Multi-Scale Watershed Assessment

Appendix A. Memphis Metropolitan Stormwater – North DeSoto County Feasibility Study

User Guide: DeSoto County, Mississippi

Memphis District
Engineer Research and Development Center

US Army Corps of Engineers®

Acknowledgments

The application of the Multi-Scale Watershed Assessment (MSWA) using the Stream Condition Index (SCI) model was a multidisciplinary and multiagency effort which included numerous coordinated meetings and field work by the Project Delivery Team (PDT) listed below. Photographs on cover page by Bruce Pruitt.

Regular conference calls, which facilitated the development of this User Guide, were held from July 2020 through April 2021 to discuss, in part, data acquisition, reduction, analysis, and interpretation related to the formulation of the SCI model. The SCI is the focus of this User Guide including the companion spreadsheet calculator. Andrea Carpenter-Crowther (Biologist, Memphis District) assisted Drs. Bruce Pruitt, Todd Slack and Jack Killgore (Fish and Invertebrate Ecology Team (FIET)) of the Engineering Research and Development Center (ERDC) in model formulation, verification, and application.

Caveats

As used herein, ecological models (SCI) are algorithms which are empirical equations that express a relationship or correlation based solely on observation rather than theory. An empirical equation is simply a mathematical statement of one or more correlations in the form of an equation. In this case, the correlations were observed to be positive (direct). In turn, the variables were observed to be dependent or independent with respect to each other. The observed interaction between variables occurs when the simultaneous influence of two measures on a model score is not additive. "Interaction" is analogous to dependence where a variable has a statistically significant influence on other variables.

This User Guide was developed as part of the North DeSoto County watershed assessment under the 1996 Memphis Metro Authority. The watershed assessment was undertaken by the USACE Memphis District and the Engineer Research and Development Center (ERDC). The SCI described herein was field verified and validated. Verification is defined as the field testing and initial refinement of model variables. Validation is defined as checking or proving the refined variables are usable in different watersheds not part of the initial assessment. Consequently, validation confirms the application of the model variables within the study area.

Appropriate Citation

B.A. Pruitt, K.J. Killgore, W.T. Slack, and Andrea Carpenter-Crowther. 2021. Multi-Scale Watershed Assessment User Guide for North DeSoto County, Mississippi, Engineer Research and Development Center. *In support of* the North DeSoto County Environmental Impact Statement, U.S. Army Corps of Engineers, Memphis District.

Table of Contents

List of Tables

List of Figures

Background

This User Guide was developed by the USACE Engineer Research and Development Center (ERDC) as an integral part of the Draft Integrated Feasibility Report (IFR) and Environmental Impact Statement (DEIS) developed by the Mississippi River Valley Division, Regional Planning and Environmental Division South (RPEDS) for the North DeSoto Feasibility Study, DeSoto County, Mississippi. The study area included the Horn Lake Creek, Hurricane Creek, Johnson Creek, and Coldwater River watersheds including the cities of Horn Lake, Southaven, Olive Branch, Walls, and Hernando located in northern DeSoto County, Mississippi (hereinafter, referred to as "DeSoto study"). The primary problem identified in the study area is the risk of flood damages in numerous watersheds lying within the Horn Lake Creek and Coldwater River basins. Because of the high flood risk and flashy conditions, stream channels are highly eroded and, in many cases, exhibit steep banks with little to no protection. Consequently, aquatic habitat and biodiversity have been compromised.

This User Guide was developed to provide detailed variable descriptions for the practitioner to score and rank stream conditions at a range of scales from the stream segment scale to the watershed scale. The purpose of this User Guide is to provide detailed guidance on using a visual stream condition assessment called, the Stream Condition Index (SCI). Paramount to assessment of the DeSoto County watersheds across various degrees of ecological impairment at different scales, the SCI was formulated, verified, and validated at 65 unique stream reaches across 12 watersheds. The SCI was used to identify a gradient of stream conditions including attainable reference conditions at multiple scales, describe the major water resources problems and opportunities in the region, calculate Annual Average Habitat Units (AAHU), as part of the Habitat Evaluation Procedure (USFWS 1980), and recommend a strategic course of action for achieving the desired conditions in the study area.

