rikke Jepsen, Claire Buchanan Andrea Nagel, and Mike Mallonee)
- University of Maryland, Baltimore County (UMBC) (Matt Baker)
- Maryland Environmental Service (MES) (Theresa Foye and Douglas Mace)
- Maryland Water Monitoring Conference (MWMC) Stream Monitoring Subcommittee (Lisa Fraley-McNeal, Greg Noe, and others)
- Chesapeake Bay Program (CBP) (Peter Claggett, Labeeb Ahmed, and Renee Thompson)
- U.S. Environmental Protection Agency (USEPA) Water Resources Registry (Emily Gentry)
- Virginia Tech (Tess Thompson)
- Fairfax County (Chris Ruck)
- Biohabitats (Joe Berg)
- Maryland Department of Natural Resources, Forest Service (Anne Hairston-Strang)
- FACET Team (Labeeb Ahmed, Peter Claggett, Krissy Hopkins, Marina Metes, and Greg Noe)
- Maryland Department of Natural Resources, Center for Economic and Social Science of Chesapeake and Coastal Service (Elliott Campbell)
- USGS MD-DE-DC Water Science Center (Matt Cashman)

Details of these interviews are available in the revised minutes document (Appendix A).

3. 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. This project is investigating the potential of physical indicators as embodied in hydraulics and geomorphology.

It is important to recognize that these hydraulics and geomorphology elements, and indeed all the components of stream condition that can affect 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 functional aspects of these processes. Therefore, comprehensive hydromorphology indicators of stream health ultimately need to incorporate the key processes and functions occurring at the seven scales illustrated in Figure 1 from the European Commission REFORM (REstoring rivers FOR effective catchment Management) project (Gurnell et al. 2014).
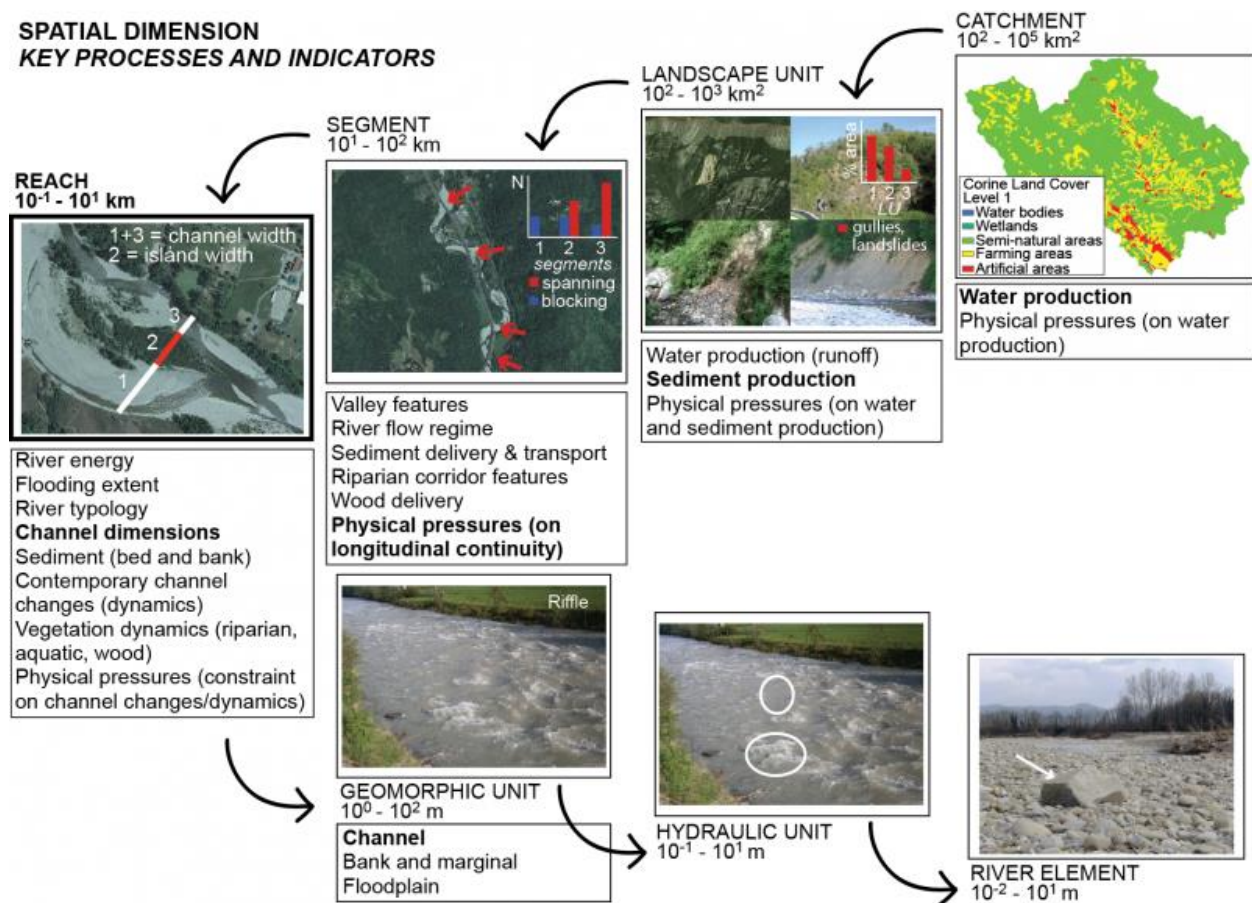
Figure 1. Spatial dimension with key processes and indicators of river dynamics from the European Commission REFORM (Restoring rivers FOR effective catchment Management) project (https://wiki.reformrivers.eu/index.php/Hydromorphology)

Compensatory mitigation requirements under the Clean Water Act for impacts to waters have for decades required the use of procedures (often various "habitat evaluation" procedures [HEP]) to determine appropriate mitigation. Such HEP have also been used to guide restoration of aquatic ecosystems, although this requires ensuring that the HEP include consideration of critical stressor variables. One widely used compendium of methods to assess stream functions is the Stream Functions Pyramid (Pyramid), developed in response to the 2008 Mitigation Rule requiring compensatory mitigation for authorized impacts to streams under Section 404 of the Clean Water Act. The Pyramid utilizes a hierarchical relationship among stream functions, where some functions rely on others and other functions support others. This Pyramid framework (Harman et al. 2012) comprises hydrology, hydraulic, geomorphology, physiochemical, and biology, and ultimately rests on the foundation of geology and climate (Figure 2). Understanding how functions influence one another assists in developing cause-and-effect relationships and in identifying impaired stream functions and watershed stressors. It should be noted that, while the Pyramid framework does not specifically use these functions to prioritize stressors to aquatic life, it does state that watershed assessments should be conducted to understand how the watershed, including stressors, influences reach level functions. In addition, the USEPA has developed the Stressor Identification Weight-of-Evidence approach to prioritize stressors that could be considered in future phases of this work. Function and stressor information is needed to effectively manage watershed and stream health.
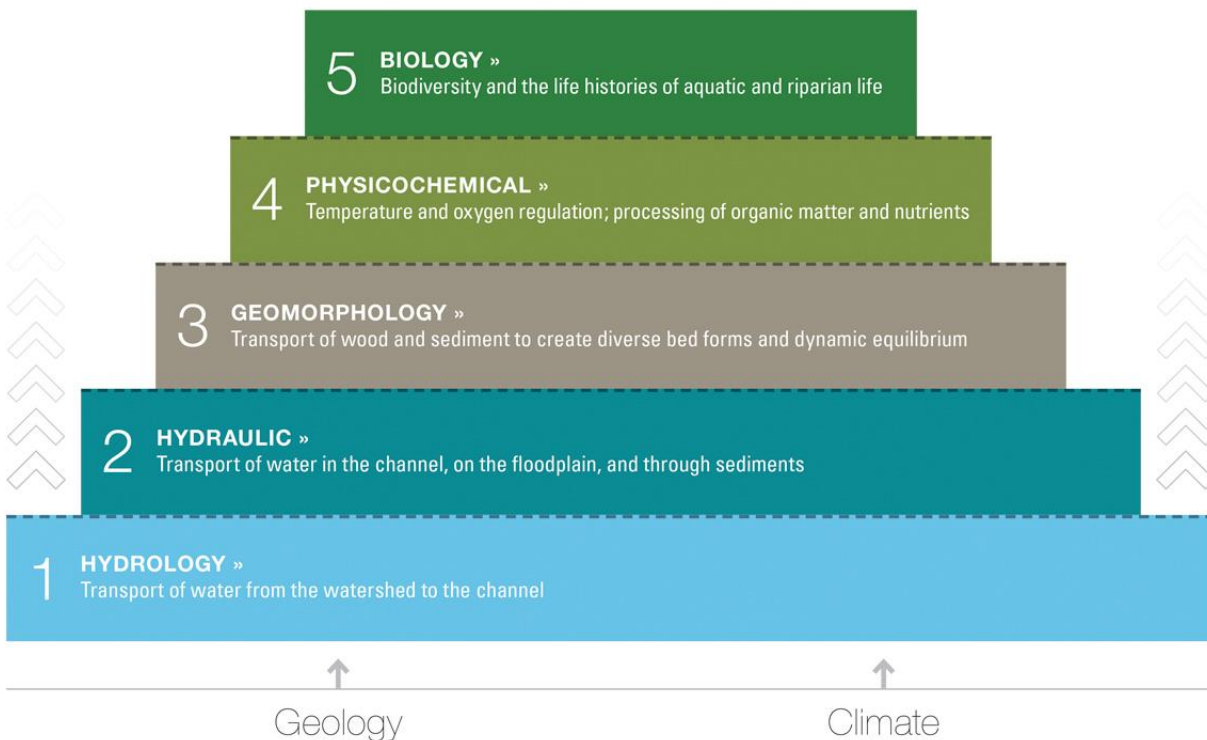
Figure 2. Stream Functions Pyramid (Harman et al. 2012) (https://stream-mechanics.com/Pyramid_factsheet_web%20version.pdf)

To further a holistic assessment approach, this project developed a multi-metric hydromorphology stream health indicator framework based on both the REFORM and Pyramid frameworks. REFORM brings in the longitudinal connectivity of stream processes and the Pyramid brings in the hierarchical influence of stream functions. Our framework includes the following REFORM spatial dimensions: **catchment (basin), landscape unit, river segment, reach, geomorphic unit, and hydraulic unit**; and the following Pyramid levels: **hydrology, hydraulics, and geomorphology**. We used this framework to identify near-term, practical, and useful reach and smaller-scale indicators of hydraulics and geomorphology within the context of landscape-scale indicators that can be pursued in the future. This approach highlights the potential for indicators of hydromorphology to help capture the physical integrity component of stream health.

4. Potential Indicators

Physical indicators of stream health are challenging because of the dynamic nature of hydromorphology 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 floodplain and stream channel characteristics that reflect the natural range of vertical and lateral stability. New technologies, such as high-resolution land use/land cover (LULC) and hyper-resolution terrain imagery may be able to predict vertical and lateral stability similar to field measurements. At the same time, the ability of these remotely sensed data to accurately measure hydraulics and geomorphology declines or is absent at finer scales.

The goal of this project is to identify the most promising indicators of hydromorphology that can be assessed using a desktop analysis tool as a complement to the Chessie BIBI and other potential indicators of stream health. The ultimate suite of indicators will better reflect the full range of stressors that affect stream health. One such indicator is stream stability, 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 over widened, or (3) the planform (sinuosity) has changed over time. Unstable streams are likely experiencing excessive erosion and sedimentation, which can damage aquatic communities sensitive to these conditions. A stable stream retains roughly the same channel characteristics over time, and erosion and deposition are in balance.

Our multi-metric hydromorphology stream health indicator framework is based on the REFORM spatial dimensions and Pyramid levels. These descriptions were used to guide the recommendation of appropriate physical stream health indicators.

4.1   Proposed Multi-Metric Hydromorphology Indicator Framework

- <u>Catchment (Basin) and Landscape Unit/Pyramid Level 1–Hydrology.</u> The landscape unit scale provides a broad context for understanding how watershed conditions (e.g., LULC) affect a stream. The amount and rate of flow and sediment reaching a stream are influenced by the overall physiographic setting at this scale. Topography should also be considered (e.g., plains, rolling hills, steeper mountainous areas) and rock type, such as carbonate, may influence sediment production.
- <u>River Segment/Pyramid Level 2–Hydraulic</u>. The river segment scale characterizes the relationship of the stream to its valley; how valley conditions affect stream energy; and the available floodplain area for storm flows. Valley type and the presence of larger dams should be considered at this scale.
- <u>Reach/Pyramid Levels 2—Hydraulic and 3—Geomorphology</u>. The reach scale is characterized by differences in stream dimension, pattern, and profile; the degree to which flow is confined within a channel; and the prevalence and type of riparian vegetation cover. The influence of smaller dams can also be seen at this scale.
- <u>Geomorphic and Hydraulic Units/Pyramid Levels 2—Hydraulic and 3—Geomorphology</u>. Geomorphic units are areas containing a landform created by erosion and/or deposition of sediment, essentially the creation of a stream system network through stream energy. Channel vertical and lateral features can be used to describe how stream energy is influencing channel stability conditions. Physical features providing habitat for biota arise at this scale.

4.2   Description of Relevant Data Tools

Previous and current work on stream and floodplain characteristics, stream stability, and stream function provide a starting point for identifying potential indicators of hydromorphology conditions. Below is a brief description of relevant work.

European Commission REFORM Project
REFORM (Gurnell et al. 2014, Rinaldi et al. 2015) has identified key processes and indicators by spatial dimension (see Tables 1 and 2 below). This document provides metrics, measurement methods, measurement tools, and data sources. While some of the metrics require field measurements, others use desktop data. The REFORM framework captures the longitudinal connectivity of key processes and landscape features, from catchment level to reach level, that influence stream stability. It also has a review of other assessment methodologies that could be helpful in refining potential multi-metric

hydromorphology indicators and measurement methods for future stream health desktop assessment tool development.

Table 1. Summary of main hydromorphology indicators (Table 3.2 in Rinaldi et al. 2015)

Table 3.2 Summary of main hydromorphological indicators representative of processes at spatial scales from catchment to river segment.

Key Processes	Indicators (indicative units)
Catchment scale	
Water production	Catchment area (km^2)
	Average annual precipitation (mm)
	Average annual runoff / water yield (mm)
	Average runoff coefficient (dimensionless)
	Geology (% WFD classes)
	Land Cover (% CORINE level I classes)
Landscape unit scale	
Runoff production / retention	Exposed aquifers, permanent snow-ice cover (%)
	Soil permeability (% permeability classes)
	Large surface water bodies (% cover)
	Delayed, intermediate, rapid runoff production areas (% cover based on CORINE level 2, 3 land cover classes)
Sediment production	Soil erosion (t/ha/year)
	Coarse sediment source areas (unstable slopes, gullies, etc., ha, % area)
River segment scale	
Valley features	Valley confinement (categorical)
	Valley gradient (m/m, %)
	River confinement (valley width/river width, dimensionless)
River flow regime	Flow regime type (categorical)
	Average annual flow (m^3/s)
	Base flow index (categorical)
	Annual floods of different return periods (Qp_2, Qp_{10}, Qp_{median}, m^3/s)
	Timing of maximum and minimum flows (Julian day)
Sediment delivery and transport regime	Eroded soil delivery (t/year/km^2)
	Annual suspended load (t/year, t/km^2/year)
	Annual bed load (t/year, t/km^2/year)
	Sediment budget (categorical (gain, loss, balanced); t/year, t/km^2/year)
Disruption of longitudinal continuity of water, sediment and wood	Number of major (categorised as high and medium) blocking and spanning structures (e.g. dams, drop structures, weirs, bridges)
Riparian corridor size, functions, succession, wood delivery potential	Size of riparian corridor (average width, m)
	Longitudinal continuity / fragmentation of riparian vegetation along river edge (% of river length)
	River channel edges bordered by mature trees (i.e. potential sources of large wood, %)
	Dominant riparian plant associations

Table 2. Spatial units within the REFORM Framework (Table 4.1 in Gurnell et al. 2014)

Table 4.1 Spatial Units within the Framework: Definitions, Delineation Criteria and Potential Data Sources and Methods