The DeSoto study is a modification of the watershed assessment certified for use in the Duck River basin located south of Nashville, TN (Pruitt et al. 2020). The Duck River watershed assessment represented a new method of assessing ecosystems using multi-attributes across multi-scales, called the "Multi-Scale Watershed Approach (MSWA). The concept behind the MSWA was to establish a means of utilizing readily available data to create an overall knowledge base collected by multiple agencies and stakeholders. The outcome of MSWA can become the principle component of the decision-making process such that water resource managers have the ability to make scientifically defensible decisions not only at

project specific scales, but also beyond the footprint of the project to the entire watershed. From the watershed perspective, the cause and effect relationships between land use, water quality and quantity, in-channel and riparian conditions, and biotic responses culminate at a single outlet from the watershed and are representative of the ecological condition of the watershed. In addition, assessment at the watershed scale offers advance planning including design, construction, operation, maintenance, repair, replacement and restoration of aquatic ecosystems. This User Guide has immediate utilization including: 1) watershed prioritization; 2) trend analysis; 3) identification of reference attainable conditions; 4) statistical extrapolation and comparison of reference conditions across watersheds; and 5) monitor ecosystem outcomes or ecological lift (i.e., restoration success) including ecological benefits of channel stabilization measures. The results of the SCI can be used in future watershed assessments and associated environmental planning in DeSoto County and throughout the ecoregion.

Multi-Disciplinary Team

In August 2020, MVM requested ERDC to conduct a study on selected streams ("Targeted Streams") in DeSoto County, Mississippi. Problems, opportunities, goals and objectives were discussed during a series of conference calls which were documented in minutes and distributed to the Project Delivery Team (PDT). The PDT membership included:

Scientist / Role	Discipline	Affiliation
Elizabeth Burks, Project Manager	Civil Engineer	MVM
Andrea Carpenter-Crowther, MVM POC	Biologist	MVM
Cherie Price, Supervisor	Civil Engineer	MVM
Mike Thorn, Review	Biologist	MVM
Evan Stewart, Review	Economist	MVM
Jon Korneliussen, Review	Civil Engineer	MVM
Zack Tieman, Land Cover Mapping	GIS Specialist	MVM
Cori Holloway, Land Cover Mapping	GIS Specialist	MVM
Edward Lambert, Chief	Biologist	MVM
Donald Davenport, Review	Hydraulic Engineer	MVM
Todd Slack, ERDC POC, Author	Fish Ecologist	ERDC-EEA
Bruce Pruitt, Senior Author, Tech. Rpt.	Watershed Hydrologist	ERDC-EEA
Jack Killgore, Author	Fish Ecologist	ERDC-EEA
Chris Haring	Geomorphologist	ERDC-CHL
David Biedenharn	Hydraulic Engineer	ERDC-CHL

The project sponsor is the DeSoto County Government. Stakeholders include municipalities, residents and businesses in DeSoto County to include but not limited

to the cities of Olive Branch, Hernando, and Southaven. Since July 2020, regularly scheduled semi-monthly conference calls have been organized and attended by the PDT including ERDC scientists. Consequently, the process of data acquisition, reduction, analysis, and interpretation has been well vetted by the PDT leading to the formulation and testing of the SCI which is the subject of this User Guide.

Geographic Region and Scale

This User Guide was developed for the application of the MSWA protocol. It was designed to be applied consistently and rapidly, yet maintain precision and reproducibility across assessment areas and between practitioners possessing a fundamental understanding of hydrological, geomorphic, and ecological processes. The assessment protocol is based primarily on physical and biological attributes of stream corridors including aquatic habitat, riparian zone, and watershed/valley conditions. It is intended to be applied at multiple scales using satellite imagery (GIS), low altitude photogrammetry (if available), surface assessments (boots-on-the-ground) or in combination.

The MSWA User Guide provides a means of systematic assessment of relevant aspects of stream and riparian zone conditions with respect to geophysical and biological attributes, assuring that all important factors are consistent and reproducible among users. Because of its utility, ease-of-use and application across several scales, the MSWA using satellite imagery, LiDAR, and low altitude, high resolution photogrammetry (if available) provides the following advantages:

1. At watershed and stream segment scales, it provides a rapid and reproducible method of covering more area expeditiously.
2. Acquiring private property access is not usually required.
3. Planform geometry (meander wavelength, radius-of-curvature, and amplitude) is easily elucidated and measured using photogrammetry especially on large rivers.
4. Watershed-scale models (SCI) can be tested, refined and finalized by re-visiting the historic and current photogrammetry several times without the need for additional fieldwork.
5. Land use/cover and relative riparian zone condition is more obtainable.
6. Identification of sources of pollutants and sources of accelerated sediment is easily elucidated.
7. Identification of attainable reference conditions, by establishing the reference domain of all stream segments, is more easily achieved.
8. At the valley flat scale, photogrammetry assessments facilitate the potential of re-coupling adjacent wetlands to the frequent flood event.
9. The upstream and downstream effects of dams (fish barriers) can be visualized better.

10. Based on historic and contemporary satellite imagery, trend analysis can be conducted at watershed and stream segment scales including monitoring natural and anthropogenic changes, catastrophic events, and effects of climate change on stream hydrology and geomorphology.

Initially, the SCI was formulated and certified by ECO-PCX for the Duck Watershed, Tennessee (Pruitt et al. 2020). Consequently, that certified model and associated variables were tested and refined for use in the DeSoto study.

User Guide Purpose

The MSWA User Guide was developed as a companion to the Excel ™ spreadsheet used to calculate the SCI and subsequent Habitat Units. The MSWA is meant to be a rapid, uncomplicated method. In general, it represents a relatively coarse level in a hierarchy of ecological assessment protocols. However, based on model verification and validation from surface assessments, the SCI calculator and associated input variables can be applied at a range of scales from the stream segment scale to a coarser watershed scale.

The overall purpose of this User Guide is to provide the rationale and scoring descriptions of the input variables required in the SCI. Even though the SCI was formulated based on surface assessments, the protocol can be extrapolated using Geographic Information Systems (GIS). Thus, it can be used at multiple scales: 1) surface assessments; 2) low altitude flyovers (e.g., helicopters, unmanned aircraft systems); and 3) GIS satellite imagery. Consequently, MSWA can be used for remote surveys, reconnaissance including identification of attainable reference conditions, routine on-ground, field assessments at the stream segment scale, or identification of more intensive investigations. Generally, remote or reconnaissance assessments are conducted first, followed by identification of areas needing more intensive investigations. In addition, MSWA can be used for determining departure from attainable reference conditions and monitoring of restoration activities including developing success and performance criteria.

In general, this user guide provides three options to evaluate streams at different spatial scales: GIS satellite imagery, low-altitude photogrammetry, and surface assessments. The practitioner would use readily available data to score or rank model variables. This initial approach is limited to remote surveys using aerial imagery (preferably low altitude photogrammetry), web-based tools and data sources, and information already published in existing reports (e.g., ambient monitoring). At this level, practitioners would need to rely on indicators or surrogates of stream condition or impairment and land use stressors unless previous assessment data are available. However, as additional sites are scored via reconnaissance, an environmental gradient of stream conditions is realized, and sites can be prioritized for intensive studies or

stratified into a sample population for statistical extrapolation to the parent population across watershed boundaries. Intensive assessments require effort beyond the scope of the MSWA and associated variables and site scoring. However, the SCI should be verified by conducting surface assessments using scientifically accepted sampling methods and protocols.