Spatial Unit (equivalent terms)	Definition / Description	Delineation criteria (#)	Methods and Data Sources (#)
Region (Ecoregion, Biogeographical region)	Relatively large area that contains characteristic assemblages of natural communities and species that are the product of broad influences of climate, relief, tectonic processes, etc.	Differences in main climatic variables and distribution of main vegetation types as shown in maps delineated at European scale (see sources column)	www.globalbioclimatics.org, using Biogeographic Region and Sub-Region
Catchment (Drainage basin, Watershed)	Area of land drained by a river and its tributaries.	Topographic divide (watershed)	Digital Elevation Models (e.g. EU-DEM, SRTM, ASTER GDEM) using GIS algorithms to delimit the divide EU-wide CCM2 River and Catchment Database (v2.1) or EEA Ecrins (connected watersheds, rivers, lakes, monitoring stations, dams) data set
Landscape Unit (Physiographic Unit)	Portion of a catchment with similar landscape morphological characteristics (topography/landform assemblage).	Topographic form (elevation, relief – dissection, often reflecting rock type(s) and showing characteristic land cover assemblages)	GIS overlay of some of the following in the stated order of priority (1) Digital Elevation Model (e.g. EU-DEM, SRTM, ASTER GDEM) (2) Geological maps (One Geology Europe) (3) CORINE Land Cover (4) Supporting information from: Google Earth / Orthophotos
River segment (River sector)	Section of river subject to similar valley-scale influences and energy conditions.	Major changes of valley gradient Major tributary confluences (significantly increasing upstream catchment area, river discharge) Valley confinement (confined, partly-confined, unconfined) In mountainous areas, very large lateral sediment inputs	(1) Major segments are identified by applying GIS tools to a DEM with river network overlay, to define downstream breaks in valley gradient (and width) and in upstream contributing area. (2) Major segments may be subdivided according to valley confinement interpreted from DEMs Google Earth images Orthophotos

Spatial Unit (equivalent terms)	Definition / Description	Delineation criteria (#)	Methods and Data Sources (#)
River reach	Section of river along which boundary conditions are sufficiently uniform that the river maintains a near consistent internal set of process-form interactions. (A river segment can contain one to several reaches)	Channel morphology (particularly planform) Floodplain features (minor changes in bed slope, sediment calibre, may be relevant) Artificial discontinuities that affect longitudinal continuity. (e.g. dams, major weirs / check dams that disrupt water and sediment transfer)	Segments are subdivided into reaches by visual interpretation of consistent river and floodplain (bio) geomorphic pattern using Google Earth Orthophotos Multi-spectral remotely-sensed data Lidar data (Field reconnaissance can provide useful confirmation / additional data)
Geomorphic unit (Morphological unit, Mesohabitat, Sub-reach)	Area containing a landform created by erosion and/or deposition inside (instream geomorphic unit) or outside (floodplain geomorphic unit) the river channel. Geomorphic units can be sedimentary units located within the channel (bed and mid-channel features), along the channel edges (marginal and bank features) or on the floodplain, and include secondary aquatic habitats within the floodplain. Some geomorphic features (biogeomorphic units) are formed in association with living and dead (e.g. large wood) vegetation as well as sediment.	Major morphological units of the channel or floodplain distinguished by distinct form, sediment structure / calibre, water depth/velocity structure and sometimes large wood or plant stands (e.g. aquatic / riparian, age class)	Requires field survey but preliminary analysis can use: Google Earth Orthophotos Multi-spectral remotely-sensed data Lidar data
Hydraulic unit	Spatially distinct patches of relatively homogeneous surface flow and substrate character. A single geomorphic unit can include from one to several hydraulic units.	Patches with a consistent flow depth / velocity / bed shear stress for any given flow stage and characterized by narrow range in sediment calibre	Requires field survey
River element	Elements of river environments including individuals and patches of sediment, plants, wood, etc.	Significant isolated elements creating specific habitat or ecological environments	Requires field survey

(#) All spatial scales equal to or greater than the reach scale may be delineated using secondary sources and a desk-based analysis – types of data are suggested here.

Watershed Resources Registry – Stream Stability Index
The Watershed Resources Registry (WRR) is a partnership project supported by EPA Region 3's Water Protection Division through its Office of State and Watershed Partnerships. WRR scores potential restoration and preservation areas on a scale of one to five stars based on their potential benefits. WRRs are now available in four mid-Atlantic states, including Delaware, Maryland, Pennsylvania, and West Virginia. Virginia's WRR is in progress.

USEPA Region 3 and Maryland Environmental Service (MES) undertook an effort to develop a Stream Stability Index for the Watershed Resources Registry. The effort investigated readily available GIS data and GIS-based stream tools. The effort ultimately focused on using the Floodplain and Channel Evaluation Tool (FACET) combined with channel dimension derived from regional curves to assess stream stability, specifically bank height ratio (BHR), entrenchment ratio (ER), and stream power. The effort concluded before the feasibility of using FACET was tested. A white paper documenting the effort is forthcoming.

Function-based Rapid Stream Assessment Protocol Revision
USEPA Region 3 and U.S. Army Corps of Engineers (USACE)-Baltimore District are currently revising the Final Draft Function-Based Rapid Stream Assessment Methodology (FBRSA) (Starr et al. 2015) to update critical stream function metrics and include new key floodplain indicators related to stream connection. It is being updated to reflect changes in the understanding of stream and floodplain processes and to include additional metrics that reflect the potential functional uplift associated with floodplain/valley/beaver analog/legacy sediment removal restoration projects. The critical stream stability indicators from this protocol can be used as potential indicators for a desktop stream health assessment tool.

Maryland Department of Transportation/State Highway Administration (SHA) – US 301 Waldorf Area Transportation Project, Environmental Stewardship Methodologies and Results
The U.S. Fish and Wildlife Service (USFWS), Maryland Department of Natural Resources (DNR), and The Conservation Fund (TCF) conducted a watershed level assessment of four watersheds in the Coastal Plain. GIS data were used to predict stream stability, wetland locations, and forest stand condition. For the stream stability analysis, the GIS stream stability prediction results were compared to 200 field assessed sites. While a statistical analysis was not conducted, the GIS-predicted stability conditions were accurate for 85 percent of the 200 sites. The four GIS layers used to predict stream stability included: erodible soils, stream slope, riparian vegetation, and impervious cover (IC).

USEPA Dynamic Stream Systems
USEPA Office of Water is currently developing potential design considerations, monitoring procedures and requirements, performance standards, and adaptive management approaches for dynamic alluvial valleys. Dynamic alluvial valley designs are a process-based restoration design approach that focuses on restoring access to floodplains and dynamic management of sediment and wood within the stream valley. USEPA has recognized the need for the restoration community to identify when a dynamic valley is successful, and when intervention is necessary. As a result, their draft document is identifying key indicators, measurement methods, and performance targets. While many of the recommendations require field survey, it is possible that some of the indicators can be measured using desktop tools.

Multi-jurisdictional Rapid Habitat Assessment Database
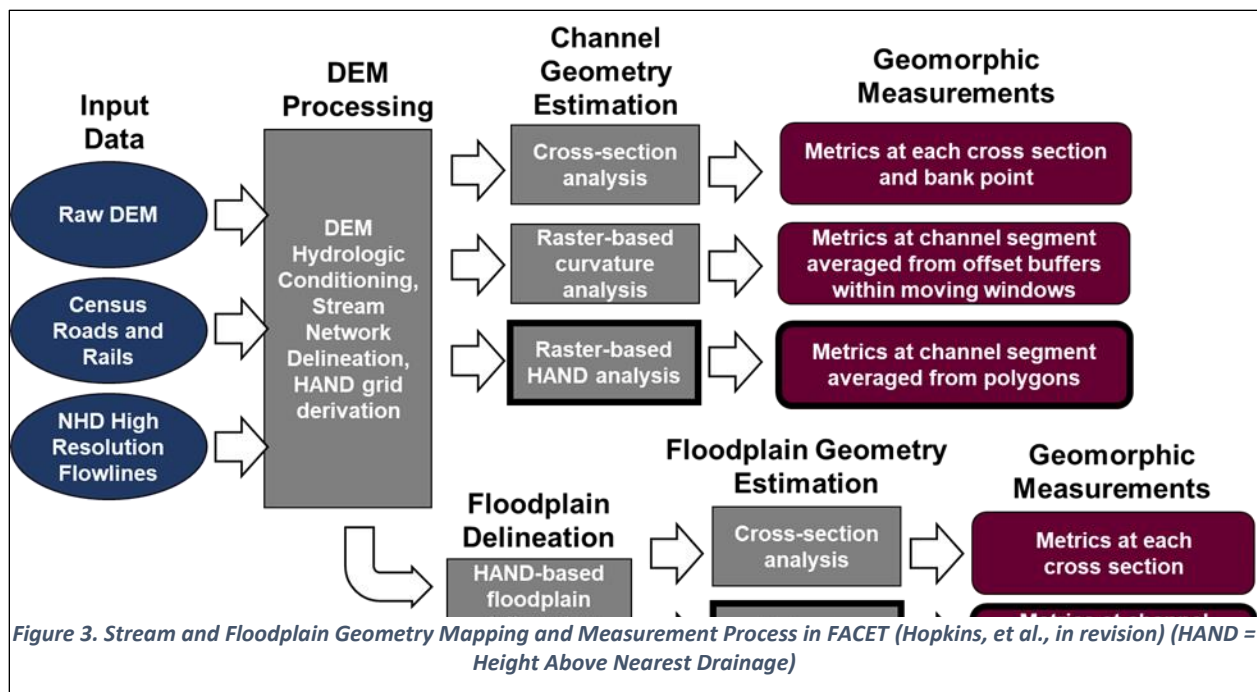USGS and ICPRB worked together to compile a multi-jurisdictional rapid habitat assessment database and identified the following 12 original metrics, plus two summary habitat metrics developed through Principal Component Analysis. The metrics in this database vary by jurisdiction, with some being observed and others modeled, therefore only a subset of metrics provides complete Bay watershed

coverage. It may be possible to model appropriate metrics for the remainder of the Bay watershed and apply the results in the Multi-Metric Hydromorphology Indicator Framework.

- Epifaunal Substrate/Available Cover
- Embeddedness
- Pool Substrate Characterization
- Velocity/Depth Combinations
- Pool Variability
- Sediment Deposition
- Channel Alteration
- Frequency of Riffles
- Channel Sinuosity
- Bank Stability
- Bank Vegetative Protection
- Riparian Score
- Habitat Component 1 (embeddedness, riffle frequency velocity/depth combination)
- Habitat Component 2 (riparian condition score, bank stability, bank vegetation, sediment deposition)

Stream and Floodplain Geometry Mapping and Geomorphic Change Modeling
USGS (Hopkins, et al., in revision) developed a desktop-based tool that can map stream and floodplain geometry using FACET (Figure 3). Initial output, using 3-m DEM, is available for most of the Chesapeake watershed (Hopkins et al. 2020). USGS (Noe et al. 2022) previously published statistical modeling of streambank and floodplain geomorphic change and associated sediment and nutrient fluxes for every NHDPlusV2 stream in the Chesapeake Bay watershed. Nearly all of that geomorphic change can be considered fluvial, with floodplain deposition or erosion a consequence of floodplain connection (and sediment supply from upstream). FACET also estimates the geomorphically active floodplain with an approximate 2-yr recurrence interval (50% annual probability) . The catalog of about 100 metrics will be rerun with new 1-m DEM in 2023.

Figure 3. Stream and Floodplain Geometry Mapping and Measurement Process in FACET (Hopkins, et al., in revision) (HAND = Height Above Nearest Drainage)

Currently, USGS is exploring using FACET tools to develop metrics associated with floodplain connectivity and lateral stability, as follows:

- Use FACET floodplain width and channel width to develop a proxy for entrenchment ratio to reflect floodplain connectivity
- Map inundation extent under different recurrence intervals using USGS stream gage data (to include 2, 5, 10, 20, etc. year intervals) to inform our understanding of the frequency of floodplain inundation
- Use FACET channel width and channel depth to develop a proxy for width to depth ratio to reflect incision and stability
- Develop index of channel alteration based on departure from expected channel width based on regional curves to reflect stream channel modification

Flow Alteration Metrics
USGS (Maloney et al. 2021) 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. The flow alteration indicator could possibly be used to assist in evaluating floodplain connectivity.

Maryland Healthy Watersheds Assessment – Hydrology and Geomorphology GIS 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), Maloney et al. (2021), FACET (USGS 2019), and FACET-derived work by Greg Noe and others were important in explaining biological condition in Maryland streams (Table 3). Kelly Maloney has cautioned that decoupling FACET metrics might not be advisable. However, some of the other metrics could prove useful for the Multi-Metric Hydromorphology Indicator Framework.

Table 3. Hydrology and Geomorphology GIS Metrics from Maryland Healthy Watersheds Assessment (Roth et al. 2022)

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

Maryland Stream Restoration Screening Tool

The Chesapeake Conservancy Conservation Innovation Center (CIC) and Maryland DNR are developing a Maryland Stream Restoration Planning Tool designed to support conservation and restoration planning by Maryland DNR's Resource Assessment Service (RAS) and Chesapeake and Coastal Service (CCS). This tool will include various biological metrics, such as presence of trout, coldwater-obligate benthic macroinvertebrates, Sensitive Species Project Review Areas (SSPRAs), stronghold watersheds, and the fish and benthic macroinvertebrate Indices of Biotic Integrity (IBIs), but also innovative hydromorphology information.

The tool uses the FACET stream network and bank points, from which bank height, channel width, and other geometric properties of the channel and floodplain are derived. Much effort was spent in an attempt to utilize CIC's new hyper-resolution hydrography data that generates estimates of bank height using the results of the geomorphon algorithm; however, analysis of the results showed them to be inconsistent when compared against terrain cross sections, especially in high-relief areas. While the bank height estimates were generally accurate in low-relief terrain, in high-relief areas the algorithm often identified valley walls or the upslope channel bed as banks, and generated erroneously high estimates of bank height. As a result, FACET data were used because the bank height estimates were generally more accurate across a wide variety of terrain.

The mean bank height of a stream reach, as estimated using the 1-dimensional slope break method was summarized for stream restoration planning as a quintile ranking of bank height stratified by stream order (and merged across HUC-8s). This approach provides a fair evaluation of bank height as differences in bank height owing to stream order or physiographic location are inherently accounted for by the stratification process.

Along with these data tool efforts, the following technical guidance reports were used to identify 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

4.3   Candidate Desktop Indicators

Our review of these data tools indicates that the indicators shown below are potentially the most important for characterizing physical stream health (especially stream stability) using GIS data. As described in our Multi-Metric Hydromorphology Indicator Framework, these indicators reflect basin/landscape-level to reach-level stream processes and land features that influence stream stability. It is critically important to assess not only reach-level stability indicators, but also those basin/landscape-level features and processes that influence stream stability. This approach could result in absolute, or potentially relative values, and relevant thresholds for stream and floodplain characteristics using GIS layers to predict stability. It should be noted that, at smaller drainage areas and stream sizes, even high-resolution terrain imagery may not be detailed enough to accurately measure stream and floodplain characteristics or develop thresholds. This is another reason why developing a desktop stream/stability tool should not solely rely on reach-level data to predict stability. It is also important to consider whether the GIS data can determine 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 USGS 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 that could be used as part of the desktop stream health assessment tool.

Multi-Metric Hydromorphology Indicators and Descriptions

Catchment (Basin) and Landscape Unit/Pyramid Level 1 – Hydrology
- Runoff – Amount and rate of storm water runoff (e.g., flow regime) influences stream energy and thus channel stability.
- Sediment Production – Amount of potential sediment load being delivered by the watershed. Sediment load significantly influences channel stability.
- Geology – Used to assess runoff and sediment production (includes topography, elevation, rock type).
- Climate – Can influence flow regime.
- LULC – Used to assess runoff and sediment production.

River Segment/Pyramid Level 2 – Hydraulic
- Valley confinement (both natural and non-natural) – Influences stream characteristics and determines whether there is enough floodplain area to reduce stream and floodplain scouring flows.
- Sediment Transport – The ability of a stream and floodplain to process sediment load significantly influences streambed stability (whether stable, aggrading or degrading).

Reach/Pyramid Levels 2 — Hydraulic and 3 — Geomorphology
- Planform – Valley type and watershed position will predict stream pattern, i.e., if the stream is naturally confined, a low sinuosity (sinuosity index <1.2) channel would be expected and, if unconfined, it would be sinuous (>1.2), meandering, or anastomosing.
- Stream Energy – Stream energy influences channel dimension, patten, and profile. Excessively high or low stream energy can result in stream instability (excessive degradation or aggradation).
- Floodplain connectivity – Assesses the frequency of flood flow access to the floodplain and the size of the available floodplain. Access by flood flows is necessary to reduce stream energy and the potential for a stream to erode.
- Channel Dimension – Can influence stream energy. High width-depth ratios increase floodplain connectivity, though a too-wide ratio results in sediment deposition. Low width-depth ratios can result in degradation. The key is to determine the range of width-depth ratios included in natural channel migration.
- Buffer Width – Vegetation in the riparian area, specifically along the streambank, can be an indicator of lateral stability. Lack of a riparian buffer can suggest lateral instability exists.