Surface Assessments (Model Verification and Validation)

Following a clear and concise statement of problem, identification of goals and objectives, and several PDT meetings (as stated above), field surface assessments were conducted November 3 through 10, 2020. Members of the field team included: David Biedenharn, Chris Haring, Jack Killgore, David May, Autumn Murray, Bruce Pruitt, and Todd Slack of ERDC. Rick Garay (Soil Technician, USDA-NRCS) joined the team and provided logistical support. In addition, Jon Korneliussen (Civil Engineer, MVM) accompanied the ERDC field team November 4 and 5. A subset of the Targeted Streams (29 stream reaches) was tested (i.e., model verification) initially which included: Johnson Creek, Horn Lake Creek, and Nolehoe Creek watersheds. Once sampling methods were established November 3 – 5, the field team departed on November 6 with the exception of Bruce Pruitt who remained to validate model variables in unique watersheds not assessed initially (i.e., model validation including an additional 36 stream reaches on Hurricane Creek, Cow Pen Creek, Rocky Creek Bean Patch Creek, Lick Creek, Coldwater River and Camp Creek Canal). Model validation for the project area was completed November 10.

Application of the SCI to Calculate AAHU

Average Annual Habitat Units (AAHU) have been used to estimate project cost/benefits and forecast Future without Project (FWOP) and Future with Project (FWP). Historically, AAHUs are calculated based on the Habitat Evaluation Procedure (HEP), which is the product of Habitat Suitability Indices (HSI) and area of the project (e.g., acres) to obtain Habitat Units (HU) annualized over the life of the project (AAHUs). Consequently, in the past, a Tentatively Selected Plan (TSP) has been justified by ecological restoration benefits based on AAHUs. AAHUs are used as input to the Cost Effectiveness Incremental Cost Analysis (CE/ICA) per ER 1105-2-100 to compare the alternative plans' average annual cost against the AAHU estimates. Several problems have arisen by limiting the TSP to AAHUs based predominantly on traditional measures of habitat suitability:

- Attempts to estimate AAHUs based on the HSI scores (habitat requirements) of individual evaluation species have often fallen short of accounting for structure, function, and processes especially at the ecosystem scale.
- A common pitfall in developing a TSP from AAHUs generated from HSI of evaluation species is a suite of functions and processes are not accounted for including stream and valley components (e.g., riparian zone condition).

- The effects of restoration measures including engineered channel stability structures cannot be adequately evaluated using traditional "Blue Book" HSI models.
- The results of on-site HSI models cannot be easily extrapolated to multiple scales from the stream reach to stream segment to watershed scales.

Ecological models, such as the SCI, help define the problem, lead to a better understanding of the correspondence between biotic and abiotic attributes of an aquatic ecosystem, provide analytical tools to enhance data interpretation, enable comparisons between and across ecosystem types and physiography, and facilitate communication in regards to ecological processes and functions across scientific disciplines and to the public. In addition, a process-based approach was applied to this effort that identified critical processes and pathways in regards to the cause and effect relationship between geospatial data and stream conditions.

The SCI provides an excellent method of rating watersheds based on their valley land use and cover, riparian zone condition, stream geomorphology, stream bedforms and habitat diversity, and water quality conditions. The SCI was formulated using statistical methods, consequently, reducing bias and subjectivity yet increasing model extrapolation power. This User Guide was developed to provide detailed variable descriptions for the practitioner to score and rank stream conditions at a range of scales from the stream segment scale to the watershed scale using the spreadsheet calculator. The spreadsheet calculator is designed to characterize and generate a SCI value for each station intended to be included within the analyses. Utilizing the spreadsheet calculator provides a means to better document station by station assessments but will also require a second stage approach in order to compile all of the SCI values for the project area to illustrate patterns/trends. The spreadsheet calculator is capable of scoring 15 variables (MSWA_SCI_Calculator.xlsx).

Documentation of each of the 15 variables will be facilitated within the SCI Calculator and self-populated on the SCI Score Card tab 21. The Calculator is composed of 24 worksheets ("tabs") as follows (numbers below coincide with worksheet sequence in SCI Calculator):

1. Desktop
2. Available_Data_Web_Resources
3. Site_Properties
4. ID_Stressors

SCI Variables:

5. Channel Evolution Model (CEM)
6. Hydrologic Alteration (ALT)
7. Bank Stability (STB)
8. Aquatic Habitat Diversity (HAB)
9. Fish Cover (FC)