- Built Environment/Infrastructure – channelization, levees, dams, bridges, pipelines, etc.

Geomorphic and Hydraulic Unit/Pyramid Levels 2 — Hydraulic and 3 — Geomorphology
- Lateral Stability – The presence and stability of streambank features can be indicative of lateral stability. For example, lack of riparian buffer, erosion of outer banks, and excessive formation of point bars from deposited sediments can signal lateral migration.
- Bed Stability – Bed stability condition is an indicator of supporting stream function conditions, such as floodplain connectivity, stream energy, sediment transport, etc. Measurement of bed stability could, along with these other indicators, improve accuracy of desktop stream stability predictions.
- Bedform and Habitat Features – Finer scale features of the stream bed, such as embeddedness and riffle/pool frequency, provide habitat for biota that is critical for stream health.

As stated above, this list of Multi-Metric Hydromorphology Indicators reflects catchment (basin)/landscape-level to finer-scale stream processes and land features that influence stream health along with other stressors. A tool developed that includes indicators at these levels would likely improve predictions of existing stream health and possibly provide information on the causes of degradation. However, development of such a tool could be a long-term effort. Therefore, below is a refined list of proposed stability indicators that are the most critical and influential. While these indicators may not be able to identify potential causes of instability, they have the potential to accurately predict stream stability. By focusing on fewer indicators with associated GIS layers, a tool for predicting stability could likely be developed within a shorter time period.

Refined List of Multi-Metric Hydromorphology Indicators Focused on Stability

- Valley type/confinement
- Floodplain connectivity
- Riparian vegetation
- Bedform diversity/stability
- Lateral stability

5. Data Sources

After identifying potential indicators, we found potential data sources that could be used to measure indicator conditions. Through our literature review and interviews with experts, ten data sources were found and are detailed in the Excel data sources document (Appendix B). The five most promising data sources are summarized below.

1. *Multi-jurisdictional Rapid Habitat Data*

Rapid habitat data were collected from jurisdictions across the Chesapeake Bay watershed by the 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 the potential for describing habitat quality. Because these rapid habitat data are field assessments at specific sites, USGS is modeling unsampled streams to provide Bay-wide coverage, as is done for the Chessie BIBI.

2. *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 collaborated to produce these foundational data for the Chesapeake Bay watershed 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 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.

3. *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.

Specifically, FACET uses upstream nodes of first-order streams from the 1:24,000 NHD network to initiate each first-order stream reach, then stream lines are routed downslope from the upstream nodes following a hydro-conditioned LiDAR DEM. The result is a stream network with the same density as the 1:24,000 NHD network, but the stream lines are more accurate and follow the topography more precisely than those in the NHD. FACET then generates evenly-spaced cross sections along every stream reach and analyzes the slope of the LiDAR terrain along each cross section to attempt to identify bank points, from which bank height, channel width, and other geometric properties of the channel and floodplain are derived.

While the FACET data (Lamont et al. 2019) are available using the 2009 DEM downscaled to 3 meters, 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 FACET team will be re-running FACET and other derivatives of the DEM over time.

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.

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

4. *Hyper-Resolution Terrain-based Hydrography Mapping*

Matt Baker of UMBC, in partnership with the Chesapeake Conservancy CIC, 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). In CIC's hydrography data, streams are identified directly from terrain using the geomorphon algorithm resulting in an accurate dataset with minimal omission or commission errors. 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 the 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 ultimately be useful for developing hydromorphology indicators and other efforts, such as refining riparian modeling for the Bay.

Marina Metes of USGS has used topographic openness (derived from LiDAR DEMs) to map ephemeral headwater streams (Metes et al. 2022) and stream channel incision (Metes et al. in review). Specifically, she has remotely mapped gullying and incision in Maryland Piedmont headwater streams using repeat airborne LiDAR.

5. *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 valueadded look up (valu) table containing "ready to map" attributes. The gridded map layer is offered in an ArcGIS file geodatabase raster format. The 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 to determine 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.

6. Example Uses of GIS Data

While testing and validating the recommended potential indicators is reserved for a later project, we conducted preliminary analyses of two concepts: (1) what is the ability of the FACET GIS tool to accurately reflect field-measured metrics of floodplain connectivity, specifically bank height ratio (BHR) and entrenchment ratio (ER) and (2) can simple GIS layers, such as slope, IC, soil erodibility, and riparian vegetation, accurately predict field-determined stream stability.

6.1   Stream Restoration Sites with Field Measurements and Stability Assessments

Eight stream restoration sites, provided by EPR, were selected for the comparison testing. The sites were selected based on having a range of physiographic regions, project sizes (i.e., drainage areas (DA)), and known stability conditions. The following eight sites were selected:

1. Broad Creek Valley West, MD: DA – 0.15 mi^2, Coastal Plain Region, 38.970047,-76580141
2. UT Flat Creek, MD: DA – 0.27 mi^2, Coastal Plain Region, 38.952208,-76.625244
3. Heritage Harbour, MD: DA – 0.39 mi^2, Coastal Plain Region, 38.970773,-76.596366
4. Beck Creek, PA: DA – 2.42 mi^2, Piedmont Region, 40.286740, -76.458800
5. Big Cove Site 1, PA: DA – 6.4 mi^2, Ridge and Valley Region, 39.909328,-78.013957
6. Bush Creek, MD: DA – 7.66 mi^2, Piedmont Region, 39.371655,-77.252766
7. Big Cove Site 2, PA: DA – 10.3 mi^2, Ridge and Valley Region, 39.891018,-78.022149
8. Big Cove Site 3, PA: DA – 15.9 mi^2, Ridge and Valley Region, 39.880632,-78.027757

6.2   Comparing FACET to Field Measurements

As a first test of the ability of the FACET GIS tool (using the 1-meter DEM available for these sites) to accurately reflect field-measured metrics of floodplain connectivity, we compared the following variables with values measured at the eight EPR field restoration sites.

- Channel Width at Top of Bank
- Active Channel Mean Width
- Active Channel Mean Depth
- Bed Slope
- Water Surface Elevation

The figures below show boxplots of the percent differences in the FACET and field variable values, combined across sites (Figure 4) and by site (Figure 5). The results show considerable variation within and among sites for all the variables, except water surface elevation. Recognizing that the exact locations of the FACET cross sections often differed from the field measured (as produced in HEC-RAS) cross sections, we conducted a second visual test of co-incident cross sections. Figure 6 shows six selected cross section comparisons across a range of channel configurations and elevation changes. These co-incident cross section comparisons show a better match and merit further investigation at the next stage of the project. The biggest challenge of using FACET, however, is that FACET only measures the water elevation and not true bottom of the channel. This will present a problem for streams with water depths greater than a few tenths of a foot.

Figure 4. Percent differences in the FACET and field variable values combined across sites

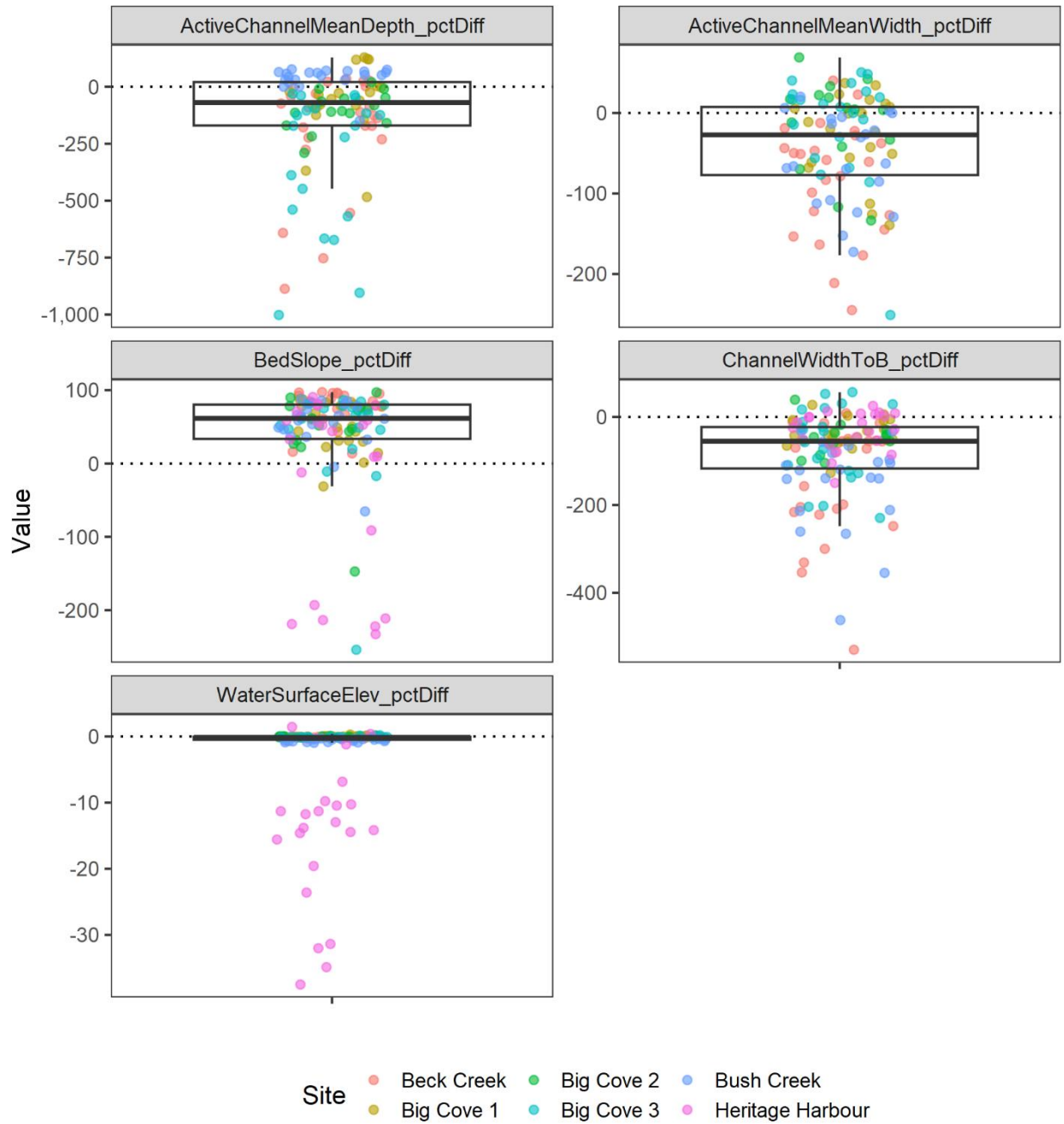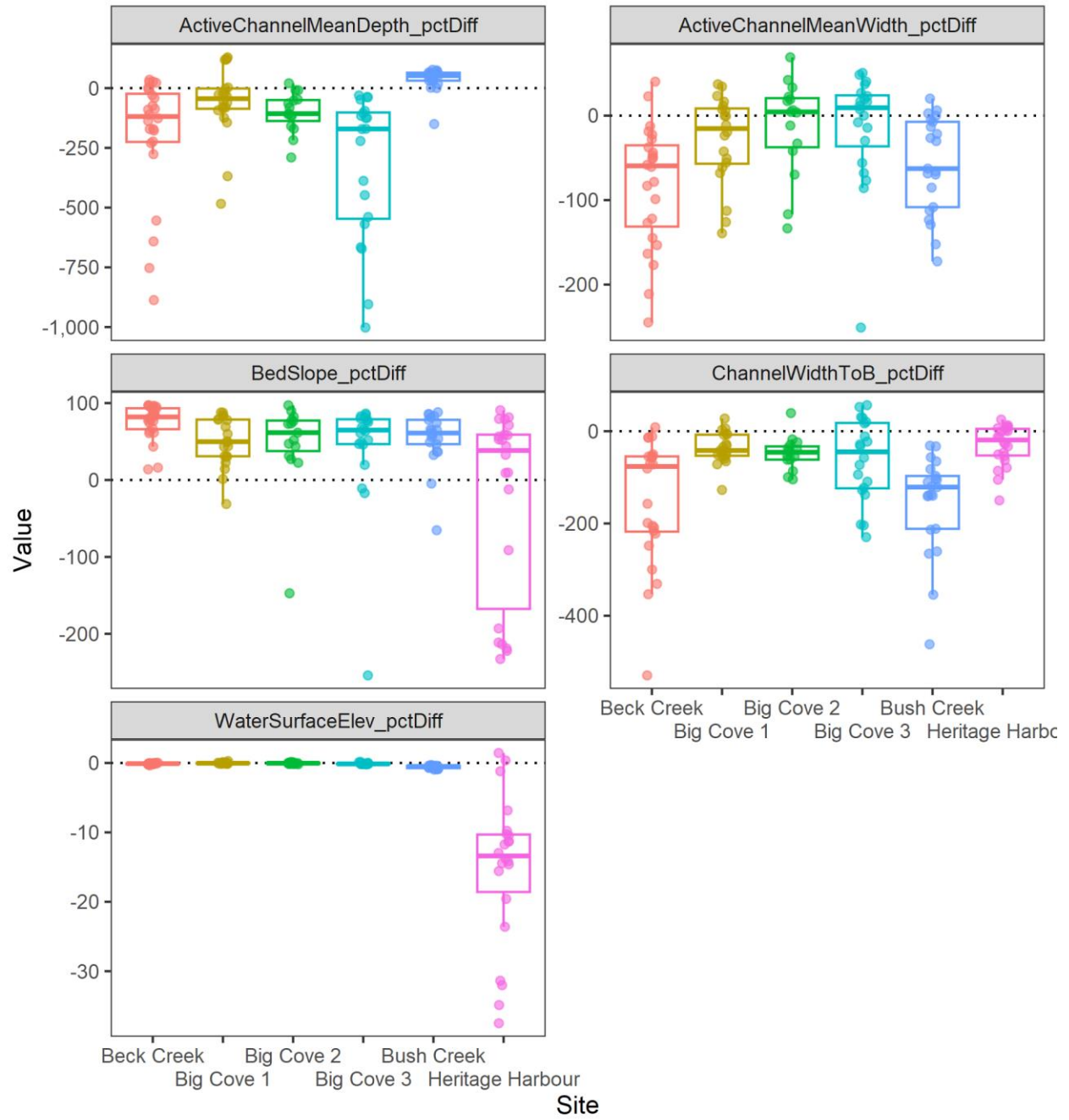*Figure 5. Percent differences in the FACET and field variable values for each restoration site*

Beck Creek- Station 18+28

Beck Creek- Station 22+79

24

Big Cove Site 2 - Station 19+61

Big Cove Site 3 - Station 18+95
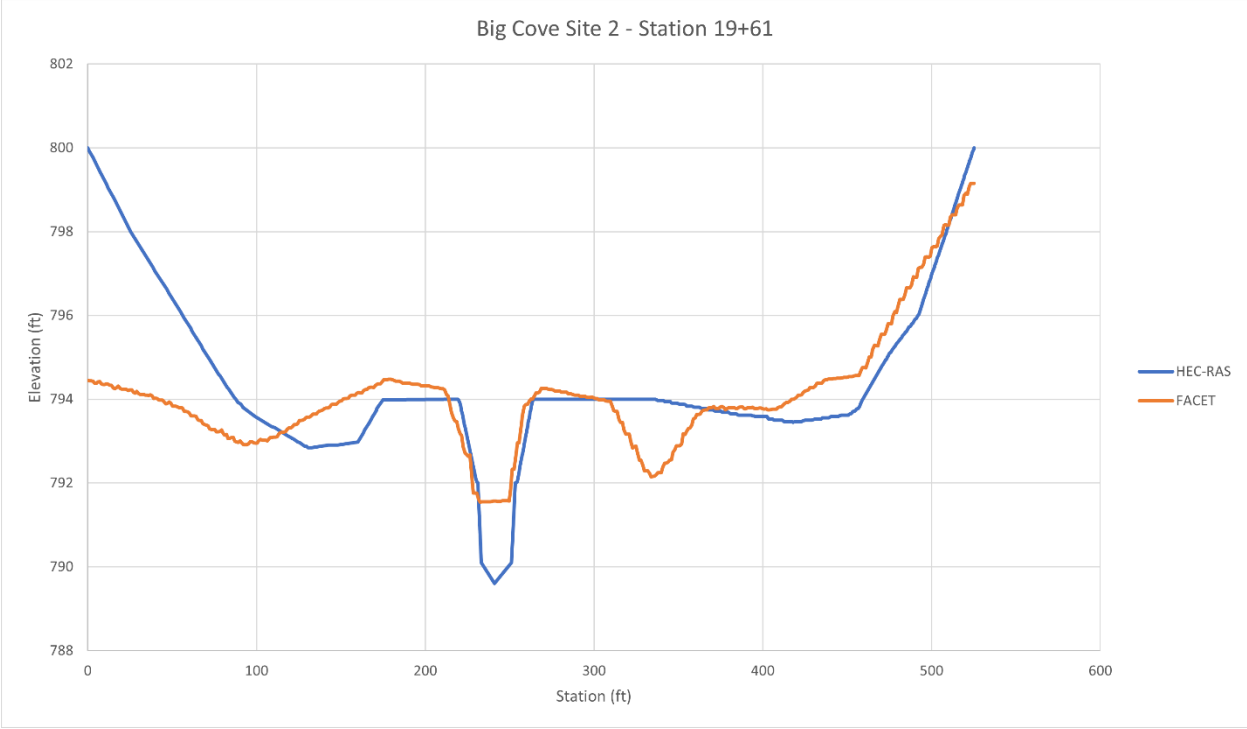
Figure 6. Visual comparisons of FACET and field-measured (HEC-RAS) cross sections at selected restoration sites

6.3   Using GIS Layers to Predict Stability

We expect that whichever metrics are identified as indicative of stream health, the most useful hydromorphology indicator(s) will be a combination of individual metrics. To be applied watershed wide, these metrics will need to be direct measurements available as GIS layers or modeled results of sampled measurements across unsampled areas. To demonstrate the approach of combining hydromorphology metrics (and to evaluate their preliminary potential), we compared the field-determined stream stability metrics assessed at the eight sites listed above with the GIS-derived stability predictions using the following four layers: (1) soil erodibility (NRCS soil erodibility rating, as K Factor), (2) percentage of impervious cover (IC) in catchment, (3) riparian buffer presence (LULC forest within 25 feet of stream channel), and (4) stream slope (GIS derived for the catchment).

Table 4 shows the individual metric values for each GIS layer at each site and whether the value is indicative of a stable or unstable stream (e.g., a stable slope threshold would be 2% for Piedmont streams and 1% for Coastal Plain streams). The metrics values are also summed with equal weights to indi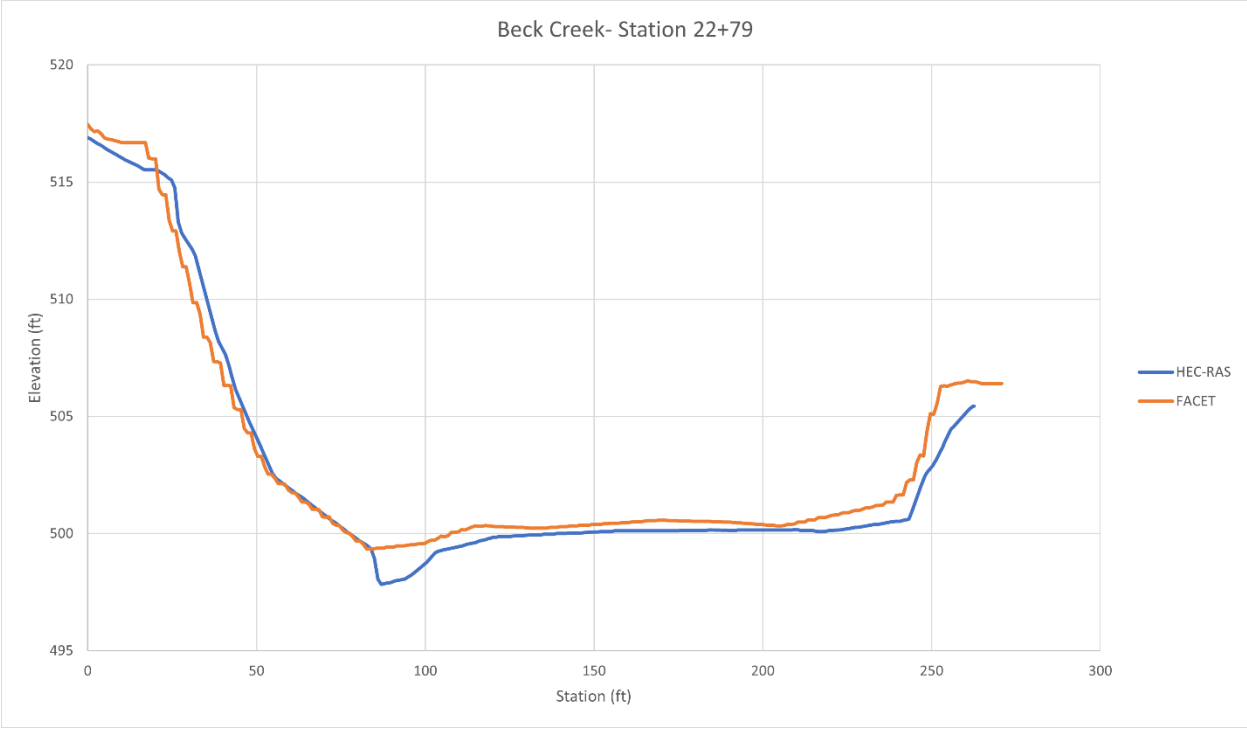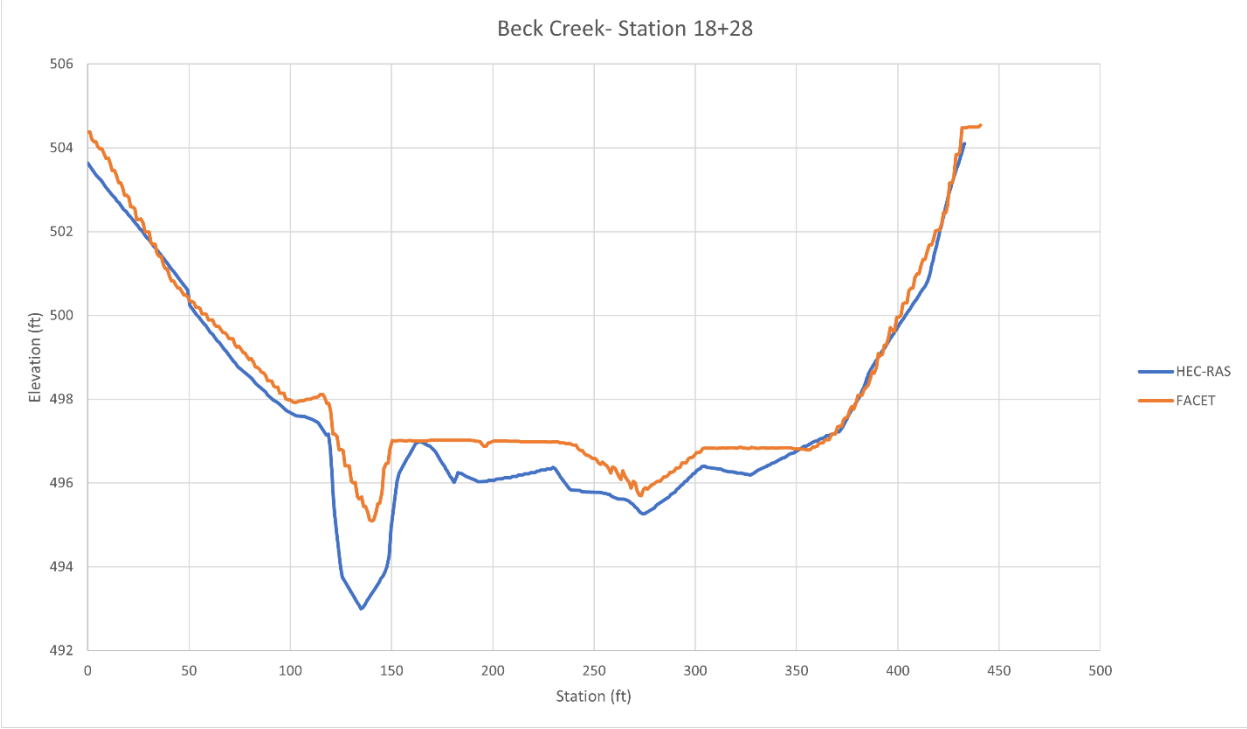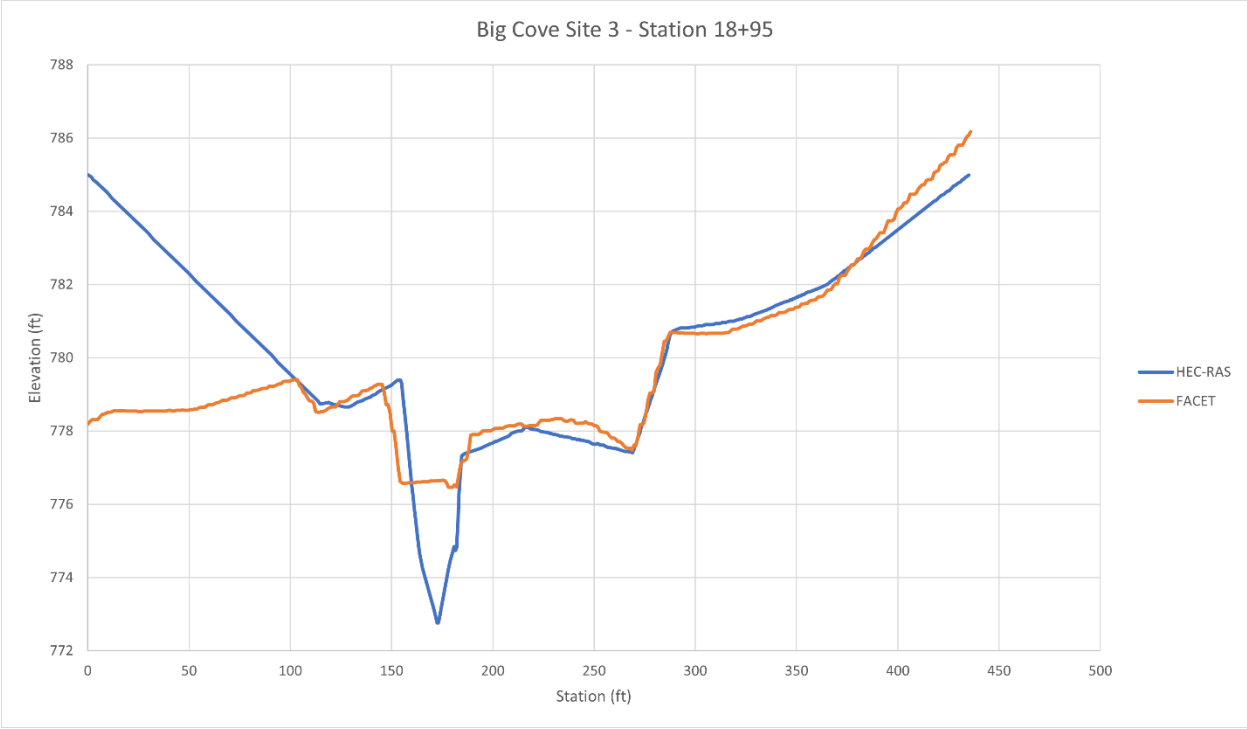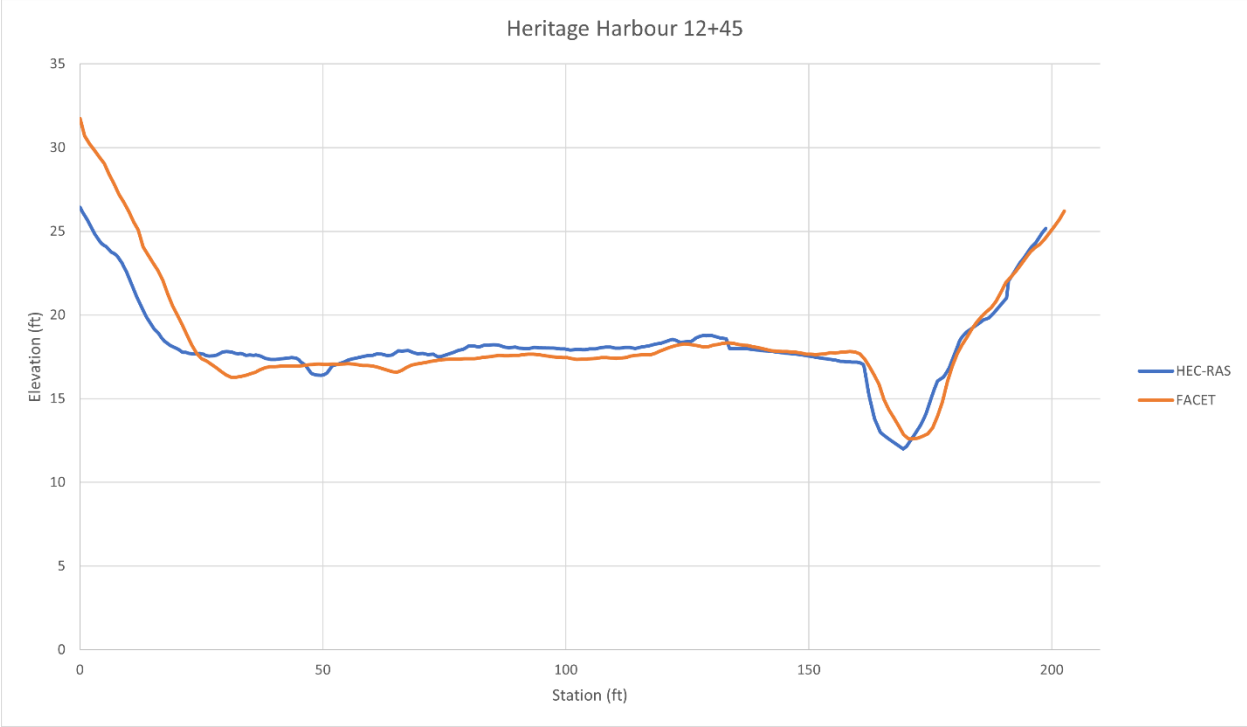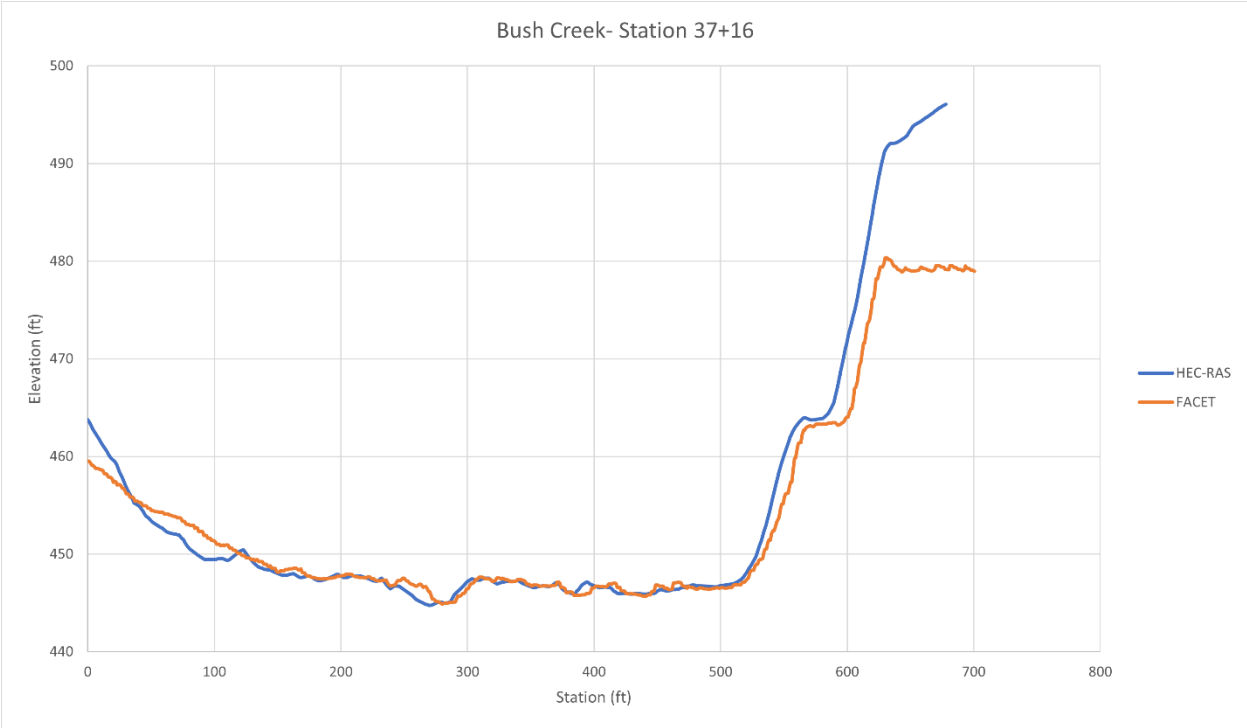cate overall degree of stability at each site and compared to the field-determined stability of the stream restoration projects. Overall stability ratings were determined by the following criteria:

- If the soil K Factor rating was unstable and the forest buffer rating was unstable, then the site is considered unstable
- If the soil K Factor rating was unstable and the slope rating was unstable, then the site is considered unstable
- If three (3) or more ratings were unstable, then the site is considered unstable

Based on the detailed field survey, all 8 sites were determined to be unstable. Seven out of the eight sites were rated as unstable using the GIS layers. Bush Creek was the only site rated as stable. Note, however, that the forest GIS layer does not accurately represent existing forest buffer conditions derived from field observations. It greatly over-predicted the percent forest buffer. If it had accurately predicted forest buffer, the Bush Creek site would have been rated as unstable. In addition, the GIS slope values are likely higher than actual because hydrology layers consistently underrepresent existing meandering stream length. This initial analysis generally predicted stability conditions and identified the limitations of some of the selected GIS layers. A more comprehensive analysis using additional sites along the stable-unstable continuum would provide more robust conclusions.