10.   Canopy (CAN)
11.   Riparian Zone (RIP)
12.   Root Depth (DEP)
13.   Root Density (DEN)
14.   Surface Protection (SUR)
15.   Bank Angle (ANG)
16.   Upper Bank Condition (UPP)
17.   Middle Bank Condition (MID)
18.   Lower Bank Condition (LOW)
19.   Bed Material and Stability (BED)
20.   Advanced_User_All_Variables
21.   SCI_SUR (Surface Protection)
22.   SCI_5_Variables
23.   SCI_Score_Card
24.   SCI_Summary_Table

Tab 1: Desktop

In general, the Desktop tab (Tab 1) is populated with background information prior to remote assessments or surface assessments ("boots-on-the-ground"). It provides remote characterization and stream morphology. However, it should be updated as additional information is made available following remote or surface assessments. The project objectives should be clear and concise, provide the foundation for the project outcomes, and facilitate the decision-making process. The Desktop includes information at coarse or broad scales not limited to GIS imagery, all of which, improve the knowledge base and identification of stream conditions at physiographic and watershed scales.

The users should complete this worksheet based on GIS analysis and available data. However, in many cases, the existing stream morphology may not be known until a field surface assessment is conducted. In addition, protocols such as Bank Erosion Hazard (Rosgen 2001) and width-depth ratios require more effort than required to collect visual data needed for the SCI score. Even though more intensive, direct measures are not required to run the SCI model, direct measures can be used to validate and improve model confidence and reduce uncertainty. Consequently, it is at the discretion of the practitioner to determine the level of effort required to meet the project objectives and decision process.

Tab 2: Available Data and Web Resources

Tab 2 provides potential resources needed to populate Tab1. The importance of compiling existing studies and dataset into a knowledge base cannot be over emphasized. Existing studies and databases provide a means of improving and validating indirect measures and observations (i.e., surrogates). Sources of pertinent data can be obtained from local, state and federal agencies, non-governmental organizations, state and federal parks, and a plethora of on-line web sites. Obviously, since web resources are listed, the practitioner should update this worksheet frequently.

Tab 3: Site Properties

In general, descriptions of site properties are surface assessments (e.g., X, Y and Z). However, remote data visualized from satellite imagery or low-altitude photogrammetry can also be used to populate this worksheet. Even though the approximate location of the Stream Assessment Reach (SAR) was established on the Desktop Tab 1, more precise GPS coordinates should be obtained during the surface assessment.

Tab 4: Identification (ID) of Stressors

In the context of the MSWA and the User Guide, stress refers to any cause of stream physical or hydrologic alteration or aquatic life impairment from in-stream or land use sources of pollution or disturbance. Several causes of stress or disturbance at different scales can be attributed to the following stressors:

Watershed, Valley and Riparian Zone Scales
- Vegetative Clearing
- Soil exposure or compaction
- Land grading
- Hard surfacing and imperious surfaces
- Contaminant runoff
- Irrigation and drainage
- Overgrazing
- Cattle access
- Concentrated feed lots and operations
- Roads and railroads
- Utility crossings
- Trails

- Reduction in floodplain
- Exotic or non-native species

Stream Reach or Segment Scale
- Channelization or dredging
- Woody debris removal (de-snagging operations)
- Head cutting (channel degradation)
- Accelerated sedimentation/siltation (channel aggradation)
- Dams
- Artificial levees
- Water withdrawal
- Streambed disturbance
- Stream bank armoring
- Dredging for mineral extraction
- Bridges/culverts (especially undersized)
- Piped discharge

When scoring model variables, the above stressors and potential sources of stream impairment should be recorded on the ID Stressors worksheet. Establishing the cause and effect relationship is critical in the decision process and also leads to project justification and significant project ranking ("J-Sheets"). It also facilitates the process of project prioritization and alternative analysis and ultimately restoration objectives including the need to integrate natural channel design with engineering methods necessary to stabilize stream beds and stream banks characterized with high bank erosion hazard.