Similar GIS layers were previously used to determine stream stability in the SHA US 301 Waldorf Area Transportation Project, Environmental Stewardship Methodologies and Results study. In addition, EPR is currently field testing a different GIS layer overlay procedure at Big Cove (near McConnellsburg PA) and Spring Creek (near Hershey PA) using the following six layers: (1) sinuosity, (2) forest, (3) agriculture, (4) development, (5) roads, and (6) soils. In this approach, each metric is scored 1-2-3 for low-medium-high instability and then the scores are summed. The total value is then broken into thirds for assignment of the overall stability rating. The EPR field study of these two sites will be completed by August-September of 2023 with 66 more sites available for further testing.

Table 4. Values and stability of each site for slope, soil erodibility, impervious cover, and forest cover metrics

Site	Drainage Area (mi²)	Slope (degrees)	Slope (percent)	Slope Rating[1]	Soil K Factor	Soil K Factor Description[2]	Soil K Factor Rating	Impervious Cover (IC)	Percent IC (percent)	IC Rating[3]	Forest Buffer (m²)	Forest Buffer (percent)	Forest Buffer Rating[4]	Overall Stability Rating
Beck Creek (piedmont)	2.42	1.61	2.82	Unstable	0.41	High erosion susceptibility	Unstable	2188	2	Stable	7,875	5	Unstable	Unstable
UT Flat Creek (western coastal plain)	0.27	3.45	6.04	Unstable	0.33	Moderate erosion susceptibility	Unstable	0	1	Stable	25,236	90	Stable	Unstable
Heritage Harbour (western coastal plain)	0.39	0.07	0.134	Stable	0.43	High erosion susceptibility	Unstable	0	33	Unstable	0	0	Unstable	Unstable
Big Cove Site 3 (use carbonate curve)	15.9	2.01	3.52	Unstable	0.35	Moderate erosion susceptibility	Unstable	713	3	Stable	34,36	10	Unstable	Unstable
Big Cove Site 1 (use carbonate curve)	6.4	1.49	2.61	Unstable	0.31	Moderate erosion susceptibility	Unstable	788	3	Stable	11,061	20	Unstable	Unstable
Bush Creek (piedmont)	7.66	0.78	1.37	Stable	0.32	Moderate erosion susceptibility	Unstable	0	15	Stable	15,404	92	Stable	Stable
Big Cove Site 2 (use carbonate curve)	10.3	0.75	1.319	Stable	0.31	Moderate erosion susceptibility	Unstable	219	3	Stable	2	1	Unstable	Unstable
Broad Creek Valley West (western coastal plain)	0.15	0.00	0.013	Stable	0.43	High erosion susceptibility	Unstable	0	11	Stable	0	0	Unstable	Unstable

[1] Rating based on the following criteria
- Slope: Piedmont – greater than 2% is unstable; Coastal Plain – greater than 1% is unstable

[2] Rating based on the following criteria
- Soil K Factor: <0.25 = low erosion susceptibility, 0.25-0.4 = moderate erosion susceptibility, >0.4 = high erosion susceptibility (Technical Guide to RUSLE, NRCS/USDA) (moderate or high are considered unstable)

[3] Rating based on the following criteria
- Impervious Cover: Greater than 15% is unstable

[4] Rating based on the following criteria
- Forest: Value less than 50% of the assessed buffer area is unstable

7. Recommendations

Our recommendations of hydromorphology indicators using GIS data provide a holistic and multi-scale approach for further evaluating potential metrics and ultimately developing indicator(s) of hydraulics and geomorphology typically associated with stream health in the Chesapeake Bay watershed. We propose a Desktop Hydromorphology Assessment Tool with a long list of candidate metrics and data sources. While developing this comprehensive tool would be a longer effort, applying the approach to the smaller list of metrics below (and highlighted in Table 5) might produce useful indicator(s) in the short term:

- Valley type/confinement
- Floodplain connectivity
- Riparian vegetation
- Bedform diversity/stability
- Lateral stability

Appropriate indicators for stream hydromorphology need to quantify the degree of health or include thresholds that are indicative of healthy vs. unhealthy stream hydromorphology. These ratings or thresholds will likely take the form of deviations from expected values. 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 form of rating may involve observations of change over time to determine if a stream has recently become degraded, is continuing to be degraded, or is nearing health again. The ratings and thresholds should be put in the context of physiographic region and stream size, such as scaling streams on watershed size, stream order, valley types, stream type, etc. Lastly, both absolute and relative values should be investigated in terms of practicality, accuracy, and precision. Ultimately, statistical analyses will be needed to develop the ratings or thresholds that may exist.

Any prospective indicators need to be tested against empirical data collected in the field and/or modeling results using independent information. Stream restoration sites such as those assessed by EPR for our initial comparisons can provide information across stream types and physiographic regions, but they do not provide a gradient of stream health (i.e., the stream sites in those case studies were selected for restoration because they were degraded). Therefore, indicator test sites with field data need to include adequate replicates across a gradient of stream health conditions, stratified by stream type, physiographic region, catchment size, etc.

7.1   Principles of Indicator Development

To be reliable, indicators should be developed using sufficient high-quality calibration data, an independent validation process, and well-documented indicator development methods. The data should represent conditions from a full range of the condition gradient, from least-disturbed to most-disturbed, so that the indicator can show responsiveness across the gradient. The USGS conducted FACET calibration and validation covering 85% of the Chesapeake Bay watershed (across 6 physiographic regions) using field data at 67 reaches. A similar sample survey using traditional field methods could be conducted to validate the candidate metrics and indicators of hydromorphology. Another potential method for field validation is automated High-Definition Stream Survey (HDSS) methods to rapidly collect, classify, and assess stream corridor data (https://truttasolutions.com/hdss-overview/). An HDSS assessment provides continuous 1-meter longitudinal resolution output documenting the conditions

observed along a river or stream corridor. This continuous georeferenced, high-resolution data is applicable for fine scale (i.e., microhabitat) to broad scale (i.e., watershed) analyses.

A common approach for calibrating an indicator to a stressor gradient is to test the sensitivity of diverse metrics across the gradient. Metrics that respond to stressors consistently and predictively are good candidates for components of the indicator. When selecting metrics to form a multi-metric index, each metric should have a strong response to stressors, should represent diverse aspects of potential stressor response mechanisms, and should be unique within the metric set (not contributing redundant signals).

Once developed, the indicator should have several performance characteristics that allow distinction of conditions relative to stressors of interest. The indicator should be precise within least-disturbed sites, especially within comparable natural site types. The indicator should have distinguishable values between the least-disturbed and most-disturbed stressor conditions. The distinctions should be identifiable not only in the calibration data, but also within the validation data or validation process. To the great extent possible, the indicator values should be readily interpretable. For example, a high-performing indicator could be associated with a range of indicator values for least-disturbed sites, so that sites with indicators within that range will be recognized as relatively undisturbed. However, interpretation of the indicator will be enhanced if the indicator values are not only a range along a scale, but also associated with meaningful measurement units or standardized descriptions of the scale.

7.2   Recommendations for Developing a Desktop Hydromorphology Assessment Tool

We recommend the following desktop hydromorphology assessment tool be developed following the proposed Multi-Metric Hydromorphology Stream Health Indicator Framework described above and illustrated in the Recommended Metrics and Data Inventory Matrix for Hydromorphology Indicator Development (Table 5). This tool would be an analytical method for identifying appreciate metrics, thresholds, and scoring to produce stream health resulting using hydromorphological data. An initial version of the assessment tool could be developed using the short list of metrics described above, followed by further development that incorporates additional metrics.

This table provides a holistic approach to hydromorphic stream health by including metrics within each of four spatial dimensions embodied in the REFORM project and three lower functional levels within the Pyramid. The table contains the recommended indicators/metrics, potential measurement methods, and potential data sources. The table also includes columns for metric thresholds, which would be developed in a later project. Indicators for elements such as Bedform and Habitat Features are not included in the desktop tool, but should be added into the full suite of metrics for an ultimate Hydromorphology Stream Health Indicator.

The following are recommended as future steps to develop the Desktop Hydromorphology Assessment Tool:

1. Reevaluate recommended potential metrics/indicators. The potential exists that new useful information and/or data may be developed after this current effort, but before the development of the tool is initiated. It will be important to determine whether any new potential critical indicators of stream stability have been developed that may be suitable for the desktop tool.
2. Reevaluate potential new data sources and/or assessment methodologies. Again, new useful information might be developed prior to the initiation of tool development.
3. Select measurement methods to quantify metrics/indicators. Ideally, potential measurement methods would be scientifically based and proven to be effective.

4. Select data sources to conduct measurements. Selection of measurement methods and data sources will likely be an iterative process. A measurement method may be selected, but there may not be a data source that can be used to conduct the measurement. Therefore, measurement methods may have to be revised to reflect newly available data sources.
5. Develop metric thresholds that can quantitatively describe the range of stability for each indicator/metric. A critical aspect in developing thresholds 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. Example thresholds for stream types using valley confinement and sinuosity, developed by REFORM (Gurnell et al. 2014), are shown in Table 6. Absolute and relative values for metric thresholds should be investigated, in case data sources and/or measurement methods are not refined to a level where absolute values accurately represent existing conditions. Again, this will be an iterative process with measurement methods and data sources. The measurement method must be able to quantify the metric and the data source must be able to provide the data that must be measured.
6. Determine whether thresholds vary by physiographic region, watershed size, stream order, landscape position, valley type, stream type, or other factors. Statistical analyses can help tease out the thresholds from a continuum of these factors, if they exist.
7. Refine the Recommended Metrics and Data Inventory Matrix for Hydromorphology Indicator Development table.
8. Develop desktop stream hydromorphology assessment tool based on selected metrics, measurement methods, data sources, and thresholds.
9. Test accuracy of desktop analysis results to empirical data and/or models. This step is critical to ensuring the desktop tool accurately predicts stream health. If there are different thresholds for a given metric, then testing needs to occur for each set of thresholds. Empirical data may come from existing detailed stream and floodplain assessments or may require additional field data collection.
10. Iteratively, revise desktop stream hydromorphology assessment tool based on testing results until tool accurately predicts stream health. Testing may include comparisons with independent test sites and selection/weighting of metrics to improve indicator performance.
11. Validate revised desktop stream hydromorphology assessment tool with new data.
12. Finalize desktop stream hydromorphology assessment tool.

*Table 5. Matrix of Recommended Metrics/Data for Desktop Stream Hydromorphology Assessment Tool (priority metrics denoted with *)*

Spatial Dimension	Metric	Measurement Method	Metric Thresholds			Data Source	Comments
			Stable	Partially Unstable	Unstable		
Large Catchment and Landscape Unit (Pyramid Level 1)	Impervious Cover (IC)	Percent IC				Existing GIS IC data layer	
	Runoff	Flashiness				Existing GIS land use / land cover (LULC) and IC data layers; Flow Alteration Metrics (Maloney et al. 2021)	
	Sediment Production	Sediment Load				Existing GIS LULC, IC, soils, and riparian vegetation data layers and flow regime analysis results; Gridded Soil Survey Geographic Database (gSSURGO) and Parameter-elevation Regressions on Independent Slopes Model (USGS under development)	
River Segment (Pyramid Level 2)	Valley Type/ Confinement*	Anthropogenic Confinement				Floodplain and Channel Evaluation Tool (FACET) and valley type based on landscape position; Hyper-Resolution Terrain-based Hydrography Mapping (CIC and UMBC under development)	
	Sediment Transport	Degrading or Aggrading				FACET and floodplain connectivity and channel dimension analysis results; Multi-jurisdictional Rapid Habitat Assessment Database (USGS under development); Gridded Soil Survey Geographic Database (gSSURGO) and Parameter-elevation Regressions on Independent Slopes Model (USGS under development)	
Reach (Pyramid Levels 2 & 3)	Floodplain Connectivity*	Bank Height Ratio (BHR)				FACET and bankfull channel dimensions regional curves	
		Entrenchment Ration (ER)				Hyper-Resolution Terrain-based Hydrography Mapping (CIC and UMBC under development); Stream and Floodplain Geometry Mapping (USGS in revision)	
	Stream Energy	Stream Power				FACET and stream power equation; Stream and Floodplain Geometry Mapping (USGS in revision)	
	Channel Dimension	Width/Depth (W/D) Ratio				FACET and bankfull channel dimensions regional curves	
	Riparian Vegetation*	Width and Type				Existing GIS data layer(s)	

Spatial Dimension	Metric	Measurement Method	Metric Thresholds			Data Source	Comments
			Stable	Partially Unstable	Unstable		
	Planform	Sinuosity/Meander Pattern based on Valley Type				FACET and potential stream planform based on valley type; Multi-jurisdictional Rapid Habitat Assessment Database (USGS under development); Hyper-Resolution Terrain-based Hydrography Mapping (UMBC under development); Stream and Floodplain Geometry Mapping (USGS in revision)	
		Meander Width Ratio (C and E Stream Types)				FACET and potential stream planform based on valley type; Hyper-Resolution Terrain-based Hydrography Mapping (CIC and UMBC under development)	
Geomorphic and Hydraulic Unit (Pyramid Levels 2 & 3)	Bedform Stability*	Channel Slope				Existing GIS data layer(s)	
		Erodible Soils				Existing GIS data layer(s)	
		Percent IC				Existing GIS data layer(s)	
	Lateral Stability*	Bank Erosion Rate				Multi-jurisdictional Rapid Habitat Assessment Database (USGS under development); Gridded Soil Survey Geographic Database (gSSURGO) and Parameter-elevation Regressions on Independent Slopes Model (USGS under development); Stream and Floodplain Geometry Mapping (USGS in revision)	
		Riparian Width				Existing GIS data layer(s)	
	Bedform and Habitat Features*	Bed Habitat (embeddedness, riffle frequency velocity/depth combination)				USGS identified 12 rapid habitat metrics and 2 PCA-derived summary metrics (representing bed and bank/riparian elements) with potential for describing habitat quality. Because these rapid habitat data are field assessments at specific sites, Bay-wide coverage would require modeling unsampled streams, as is done for the Chessie BIBI.	

Spatial Dimension	Metric	Measurement Method	Metric Thresholds			Data Source	Comments
			Stable	Partially Unstable	Unstable		
		Bank/Riparian Habitat (riparian condition score, bank stability, bank vegetation, sediment deposition)				USGS identified 12 rapid habitat metrics and 2 PCA-derived summary metrics (representing bed and bank/riparian elements) with potential for describing habitat quality. Because these rapid habitat data are field assessments at specific sites, Bay-wide coverage would require modeling unsampled streams, as is done for the Chessie BIBI. Field measurements of vegetation strata, percent cover, native species, and microtopography would also be valuable if available.	

Table 6. Simple Classification of River Types (Table 4.3 in Gurnell et al. 2014)

Table 4.3 Simple Classification of River Types based on Confinement and Planform

Type	Valley Confinement	Threads	Planform	Si	Bi	Ai
1	Confined	Single	Straight-Sinuous	n/a	approx. 1	approx. 1
2	Partly confined / Unconfined	Single	Straight	< 1.05	approx. 1	approx. 1
3	Partly confined / Unconfined	Single	Sinuous	$1.05 < Si < 1.5$ *	approx. 1	approx. 1
4	Partly confined / Unconfined	Single	Meandering	>1.5	approx. 1	approx. 1
5	Confined / Partly Confined / Unconfined	Transitional	Wandering		$1 < Bi < 1.5$	$Ai < 1.5$
6	Confined / Partly Confined / Unconfined	Multi-thread	Braided		$Bi \geq 1.5$	$Ai < 1.5$
7	Confined / Partly Confined / Unconfined	Multi-thread	Anabranching		$Bi < 1.5$ or $Bi > 1.5$	$Ai > 1.5$

7.3   Potential Next Steps

This project has identified a large body of useful work in the area of hydromorphology indicators and data sources. Should the recommendations in this report lead to further development toward hydromorphology indicator(s) that could supplement the Chessie BIBI to characterize stream health in the Chesapeake Bay watershed, we believe the best approach would be to combine the efforts of current investigators into a central team. Valuable members of that team would include USGS staff working with FACET and rapid habitat assessment data. In addition, individuals working on hyper-resolution mapping at Chesapeake Conservancy CIC and UMBC are best positioned to determine the feasibility of using that data source.