Tabs 5 through 19: SCI Scoring System

Each assessment variable is scored from 0.1 (severely disturbed) to 1.0 (relatively undisturbed) (Figure 1 and Table 1). Using the appropriate variable worksheet in the Excel™ Spreadsheet Calculator, record the score that best fits the observations you make based on the narrative descriptions provided for each variable. Unless otherwise directed, assign the lowest score that applies to be consistent and environmental conservative. For example, if a reach exhibits attributes of several narrative descriptions, assign a score based on the lowest scoring description that contains indicators present within the reach. You may record values intermediate to those listed. However, round off each score to the nearest tenth (e.g., 0.28 = 0.3). Some background information is provided for each assessment variable, as well as a description of what to look for. If the evaluation is conducted on-ground, the SAR should be bound at a minimum of two meander wavelengths. If the evaluation is conducted remotely using satellite imagery or low altitude photogrammetry, the SAR

can be bound at the discretion of the practitioner at any stream length depending on the project objectives and stream condition consistency. However, the limitations and assumptions made with remote sensing techniques should be clearly articulated. In general, when satellite imagery is used, the SCI is best estimated from surface protection (SUR) on Tab 23 as described below. However, a subset (sample set) of remotely assessed SARs that represent the population of SARs within a given ecoregion and watershed should be ground-truth (surface assessment) and field verified to confirm the Level II Anderson land cover type(s) (Anderson et al. 1976).
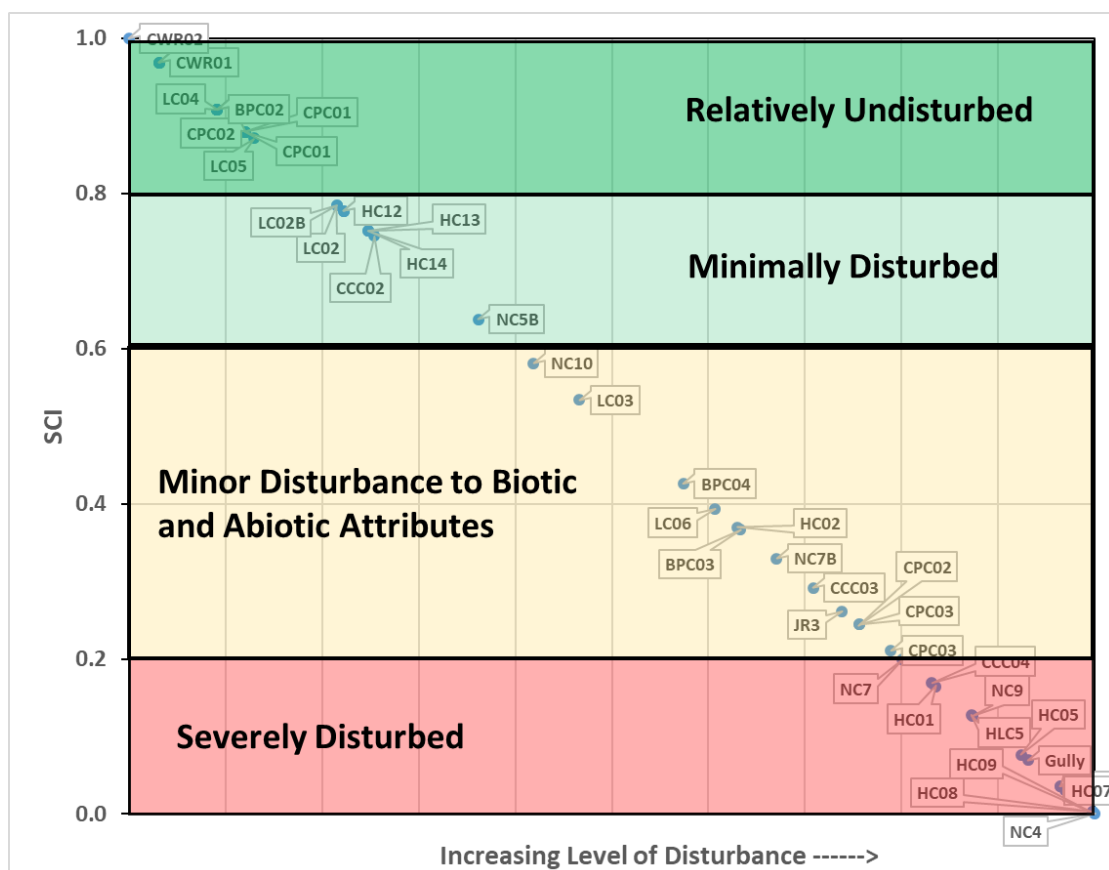

Figure 1. Level of disturbance based on SCI scores depicting DeSoto study field sites. See Tab 24 in Spreadsheet Calculator (adapted from Pruitt et al. 2020).

Table 1. Stream Condition Index (SCI) Variable Score Criteria.

Category	Relatively Undisturbed	Minimal Disturbance	Minor Disturbance to Biotic and Abiotic Attributes	High Disturbance
Score →	1.0 0.9 0.8	0.7 0.6	0.5 0.4 0.3	0.2 0.1
Channel Evolution Model – Stage (CEM)	Stable channel: CEM stages 1 and 5	CEM stage 4	CEM stage 3	CEM stage 2
Channel Alteration (ALT)	Natural planform geometry; no structures, dikes. No evidence of down cutting or excessive lateral cutting	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levees are set back to provide access to an adequate flood plain.	Altered channel; <50% of the reach with riprap and/ or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.	Channel is actively down cutting or widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to the flood plain.
Bank Stability (STB)	Banks are stable; 33% or more of eroding surface area of banks in outside bends is protected by roots or structural components that extend to the baseflow elevation.	Moderately stable; less than 33% of eroding surface area of banks in outside bends is protected by roots or structural components that extend to the baseflow elevation.	Moderately unstable; outside bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
Aquatic Habitat Diversity (HAB)	8 or more habitat types within the assessment reach	6-8 habitat types within the assessment reach	4-6 habitat types within the assessment reach	< 4 habitat types within the assessment reach
Fish Cover (FC)	>7 cover types available	4 to 7 cover types available	2 to 3 cover types available	Zero to 1 cover type available
Canopy (CAN)	> 90% shaded; full canopy; same shading condition throughout the reach.	25 to 90% of water surface shaded; mixture of conditions.	(intentionally blank)	< 25% water surface shaded in reach.
Riparian Zone (RIP)	Natural vegetation	Natural vegetation	Natural vegetation extends half of the	Natural vegetation extends a third of

	extends at least two active channel widths on each side.	extends one active channel width on each side. Or If less than one width, covers entire flood plain.	active channel width on each side.	the active channel width on each side. Or Filtering function moderately compromised.
Root Depth (DEP)	Root depth extends 80% to 100% of bank height	Root depth extends 60% to 79% of bank height	Root depth extends 30% to 59% of bank height	Root depth < 30 % of bank height
Root Density (DEN)	Root density coverage 80 to 100% of bank	Root density coverage 60 to 79% of bank	Root density coverage 30 to 59% of bank	Root density <30 % of bank
Surface Protection (SUR)	Top of bank surface protection 80 to 100% woody vegetation	Top of bank surface protection 60 to 790% woody vegetation	Top of bank surface protection 30 to 59% woody vegetation	Top of bank surface protection < 30% woody vegetation
Bank Angle (ANG)	Zero to 20% slope	21 to 60% slope	61 to 80% slope	>80% slope
Upper Bank Condition (UPP)	Structural or non-structural components protect >80% surface area of upper 1/3 of channel bank	Structural or non-structural components protect 60 to 70% surface area of upper 1/3 of channel bank	Structural or non-structural components protect 30 to 50% surface area of upper 1/3 of channel bank	Structural or non-structural components protect <20% surface area of upper 1/3 of channel bank
Middle Bank Condition (MID)	Structural or non-structural components protect >80% surface area of middle 1/3 of channel bank	Structural or non-structural components protect 60 to 70% surface area of upper 1/3 of channel bank	Structural or non-structural components protect 30 to 50% surface area of upper 1/3 of channel bank	Structural or non-structural components protect <20% surface area of upper 1/3 of channel bank
Lower Bank Condition (LOW)	Structural or non-structural components protect >80% surface area of lower 1/3 of channel bank	Structural or non-structural components protect 60 to 70% surface area of upper 1/3 of channel bank	Structural or non-structural components protect 30 to 50% surface area of upper 1/3 of channel bank	Structural or non-structural components protect <20% surface area of upper 1/3 of channel bank
Bed Material and Stability (BED)	Bed material composed of cobble or larger particles or heavy clay pan; stable side and mid-channel bars present; accelerated aggregation or degradation not	Bed material composed of sand or cobble; moderately stable side and mid-channel bars present; accelerated aggregation or degradation not observed	Bed material composed of sand; moderately unstable side and mid-channel bars present; moderate accelerated aggregation or degradation observed	Bed material composed of unconsolidated substrate; highly unstable side and mid-channel bars present or not present at all; high accelerated aggregation or degradation