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Appendix A: Minutes of Meetings for Research and Data Discovery for Hydromorphology Indicators

1.   Interstate Commission on the Potomac River Basin (ICPRB) Meeting

19Sep2022

Mark Southerland
Nancy Roth
Paige Hobaugh
Rich Starr
Rikke Jepsen, ICPRB
Claire Buchanan, ICPRB
Andrea Nagel, ICPRB
Mike Mallonee, ICPRB

ICPRB has WQ and habitat data associated with Chessie BIBI from 1986-2019. Data is from states, counties (e.g., PG, Montgomery, Howard, Fairfax), plus VCU In-Star program, and now volunteer groups.

8 habitat parameters are collected into inland and coastal groups where they were available Bay-wide. Habitat data are not apples-to-apple because of the variability in how physical parameters are measured. For example, VA DEQ and VCU data for same watershed show different results. Starr emphasized that the subjectivity of habitat results like RPB (investigators make subjective 1-20 score assignments) means that we need to work with semi-quantitative data.

Nagel compiled geomorphology data submitted by MS4s for MDE and found differences in the way the data were collected.

Starr described his previous efforts with the Water Resources Registry (WRR). He identified that land cover/ land use (LCLU) data can work to a degree. There is also promise in the FACET data based on LiDAR topographic measurements. He believes we can obtain width, depth, and floodplain width, and make a model of floodplain connectivity from that, which is the key parameter. FACET provides information on reaches, which should information if not points. Nagel and Starr emphasized the need for the very best LiDAR data, especially for the smallest streams. Roth described that Tetra Tech used the latest 1-meter LCLU to compile catchment metrics for Maryland Healthy Watersheds Assessment.

Other folks to talk to include Kelly Maloney, and Matt Cashman of USGS. Maloney tried this exercise with fish and Cashman help ICPRB QA their work.

Jepsen provided data and narrative from 2017 report by Zach Smith et al. (see below).

2017 report: ChessieBIBI_Report_Final_5-25-2017.pdf (potomacriver.org)

- Data hosted by CBP: Archive (chesapeakebay.net)
  - **1986-2017 NTBEN Source Files/** has biological counts, water quality data, habitat data, and field data (information about sampling events incl. monitoring program, site name, sample type).

- - The rest of the folders are primarily related to the Chessie BIBI scores, taxa, etc. Feel free to look around in these folders but the folder that'll be most useful is the 'Source Files' mentioned above.
  - The attached Excel spreadsheet (NTBEN_Field Names and Descriptions_13may21.xlsx) is the key for the other NTBEN data files where field codes are explained.

2.   Matt Baker UMBC Meeting

21Sep2022

Mark Southerland
Nancy Roth
Paige Hobaugh
Rich Starr
Matt Baker, UMBC

Baker was contracted to produce a new stream map for EPA Region 3 using latest Digital Elevation Maps (DEMs). The geomorphology information from the maps can help describe the hydraulic regime and inform flooding. Maps have potential to produce useful metrics and indices.

Baker along with Starr advised the WRR stream stability index project with EPA and MES, but it is uncertain how much of their recommendations were incorporated. They also provided modeling to MES to test the GIS results. We will meet Theresa Foye of MES on 21Sep2022 to determine current status of that project. There are also recordings of the discussions Baker and Starr had with MES that will be useful in reconstructing recommendations for our GIT project. Rich suggested listening to the last two recordings.

Baker said it is important to (1) understand the typical field measures that are collected by geomorphologists and (2) recognize that these measures are not the best endpoints in themselves, but only indicators of processes of interest. The GIS measures are not directly comparable to the field measures. DEMs have more terrain information than field measurements can obtain. There is more promise in relative measures, i.e., departure from expectations such as regional curves. Starr would use regional curves to identify depth and width based on the drainage area with the goal of determining floodplain connectivity.

FACET uses LiDAR data to summarize cross section data for segments of interest. Baker said that what is needed is how to translate this information to what we understand in the field.

Baker described his SMAUG map project as "stream line work" with DEMs in each of 75 HUC-8 watersheds in Chesapeake Bay watershed. The map includes channel features such as height of bank above bottom and slope. Theses 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 be "how anomalous is the bank height for the catchment," and whether it is narrowing or widening going downstream. Also, the more variable the sinuosity, the more likely the reach is not anthropogenic. SMAUG has an algorithm to connect across bridges and roads called connector length. This allows an estimate of how much of the stream is buried/daylighted.

Starr stated that the key parameters are bankfull height, drainage area, regional curve depth to determine floodplain connectivity as a performance standard. Incision is the height to flood outside of the channel and entrenchment is how far the flood expands (divide the width at the flood prone elevation by the width at bankfull elevation to determine the Entrenchment Ratio). Lateral stability is also important and best shown by the lack of vegetation on the stream banks, i.e., LULC metric (note that Tetra Tech has been using the new 1-meter LULC of the CBP for other projects).

As we work to develop proxy versions of these parameters in GIS, there needs to be validation with empirical evidence. Southerland described how the recently completed Maryland Healthy Watersheds Assessment (MD HWA) used MBSS biological data (fish and benthic IBIs) to indicate feature importance of metrics (including LULC, hydrology, and geomorphology). Starr has local case studies that could be used to validate the proxy metrics for this GIT project.

Baker stressed the importance of using GIS data as contextual indicators, not just cross sections. As an example, observations in suburban areas of the Piedmont show that when streams daylight they produce a large gully and then shallow out. This can be measured as a pattern of bank height change with downstream distance. This is a way of discovering anomalies that indicate hydraulic and geomorphic change. Starr asked how SMAUG differentiates top of bank from true bankfull is the channel is incised and Baker said that this error should be discoverable as a residual in regressions.

The 1-meter DEM and the 1-meter LULC can provide this context. SMAUG maps water with LULC because surface is problematic in DEM. Where roads intersect streams, there are likely culverts that produce ghost streams that end in head cuts and seepage downstream. LULC can help identify straight DEM channels as ditches in agriculture, ditches along roads, and gullies where there is slope. Maps of buried channels have matched well with sites of flooding.

SMAUG can connect the HUC 10 watershed maps but has not done so for all of the Bay watershed yet. It can determine stream order which differ from other maps (2x the stream density of NHD). Special products of SMAUG include geolocation of headwaters in 40 subwatersheds by David Saavedra (former UMBC student now with Chesapeake Conservancy) and UMBC student working in Gunpower-Patapsco to compare 100 SMAUG cross sections (proportional to stream order) with (1) manual renderings from LiDAR and (2) field measurements. This will produce a new regional curve for the watershed, which is due in early spring.

Baker produced a report for CBT on the SMAUG project in 2018 that has since been refined, but no papers have been published yet. He is now doing similar pilots in different landscapes such as CA, AZ, and WA. Ultimately, he would like to have SMAUG stream maps meet USGS standards and be incorporated into NHD. There will be draft data release in October that we can use for the GIT project. It should be finalized in about a year. Baker is also working on datasets for USGS partners in Gunpowder, Rappahannock, Raystown, Juniata, and Choptank. Peter Claggett is interested in using the data to refine riparian modeling for Bay. There are many research questions Baker has yet to work on.

3.   **Maryland Environmental Service (MES) Meeting**

26Sep2022

Mark Southerland
Nancy Roth

Rich Starr
Theresa Foye, MES
Douglas Mace, MES

MES led the Stream Stability Index (SSI) project to project the SSI as a tool for the Water Resources Registry (WRR). Lot of work went into the project, including literature review, stream stability mind map (network of elements), data collection, metric testing, but a final SSI indicator for WRR was not achieved.

Foye provided the draft framework document (Stream Stability Methodology) with comments for our use. A white paper will be prepared for EPA Region 3 but that is a future activity. She will compile the other products of the SSI project and supply them for our use.

The work included comparison of GIS data metrics with results from field data and modeling of floodplain connectivity by Starr and Baker, which did not correlate well enough to recommend use. Starr indicated that his comments on the comparison document were important to review, as they included some corrections.

Foye said that her take home thoughts on the SSI project was the limitation of the data and data coverage, including apples to oranges methods in different geographies. Mace said that the literature review should be useful and Foye said the list of collaborators would be included, e.g., Marina Metes, Labeeb Ahmed, and Matt Baker.

4.   MWMC Stream Monitoring Subcommittee Meeting

29Sep2022

Mark Southerland
Nancy Roth
Bill Stack, CWP
Lisa Fraley-McNeal, CWP
Greg Noe, USGS
others

Greg Noe of USGS cited the recent NAWQA study on impervious surface effects that he will discuss in our Oct 4 meeting. It is getting a lot of use (e.g., Sadie Drescher) and link is below. Noe noted the specific relevant result of modeling of stream bed particle size.

Bill Stack and Lisa Fraley-McNeal of CWP mentioned and provided an impervious cover article and the LiDAR differencing report, plus a USGS NAWQA study that may be useful (see below).
USGS NAWQA Study - Effects of urban development on stream ecosystems in nine metropolitan study areas across the United States
https://www.usgs.gov/publications/effects-urban-development-stream-ecosystems-nine-metropolitan-study-areas-across

5.   USGS/CBP Meeting

4Oct2022

Mark Southerland
Nancy Roth
Paige Hobaugh
Rich Starr
Matt Baker, UMBC
Matt Cashman, USGS MD-DE-DC Water Science Center, Geomorphologist
Marina Metes, USGS MD-DE-DC Water Science Center, Physical Scientist
Greg Noe, USGS Florence Bascom Geoscience Center, Research Ecologist
Peter Claggett, CBP Research Geographer USGS
Labeeb Ahmed, CBP Geospatial Analyst, Attain
Renee Thompson, CBP Geographer USGS

Cashman offered that the European water community has perspectives we might consider; they use the term hydro-morphology, which captures both hydraulics and geomorphology that we are addressing. He described 3 USGS initiatives that are relevant:

1. Comparing FACET, which has been developed by Mariana Metes (former Baker student now physical scientist with USGSMD-DE-DC Water Science Center), Noe, Claggett, and Ahmed, to regional hydraulic curves
2. Created a database of multi-jurisdictional rapid habitat (EPA RBP style visual assessment) data that were collected with the Chessie BIBI effort. This database is available through CBP data hub (except MD which must be requested from DNR). Modeling similar to that done for the Chessie BIBI was done to standardize the data. They identified 12 metrics, plus two summary metrics through PCA analysis for bed and bank/riparian. They are starting now on trends analysis.
3. Signals of channel change in USGS gage data. One example was the Patapsco work with Baker. They have mostly identified longer term signals, but also some shorter term signals.

Starr stated that first initiative listed by Cashman on FACET was similar to the incomplete effort by MES for WRR. He characterized the second initiative with rapid habitat data as not an independent indicator but as converging line of evidence.

Ahmed said the FACET data is available for 85% of Chesapeake Bay watershed at 3 m resolution. Next year, they will have an update at 1 m that will also fix a few things in the first version.

Noe said that an additional measure in FACET that is of interest is bank angle. He has used FACET to calculate two things: (1) Lateral erosion rate and (2) Floodplain deposition rate (vertical cm/yr), providing flux/load of sediment for all Bay COMIDs. He also has D50 and proportion of sediment type metrics. Data is available and paper published.

Noe also described the Chesapeake Stream Team that is working to detect the effect of BMP implementation. They are measuring how geomorphology reacts to both disturbance and BMP occurring upstream. These are focused geographic efforts with the analysis done for Shenandoah and with others ongoing and planned (Baltimore Metro in 2024). They are looking at geomorphic, habitat,

and riparian metrics, but also thinking about new metrics that affect biology as being discussed in Europe, especially Scandinavia.

Metes is also using FACET to map headwaters and describe topographic openness.

Baker highlighted that these new GIS data are a "different animal" that traditional field measurements, so we should move beyond recreating those field metrics in GIS to make new comparisons.

Starr said that some of the rate of change metrics can be indicative of stability. Also, poor values for rapid habitat can indicate instability.

Claggett wants to investigate metrics as deviation from expected using factors such as drainage area and physiognomic setting. He mentioned Baker's hyper-res work being able to identify culverts with their associated problems. Starr said deviations in cross section data can be used to address stability. Noe cautions that "expected" is important to define, noting that some instability is part of a healthy dynamic stream system.

Noe also cautioned that we should not be too quick to "klug" together different data just because they are available. It is critical to determine what is important to stream health and how best to represent that, i.e., we need a theory of what matters to streams. Baker emphasized that Stream Team is doing some of this important work and will help connect our measurements to a mechanistic pathway.

Cashman cited some European initiatives that have followed the EU Water Framework Directive such as the Reform Project (REstoring rivers FOR effective catchment Management) that are investigating using GIS data at multiple scales. He also supports not only focusing on what geomorphic features we can change but more importantly what affects biology, e.g., just reducing sediment load is too simple. He also cautioned that biological data need to consider confounding factor of collections that are not proportional to existing habitat types, i.e., some protocols call for only sampling certain habitat types, so overall numbers do not reflect changes in habitat type extent.

Thompson emphasized the importance of also focusing on what is relevant to the CBP Stream Health outcome, i.e., answering questions by 2025 that can inform progress on the outcome. She also stated that she sees potential for helping CBP organize is LULC, natural resources, and other data in an effective way (noting that Tetra Tech has helpful experience with all these data).

Starr offered that idea that stream health indicators are about more than the "stream," i.e., about the health of "riverscape" or river corridor. Others seconded this idea with Cashman calling the lack of considering riparian and floodplain areas a huge hole. Starr added that USACE is changing their stream mitigation protocols to incorporate riparian areas more fully.

Claggett said it is really about the watershed, where the hyper-res work of Baker is revealing many potential surface connections that we didn't see before.

Attendees offered to join other meetings as needed to brainstorm further.

6. **Emily Gentry, EPA WRR**

18Jan2023

Gentry provided this list of EcoLibrary of general models for screening tools

- Nick Osbourn of USACE uses Freshwater Network
- Roth mentioned TNC aquatic barrier tool
- USGS National Water Dashboard
- StreamStats

Southerland suggested using these screening tools to identify confounding factors affecting our metrics or our test cases.

WRRs are state specific that traces catchment and includes Bay and federal tools. There are 8 WRRs: DE, MD, PA, VA, WV and SC. Most users are regulatory, permitting, and mitigation, especially in DE and MD. Provides power of GIS for lay person, e.g., watershed advocates.

MD WRR has 200 layers organized into topics. Has package for permit reviewers and produces screening report (WRR report). WRR produces suitability analyses for protection and restoration. Users often struggle with getting too granular.

SSI suffered from trying to downscale.

7. **Chris Ruck, Fairfax County**

24Jan2023

Riparian data in LULC does not include quality which is important to stream health. Recent papers report that presence of invasives results in poor stream biology. LiDAR can be used to determine vegetation age and density. Jurisdictions have inconsistent riparian vegetation data; Fairfax County Parks has mapping of vegetation quality. Perhaps new 1-m LULC has vegetation classes like herbaceous and shrub layers.

We agreed to ask Ann Hairston-Strang for current best way to get vegetation quality from remote data.

Starr explained how we will measure floodplain connectivity using DEMs with toe-to-top of bank at riffle for average depth and compare that to regional curve to produce entrenchment ratio. Ratio would be compared to Rosgen classification, not single threshold as WRR SSI originally attempted. Starr said the width-depth ratio itself does not equate to floodplain connectivity.

The next step would be comparison of these channel shape values with field and HEC-RAS results from sites. Starr has range of sites with varying catchment sizes (from 250 ac to 4-7 mi2), but this method may not work for "wee, tiny" streams. For those, soil erodibility and slope below a stable-unstable threshold may be the best possible assessment (e.g., 7 times greater confinement), using soils, slope, vegetation, and quantify control).

Ruck cautioned that regional curves developed with 30-m data may not be reliable at our finer scale since the pixels average LC values. Fairfax County has sub-foot accuracy for IC and it was off when applied to regional curve, e.g., from 1-2% to 10-15% IC and 1/4- to 2x size of channel. Ruck's sites are usually less than 300 ac.

Starr describe how rural and urban situations differ. It the combination of losing floodplain connectivity with high IC that creates the problem.

Another situation that affects stream degradation is the previous removal of vegetation that may not be visible now that it has grown back, but is resulting in unraveling and head cuts.

We decided to ask Tess Thompson for reference reaches but she said she did not have any.

We also discussed that before and after measurements would be ideal, but that our method will be based on one-time measurements (but we can recommend revisiting when multiple time periods are available).

Starr described how identifying well-defined pools and riffles in the desired ratios can be an indicator of stability as they act to dissipate energy. It might be possible to compare FACET pool/riffle values with Rapid Habitat data. Ruck said that Coastal Plain may be too flat for this metric. This would be another case where simple stable vs unstable assessment might work without a magnitude measure.

Ruck described how large dams in Fairfax County generally produce stable stream in the parks downstream. Starr has seen the same in his Piney Reservoir work in Sykesville because it only releases a certain size storm. We discussed how we would ultimately want evidence on how upstream BMPs have affected flow regime (with target of < 5% IC), but noted that the Healthy Watersheds project learned from Olivia Devereux that it was currently not feasible.

Ruck described his stream restoration projects where improvement has been limited by pH, DO, temperature. Starr has seen pH increased where limestone is brought in, but Ruck said his results are more of a trophic cascade where epiphytic algae from sun over the summer without shade increased pH to 9 on 57-ft-wide reach at Flat Lick, extirpating native minnows. It will be interesting over time to see if return of canopy and shade returns the minnows. Fairfax County foresters say that it will 50-60 years to return a 50-60 ft forest, if ever.

8.   Tess Thompson, Virginia Tech

25Jan2023

Thompson detailed her concept of stream stability as including bank erosion and large wood recruitment resulting in some normal migration rate and creation of overhanging banks. Bank retreat is not a problem as long as it is balanced with bank advance. The rate of migration can be too high and widening is a problem.

Thompson does not have quantitative measurements of the channels in her stream restoration study, only visual assessment of geomorphic stability. Overall, the variability in data plus co-linearity killed the stats, so results were better with indicators that were actually measured. She wants to get away from bankfull because it is subjective, especially when the stream in undergoing change. Also arguing against

using bankfull is the fact that teh LiDAR that GIS-based analyses rely on cannot reliably capture bankfull. Therefore, measures like top of bank that can be measured are preferred. Her best indicators were:

- LULC (especially percent change since construction)
- Width-depth ratio

Scaling streams on watershed size, stream order, or valley width may be helpful. High width-depth increases floodplain connectivity, though too wide results in sediment deposition. The trick is to determine what range of width-depth ratios are included in natural migration vs widening, so can be called stable.

Starr suggested that the appropriate rate of migration may be reflected in bedform diversity, i.e., well-formed pools and riffles.

Thompson's key variables are:

- Geology and climate (captured by regional curve)
- Vegetation
- Valley confinement
- Sediment supply

A higher supply = wider channel. The upstream area and connectivity with channel hillslope provide the source area for sediment. Streams with greater sediment supply (mountain headwaters vs valley headwaters) will recover faster.

Thompson suggested the concept of classifying streams based on regional curves and potential sediment supply. Starr described previous work that used erodibility of soil (from soil series), slope (soil series letter may give slope), and IC to develop stability threshold in Coastal Plain. Different thresholds would be needed in Highlands and Piedmont. His 150 sites in 4 large watersheds were correctly predicted 80% of the time. Thompson suggested using GIS to determine average hillslope in 100-ft buffer as indicator of sustained sediment supply.

Thompson favors a continuum rather than bins (Rosgen "lines"). Stats can tease out the thresholds from continuum if they exist. Valley confinement, valley slope and sediment supply can define this continuum and perhaps find classes within.

Thompson feels stability is a loaded word and prefers "departure from expected."

Thompson summary:

- Put each stream type in context before you evaluate it
- Scale any metrics on channel size

Related discussion on biological uplift being constrained in urban areas. Thompson provided paper that Sally Entrekin shared with her regarding the idea of using a biological condition gradient to monitor biological integrity. This is similar to work of Mike Paul in NC. Starr calls maximum ecological uplift the

"restoration potential." That's why restoration is based on objectives, which may be pollution reduction in Chesapeake but uplift in mitigation world of wetlands and streams.

THE BIOLOGICAL CONDITION GRADIENT: A DESCRIPTIVE MODEL FOR INTERPRETING CHANGE IN AQUATIC ECOSYSTEMS
SUSAN P. DAVIES1,3 AND SUSAN K. JACKSON2 1 Maine Department of Environmental Protection, State House Station 17, Augusta, Maine 04333 USA 2 United States Environmental Protection Agency, 1200 Pennsylvania Avenue, Washington, D.C. 20460 USA
Ecological Applications, 16(4), 2006, pp. 1251–1266

Starr wants to talk design with Thompson, who is working with wood now.

9.   **Joe Berg, Biohabitats**

3Feb2023

Berg recommended reviewing the upcoming U Georgia class for regulators (Brian Bledsoe) to facilitate USACE Engineering with Nature and efforts to change cost-benefit analyses. Focus of class is going beyond NCD designs to more wood use.

"NCD generally emphasizes stream geomorphology, which is necessary, but not sufficient on its own, to support healthy ecosystems and water quality. Moreover, novice NCD practitioners may design projects based on stream classification and reference reaches while failing to account for sediment transport processes, channel evolution, hydrologic alteration, or chemical stressors, potentially leading to poor project outcomes."

> National Association of Wetland Managers & EPA Region 4 Workshop Stream Design Toolbox: How to Implement an Ecological Approach for Reviewing Compensatory Mitigation Projects
>
> Instructors: Brian Bledsoe, PhD, PE; Holly Yaryan Hall, PhD, PE (University of Georgia)
> Dates: March 21-13, 2023
> Location: Georgia Wildlife Federation's Alcovy Conservation Center 11600 Hazelbrand Road Covington, GA 30014
> Holly Yaryan Hall, PhD, PE | Assistant Research Scientist
> College of Engineering | University of Georgia
> 3221 I-STEM Building | Athens, GA 30602
> Phone: (419) 289-8608 | Holly.YaryanHall@uga.edu

All concurred that stream restoration is moving from invert-top of bank to valley perspective, specifically whether the valley is confined or unconfined.

Berg is hyper-sensitive to old geomorph ideas of constant condition that misses complexity. Only 5% of storms are the larger streams with 95% first order.

He says, ultimately, the key factor is the energy delivered to the system and resultant peak discharge and time of concentration. Starr says it is the energy associated with the valley and floodplain.

Berg cited site differences even though we know degradation is problem of poor habitat and WQ associated with land development that creates more water, more quickly through simpler drainage.

Berg cited South River example with 2 projects where 2/3 forested watershed was worse than 1/3 forested because of the development pattern.

Southerland said a way to address unknown thresholds is evaluate on a continuum and use statistics to identify thresholds. Starr said we may have to develop different thresholds by physiographic region.

Starr highlighted that there is both natural and non-natural confinement, which determines whether there is enough floodplain area to eliminate scouring flows. Development encroachment may reduce a 500 ft floodplain to 100 ft. Use valley type to identify if valley was potentially unconfined before development.

Berg said it is also important to determine if the channel is positioned against the valley wall (toe of slope) rather in the middle. This is an indicator that DEM can determine.

Berg cited Zekiah Swamp as example of obstructed flow that results in better habitat. The more U-shaped for conveyance, typically the more degraded.

Starr also suggested as an indicator "whether the channel is straight when not typical in that valley type." This planform can be determined with DEM. Perhaps we can use valley type to predict stream pattern, i.e., if naturally confined we should expect straight channel and if unconfined it should be anastomosing.

Berg recommends prioritizing scour, i.e., response time for 90% of water to be delivered, which depends on development age. Effect is to homogenize riffle-pool pattern to push water through. This could be another indicator.

Streams may evolve post development (e.g., create benches) but still faces high energy, so while bank may be stable, there is no instream habitat. For example, 6" depth may have 1-2 ft/sec but 2-3 ft depth may have 10 ft/sec, which homogenizes the flow path.

We discussed the need to change the name "stream restoration" to "watershed restoration" or "RiverScape restoration" (coined by Utah speaker in Nashville).

SHA did not agree to upland wetlands because they don't receive adequate credit, something the CBP panel should address. Berg said the current panel credits are based on self-referenced data from NURP studies of 1960s, so new data should be used.

10.   Anne Hairston-Strang, Maryland DNR, Forest Service

13Feb2023

Southerland asked Hairston-Strang, "From your experience, what measures from the LULC 1-meter should we use and do you see any other data sets down the line that could do a better job of measuring forest quality (e.g., less invasives)? As you know, the trick if finding remote data across the whole Bay

watershed that matches well with what we see on the ground. Rich Starr has a number of sites with channel measurements but also vegetation that we will compare to the remote data values."

Hairston-Strang answered:

"The Hughes Center included the fragmentation metric- I don't have a feel for how well correlated the remote sensing metric is with field conditions, other than usually seeing more invasives on edges. I'm sure some of the areas close to edges are not invaded, probably depending on land use history and soil conditions.

The stream incision measure might have some good information. Several feet of incision could limit ability of bankside trees to provide bank stabilization, again could vary a lot depending on forest/soil types, landscape context.

There are expanding methods for drone-based remote sensing and seasonal detection that could pick up some common invaders, but it's not being routinely done and definitely not statewide.

The FIA ground plots with invasives is a good data source, but not spatially explicit (just to region of the state). EDDMaps and MAEDN can confirm presence where reports are confirmed, but it's not systematic."

11.   **Elliott Campbell, Maryland DNR**

3May2023

Campbell and DNR have been working on desktop hydromorphology with David Saavedra of the Chesapeake Conservancy. Originally, they attempted to use the new hyper-resolution stream layer developed by the Conservancy with Matt Baker of UMBC, but determined it was not ready for the intended analysis. The approach was to compare bank height values with predicted bank heights according to ecoregions, specifically, bankfull channel dimensions regional curves. Campbell said that the hyper-resolution hydrography did not work well in western Maryland or Piedmont. Therefore, they pivoted to FACET as the method for determining bank height, which appeared to produce more accurate results, though they were not systematically tested.

Starr stated that the top-of-bank (TOB) that can be measured from FACET is not the same measurement as regional curve depths. Regional curve depths are not associated with TOB. It is associated with the bankfull mean depth of the channel. So, FACET TOB measurements compared to regional curve depths are not appropriate. However, Starr stated that this approach does have the potential to predict floodplain connectivity.

The values produced were scored as quintiles on 1 to 5 scale for relative bank height compared to predictions by stream order. They used NHD because FACET needed that base layer and divided it into HUC 8s and stream order. This metric of bank height difference from predicted in part of the Maryland Stream Restoration Planning Tool was developed for Monitoring and Non-Tidal Assessment (MANTA, Scott Stranko) and Chesapeake and Coastal Service (CCS, Alison Santoro and Sara Weglin) at DNR. Other indicators include:

- Stream order
- Sinuosity
- Trout
- Coldwater-obligate benthic macroinvertebrates
- SSPRAs
- Stronghold watersheds
- BIBI
- FIBI

The Tool will be used to

- update the Green Infrastructure Network
- quantify co-benefits such as carbon, water quality for species, climate resilience (vulnerability to heat and flooding) as required by MGA for Trust Fund (a co-benefits report for Trust Fund projects is required)
- guide conservation and restoration

The Tool will be accessible on Maryland iMap and either GreenPrint or a new restoration web map.

We also discussed the importance of including unintended consequences in restoration planning, a topic Stranko has been emphasizing.

DNR has a second project with Jim Imhoff of Fisheries to identify development thresholds for individual fish species. Campbell forwarded the recent update of "Estimating Impervious Surface Coverage from High Resolution Land Cover Data and Property Tax Information" by Marek Topolski.

Starr mentioned that the EPA Water Resources Registry (WRR)) would be interested in this work and Campbell said that Rachel Marks represents DNR for WRR. Campbell feels that his Tool is a value add as an index of degradation not captured by WRR utility for identifying sensitive areas.

The group discussed the potential of relative metrics of bank height since direct matches of FACET measurements to field measurements are inaccurate. Starr said we are really looking for the floodplain connectivity (i.e., ratio of bank height/bankfull height) and posited that a closer match with predicted FACET bank heights to regional curve mean depths might indicate floodplain connection and a greater deviation in match might indicate floodplain disconnection.

Starr will compare his restoration sites and references to the DNR Tool. He recommended that Campbell should contact Maryland Stream Restoration Association (MSRA), which has many members with data that could be used to test the DNR Tool.

12. Matt Cashman, USGS

Southerland and Starr discussed the follow up analysis comparing FACET with field-measured restoration sites and developed the new report text below:

"Recognizing that the exact locations of the FACET cross sections often differed from the field measured cross sections, we conducted a second visual test of co-incident cross sections. Figure 6 shows six

selected cross section comparisons across a range of channel configurations and elevation changes. These co-incident, cross-section comparisons show a better match and merit further investigation at the next stage of the desktop stability tool. The biggest challenge of using FACET, however, is that FACET only measures the water elevation and not true bottom of the channel. This will present a problem for streams with water depths greater than a few tenths of a foot and on lower-order streams." Based on Maryland Stream Restoration Planning Tool described by Elliott Campbell, relative values of bank height ratios may be the best approach going forward. Using that approach may require converting the 1-5 scoring into 3 rating values (high, medium, low stability) and ensuring they are consistent across regions (Coastal Plain, Piedmont, Highlands).

Cashman lauded the inclusion of valley confinement, floodplain connectivity, and riparian vegetation as important factors for assessing hydromorphology. However, he interpreted our presentation of recommendations for further consideration of indicators as conflating sediment, geomorphology, and habitat. Specifically, he feels it is important that the focus on sediment impacts (implicit in the focus on erosion and stability) not overwhelm the separate effects that geomorphology and habitat have on the ecology of streams. His work with Fanelli et al. indicate that this broader view is needed to address the range of stressors affecting streams. He gave the example from Fairfax County, where a stream was stabilized but finer scale habitat for biota decreased.

He believes that some metrics currently listed under the Geomorphic Unit (Pyramid level 3) be moved to the Reach Unit (Pyramid levels 2 & 3), such as channel dimension and stream energy. He recommends incorporating metrics from his rapid habitat assessment work, such as sediment size, into the Geomorphic Unit. The group recognized that metrics at this scale are not available from remotely sensed data and therefore would require modeling of field measurements, in the way that Chessie BIBI is modeled for complete Bay watershed coverage.

We agreed to restructure the matrix of recommended metrics/data for hydromorphology indicator development to better capture the Geomorphic Unit and Hydraulic Unit (from REFORM) scales. Specifically, we will move some of the metrics currently under Geomorphic Unit (e.g., channel dimension, stream energy) up to Reach scale. Cashman's work with rapid habitat data will be recommended to fill this gap at the finer scales. His work has identified two groups of metrics that cluster into (1) stability (e.g., bank stability, bank vegetation, riparian condition score, sediment deposition) and (2) habitat (e.g., embeddedness, riffle frequency, velocity/depth combination). Claire Buchanan at ICPRB has found similar clusters as she investigates what influences the Chessie BIBI.

Southerland said that he would structure the report to be comprehensive of hydromorphology related to stream health, even where remote metrics are unattainable. As with Chessie BIBI, modeling is limited by the landscape layers available, but newer layers can be expected over time. One example is the Riparian Condition Assessment (RCA) Tool in western US:

What are the Conditions of Riparian Ecosystems? Identifying Impaired Floodplain Ecosystems across the Western U.S. Using the Riparian Condition Assessment (RCA) Tool
William W. Macfarlane, Jordan T. Gilbert, Joshua D. Gilbert, William C. Saunders, Nate Hough-Snee, Chalese Hafen, Joseph M. Wheaton & Stephen N. Bennett
Environmental Management
Published: 11 May 2018
https://link.springer.com/article/10.1007/s00267-018-1061-2

13.   Stream Health Work Group

Krissy Hopkins provided a summary of how USGS (Hopkins, Greg Noe, Peter Claggett, Labeeb Ahmed, and Marina Metes) believe FACET can contribute to developing two of the refined stream health metrics identified by the Tetra Tech and EPR team for GIT #12 project (highlighted below):

- Valley type/confinement
- **Floodplain connectivity**
- Riparian vegetation
- Bedform diversity/stability
- **Lateral stability**

Specifically, USGS is looking to:

- Use FACET floodplain width and channel width to develop a proxy for entrenchment ratio to reflect floodplain connectivity
- Map inundation extent under different recurrence intervals (beyond current 2 year interval to include 10, 20, etc. year intervals) to inform our understanding of the frequency of floodplain inundation
- Use FACET channel width and channel depth to develop a proxy for width to depth ratio to reflect incision and stability
- Develop index of channel alteration based on departure from expected channel width from regional curves to reflect stream channel modification

Chris Spaur of USACE asked if Flood Risk Management (FRM) structures can be included. A substantial number exist in lower Anacostia.

Alana Hartman of WVDEP stated that true incision needs bankfull, which is not available from FACET. Metes is doing landscape openness work that may help by characterizing the curvature of the landscape. Nancy Roth of Tetra Tech asked if entrenchment ratio was available and Hopkins said not now (therefore the reason they are using a proxy), but hope to calculate it in the future. Matt Cashman of USGS said the regression curve approach was being used because the depth of the water is not available in FACET, but its role is less in smaller streams. Pairing FACET with USGS gages can give depth of water and discharge that results in flooding of roads etc.

Denise Clearwater of MDE said a better indicator of flashiness would be valuable and Claire Buchanan of ICPRB emphasized its importance to biota.

Renee Thompson of CBP said that Noe's statistical models capture "embeddedness." Cashman said that he is planning on incorporating these FACET metrics into future habitat hydromorphology predictive models of rapid habitat assessment data, including embeddedness.

FACET data can be accessed at:
https://www.sciencebase.gov/catalog/item/5cae39c3e4b0c3b00654cf57

Geomorphometry for Streams and Floodplains in the Chesapeake and Delaware Watersheds was generated as part of the project Quantifying Floodplain Ecological Processes and Ecosystem Services and

is available in Web map viewer to explore FACET data used for ecosystem services: https://www2.usgs.gov/water/southatlantic/projects/floodplains/

Kelly Maloney of USGS summarized the status and trends work being done as regional assessments (typically 2001 to 2019) of the following topics (hydromorphology highlighted below):

- Aquatic communities (benthic macroinvertebrates and fish)
- **Physical habitat and geomorphology (using Cashman's summary channel and bank/riparian metrics)**
- Flow and ecological flows
- Water temperature
- Conductivity

Spaur asked if USGS was incorporating legacy effects, such as the significant pollutions reductions post Clean Water Act (1970), including acid mine drainage. Buchanan also asked about accounting for reforestation over time. At present, USGS does not have a good way to incorporate legacy effects but EPA does have a database of 303d listings at "How is My Waterway?"

Scott Stranko of Maryland DNR raised the concern that modeling of these parameters to fill gaps in sampling is largely based on LULC, which may be missing other stressors. Cashman agreed but said that validation was being done with 100% field data.

Appendix B: Data Sources for Hydromorphology Indicators

Data Source	Year Published	Agency or Organization	Contact/Author Name(s)	Data Link	Data/Tool Type	Scale	Inputs	Outputs	Parameter(s)	Summary Notes
Model My Watershed	2022 (online)	Stroud Water Research Center	https://wikiwatershed.org/model/	Model My Watershed	Wikiwatershed web-based application/model; two models for users to choose from, python tools available as open source	HUC8, HUC12, HUC12	NLCD land cover, 30-meter elevation data, estimates of soil P concentration, and NHD stream data from USGS; GSSURGO soil and county-level farm animal data from USDA; point source data, groundwater estimates of nitrogen concentration; 30 years of daily weather data from USEPA; estimates of soil N concentration from Oak Ridge National lab	Estimates of nutrient and sediment loads on a daily, monthly, annual, mean monthly, and mean annual basis, including erosion and sediment yield; estimates of surface and subsurface runoff/flows; and estimates of surface and subsurface nutrient losses. Load output is given for each source, including upland sources (e.g., urban land, agricultural land, forests, animal populations, etc.), point sources, and streambank sources. In the latter case, a streambank erosion routine is used to estimate nutrient and sediment loads from the stream banks via an estimated lateral erosion rate across the stream network.		This is a planning-level model on watershed but not reach scale. The GWLF-E model indirectly considers stream stability in that it includes a streambank erosion routine that varies streambank-eroded loads based on various watershed-related factors such as land slope, inherent soil erodibility, grazing animal density, curve number, and percent developed land. Already run at the national scale. Uses 2011 Land Cover now, but the MMW team is updating it to 2016. API available. Limitations as it relates to Stream Stability Index: primarily designed for sediment and nutrients loads with the goal of reducing those. It could however be useful if higher loads suggest instability or if other metrics are generated. Currently, t the lateral erosion rate that is calculated based on the above five factors is applied uniformly across the entire watershed being analyzed. However, the streambank erosion routine could be modified to calculate/estimate different lateral erosion rates for different stream reaches based on varying stream bank heights or other similar factors
StreamCAT (Stream-Catchment)	2020 (Current version)	USEPA		[https://www.bing.com/search?q=streamcat&cvid=1d5d7fff403a4d24a37bcde417dd0d69&aqs=edge..69i57j0l8j69i11004.1440j0j4&FORM=ANAB01&PC=U531](url)	Web tools and GIS data	National; most metrics calculated for individual catchments and for cumulative upstream watersheds	Climate data (precipitation and temperature), mean monthly, AN81m (1961-1990); National Land Cover Database (NLCD) 2001, 2006, 2011, 2016; NPDES source location and discharge, EPA; Soils (STATSGO); US Census Population and housing density 2010; US Census Tiger Lines 2010; Mines; Lithology; pesticides use (1997 datum); National Atmospheric Deposition Program; National Inventory of Dams, USACE; National Aquatic Resource Surveys (NARS)	595 metrics, consisting of 274 local catchment (Cat), 274 watershed (Ws), and 47 special metrics; see table in this database	Includes drainage area to downstream end of reach; pollutant load; erosion rate, lateral; riparian vegetation presence or absence	Multiple datasets that currently (Aug. 2020) contain 595 landscape metrics for 2.6 million streams and associated catchments within the conterminous U.S. Most metrics are calculated for individual catchments and for cumulative upstream watersheds.

Rapid Habitat Data (submitted with Chessie BIBI data)	2017	ICPRB, USGS	Andrea Nagel, Zachary Smith, Claire Buchanan, Matt Cashman	Data: Archive (chesapeakebay.net) Report: https://www.potomacriver.org/wp-content/uploads/2017/05/ChessieBIBI_Report_Final_5-25-2017.pdf	CSV dataset of site measurements	Region, bioregion, sites	Parameter measurements at sites	Narrative ratings applied to index scores; 12 individual visual habitat metrics (plus FLOW) and 2 composite metrics were identified from larger set of parameters provided by jurisdictions	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)	Data were collected using different methods, but 12 visual rapid habitat metrics and 2 PCA-derived summary metrics (representing bed and bank/riparian elements) were developed and are listed in parameters column along with FLOW.
Floodplain and Channel Evaluation Tool (FACET)	2019	USGS	Kristina Hopkins, Marina Metes, Labeeb Ahmed, Gregory Noe, Peter Claggett	https://www.usgs.gov/software/floodplain-and-channel-evaluation-tool-facet-0	Python tool producing shapefiles and rasters of stream network, cross sections, streambank point locations, floodplain extent, reach-scale summaries of geomorphometry metrics	Stream reach	3-meter DEMs run through the FACET v0.1.0. tool, high resolution NHD, U.S. Census Tiger line files (roads and rails). A 1-meter DEM is expected in 2023 that can be used to redevelop FACET.	Floodplain extent maps and reach-scale summaries of stream and floodplain geomorphic measurements. FACET allows the user to hydrologically condition the DEM, generate the 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.	Streambank lateral erosion Streambank change (M2) Streambank sediment flux (incorporates bank height, lateral erosion, bulk density) Streambed D50 Streambed fine sediment cover Streambed fine sediment and sand cover	Uses open-source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). A new DEM is being developed at 1-meter resolution that is expected to be available summer of 2023. FACET can be revised using this 1-meter DEM.

Land Use Land Cover (LULC) for Chesapeake Bay Watershed	2022	USGS, Chesapeake Conservancy, Chesapeake Bay Program, University of Vermont	Peter Claggett	https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/	Mapping tool	NHDPlus v2 catchment	LiDAR, NAIP aerial imagery	1-meter resolution land cover data	Land Use/Land Cover Classifications: Water, Impervious Roads, Tree Canopy over Impervious Surfaces, Tree Canopy over Turf Grass, Turf Grass, Previously Developed, Harvested Forest, Extractive, Forest, Tree Canopy, Other, Natural Succession, Riverine Wetlands, Non-forested, Terrene Wetlands, Non-forested, Cropland, Pasture/Hay, Tidal Wetlands, Non-forested	The production of the CBP 1-meter "land cover" data involves the identification and classification of image objects derived from aerial imagery (National Agriculture Imagery Program, NAIP), above-ground height information derived from LiDAR, and other ancillary data. Land Use/Land Cover Classifications - https://cicwebresources.blob.core.windows.net/docs/General%20LULC%20Class%20Description.pdf
Chesapeake Bay Healthy Watersheds Assessment	2020	Prepared for USEPA by Tetra Tech	Nancy Roth, Brian Pickard, Christopher Wharton, Sam Sarkar, Ann Roseberry Lincoln, Mark Southerland	Web-tool: https://gis.chesapeakebay.net/healthywatersheds/assessment/ Report: https://d18lev1ok5leia.cloudfront.net/chesapeakebay/chesapeake_healthy_watersheds_assessment_report.pdf	Web tool	Chesapeake Bay Watershed; catchment	NHDPlus data, various Chesapeake Bay watershed-wide/regional metrics that fall under the categories of landscape condition, hydrology, geomorphology, habitat, biological condition, water quality, land use change, water use, wildlife risk, climate change.	Final recommended suite of metrics for assessing watershed health; web-tool that maps watershed health metric scores by catchment per the model/index of watershed health	See report (https://d18lev1ok5leia.cloudfront.net/chesapeakebay/chesapeake_healthy_watersheds_assessment_report.pdf) for parameters/metrics used in indicator development	Metrics characterizing multiple aspects of landscape condition, hydrology, geomorphology, habitat, biological condition, and water quality were combined into sub-indices and an overall Watershed Health index, providing critical information for maintaining watershed health. A Maryland Healthy Watershed Assessment was completed by Tetra Tech in 2022 that included new data layers and analysis to inform this project.

Name	Year	Organization	Authors	Citation/Links	Data format	Spatial unit	Data description	Designations	Measurements	Purpose
Chesapeake and Delaware Floodplain Network (CDFN)	2020	USGS	G.B. Noe, C.R. Hupp, E.R. Schenk, T.R. Doody, K.G. Hopkins	Noe, G.B., Hupp, C.R., Schenk, E.R., Doody, T.R., and Hopkins, K.G., 2020, Physico-chemical characteristics and sediment and nutrient fluxes of floodplains, streambanks, and streambeds in the Chesapeake Bay and Delaware River watersheds: U.S. Geological Survey data release, https://doi.org/10.5066/P9QLJYPX.	CSV dataset of site means, metadata, map of field area			Calculated averages sediment fluxes, fine sediment, sediment-C, sediment-N, sediment-C of floodplains and of stream banks at each site	Dataset includes site averages of measurements of: 1) floodplain and streambank sediment physico-chemistry, including concentrations of nitrogen, phosphorus, carbon, organic matter, carbonate, and particle size and sediment bulk density 2) floodplain and streambank long-term vertical and lateral geomorphic change 3) floodplain width, streambank height, channel width, and streambed particle size 4) floodplain and streambank long-term fluxes of sediment, fine sediment, sediment-C, sediment-N, and sediment-P	USGS established CDFN to provide improved information on the chemical and physical characteristics of stream and associated floodplains; 68 sites were sampled to measure fluxes of sediment and nutrients for floodplains and streambanks, and stream reach geomorphometry and streambed characteristics, of the mid-Atlantic. FACET was used to remotely map stream and floodplain geomorphic characteristics.
Eastern Brook Trout Conservation Portfolio	2017	Trout Unlimited, Eastern Brook Trout Joint Venture	K.A. Fresenmyer, A.L. Haak, S.M. Rummel, M. Mayfield, S.I. McFall, J.E. Williams	Report: https://easternbrooktrout.org/science-data/brook-trout-conservation-decision-support-tools/eastern-brook-trout-conservation-portfolio-range-wide-assessment-and-focal-area-tools/eastern-brook-trout-conservation-portfolio-range-wide-habitat-integrity-and-future-security-assessment-and-focal-area-risk-and-opportunity-analysis/view Web-tool: https://www.arcgis.com/apps/webappviewer/index.html?id=f70da52f45304ab8be440885d32d3866	Web-based mapping tool	EBT Patch, HUC12	Eastern Brook Trout Joint Venture patch characteristics, stream habitat classification data, and models of stream temperature and EBT probability of occurrence

Representation - presence of genetically unaltered populations, presence of all life histories that were historically present, presence of peripheral populations
Resiliency - large brook trout-only populations
Redundancy - Large brook trout-only populations, moderately sized brook trout-only populations with high habitat suitability, small brook-trout only populations with high habitat suitability | Designations for HUC12s: resilient, redundant, unique life history, other populations, re-establish EBT | | Applies the 3-R framework (Resiliency, Redundancy, and Representation) to evaluate each EBT population patch for its resiliency to disturbances, likelihood of demographic persistence, and representation of genetic, life history, and geographic diversity. |

Stream Stability Index	Not yet released	MES, USEPA, Mid-Atlantic Stream Stability Advisory Committee	Theresa Foye, Douglas Mace	Not yet released	Index, GIS dataset		FACET and Regional Curves Approach: FACET tool channel geometric metrics, DEMs, regional curve equation	Comparison of stream segments to one another instead of generating an absolute score for each segment.	Parameters/indicators of stream stability will be selected with an eye toward: 1) which measures best predict that a stream is stable or unstable; 2) which measures can be readily obtained for GIS analysis; 3) which measures are most appropriate to help guide preservation and restoration activities?; 4) temporal; 5) comparative analysis; 6) most stable or least stable; 7) temporal limitations of our tools; 8) condition vs. stability, 9) recovery trends from watershed development Example indicators/parameters: Lateral Stability (riparian vegetation, erosion potential, slope, soil conditions), Vertical Stability (slope, headcuts, geomorphic characteristics, floodplain extent, floodplain connectivity, HAND measurements), Channel Evolution--temporal (development change, watershed development, anthropogenic features), Overall Channel Stability (slope, riparian vegetation, soil conditions, percent impervious, recent development, adjacent land use) From 10/31/22 Draft SSI Methodology - FACET and Regional Curves Approach: Bank height ratio, floodplain area ration, stream power	Will be used to target stream restoration and preservation activities in the mid-Atlantic region. SSI itself will subsequently be used as a key GIS dataset for a stream restoration analysis and a stream preservation analysis.

Name	Version	Organization	Contact	Link	Description	Scalability/Extent	Inputs	Outputs	Application/Reference	Notes/Limitations
Hyper-Resolution Terrain-Based Hydrography	Not yet released	Chesapeake Conservancy, University of Maryland Baltimore County (UMBC)	Matt Baker	Not yet released	Methodology for creating a hyper-resolution terrain-based hydrography	Scalable; can be applied wherever adequate LiDAR coverage exists	LiDAR DEMs, high resolution NHD, high resolution land cover (optional)	Stream and channel rasters, bank height rasters, channel width rasters, valley network rasters, intermediate geomorphic rasters including additional outputs beyond the ten most common landforms, connected stream polyline network. Final list of attributes for line network not yet decided.	Stream channel	Much more accurate and precise than NHD; channel width and depth directly detected from DEM. Single input (DEM) but generates many physical qualities for each stream. Limitations as it relates to Stream Stability Index: Not yet run for entire R3 states. Novel method presents unique challenge of distinguishing which 'channel-like features' belong in the stream network versus those that don't (i.e. ditches, gullies, swales, etc.). Floodplains might not be explicitly mapped, though valley networks may be a useful surrogate.
Gridded Soil Survey Geographic Database (gSSURGO)	2022 (Current version)	USDA/NRCS; developed by the National Cooperative Soil Survey (NCSS)	Soils Hotline (soilshotline@usda.gov)	Gridded Soil Survey Geographic Database (gSSURGO)	Ag Data Commons (usda.gov)	Tabular dataset of soil geographic data, map data (spatial)	United States: Extent of SSURGO datasets are soil survey areas which may consist of a single county, multiple counties, or parts of multiple counties.	10-meter cells (raster map)	Map units contain information about component soils and their properties; each map unit may contain one to three major components and some minor components. Information available from the database includes available water capacity, soil reaction, electrical conductivity, frequency of flooding; yields for cropland, woodland, rangeland, and pastureland; and limitations affecting recreational development, building site development.	Information about tabular data domains can be found here (https://www.nrcs.usda.gov/sites/default/files/2022-08/SSURGO-Metadata-Domains-Report.pdf)	The gSSURGO database contains detailed information about soil as collected by the NCSS over the course of a century. 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 (value) table containing "ready to map" attributes. The gridded map layer is offered in an ArcGIS file geodatabase raster format.