	observed			observed

CEM stages 1 and 5 Stable Stream Channel			CEM stage 4 Bed Lowing or Incision		CEM stage 3 Widening Stage			CEM stage 2 Deeping (Incision) Stage	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Maintaining a natural channel within a normal range of geomorphic dimensions is important for several reasons including sediment transport, depth variation, bedform and aquatic habitat maintenance, aquatic fauna access to multiple habitats. Generally, the width, depth and cross-sectional area of the stream channel are measured at bankfull dimension (Figure 2). Bankfull discharge maintains the channel's cross-sectional geometry within normal ranges with respect to the watershed size. Within incised stream channels, bankfull dimensions may be contained within the channel levees, (i.e., low entrenchment ratio or high incision).

Indicators of CEM Stage

Evidence of channel instability includes increase in channel width, as measured from levee to levee (channelfull width) or bankfull width, mid-channel bar formation, and bank failure. An increase in channel width can be determined by comparison with a

reference reach of similar watershed size, a dramatic width change relative to upstream or downstream, regional hydraulic curves, or departure from reported ranges of channel width based on stream class. Ideally, determination of channel width should be measured at a riffle. If local regional curves are not available, bankfull channel dimensions versus drainage area can be used (Dunne and Leopold 1978).
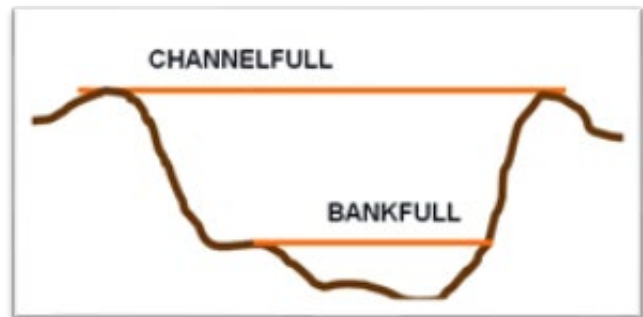
Figure 2. Stream cross-section illustrating channelfull versus bankfull in an incised channel.

Theoretically, a stream channel evolves through several stages in response to disturbance: Stage 1, stage form; Stage 2, deepening or incision; Stage 3, widening; Stage 4, deposition on point or side bars; Stage 4: re-stabilization in process (Figure 3), and Stage 5: stable form usually a channel formed within the historic channel dimension. If bankfull is channelfull and incipient overbank flooding occurs on the frequent flood event (recurrence interval 1 to 2 years), the CEM is stage 1, the stable form. However, if bankfull is contained within the channel (channelfull), stages 2 through 5 are likely and overbank flooding on the frequent flood event is not evident. Evidence of stage 2 includes: vertical or near vertical channel banks, bank failure,

head cutting of the channel bed, bank vegetation below bankfull precluded, side and point bars removed; Evidence of stage 3 includes: bank undercutting, roots exposed, bank failure, flanking and failure of woody vegetation; Evidence of stage 4 includes: sediment deposition and storage in side, mid and point bars; Evidence of stage 5 includes: revegetation of channel bars, return to a diverse bedform distribution, and cross-sectional geometry similar to attainable reference conditions.
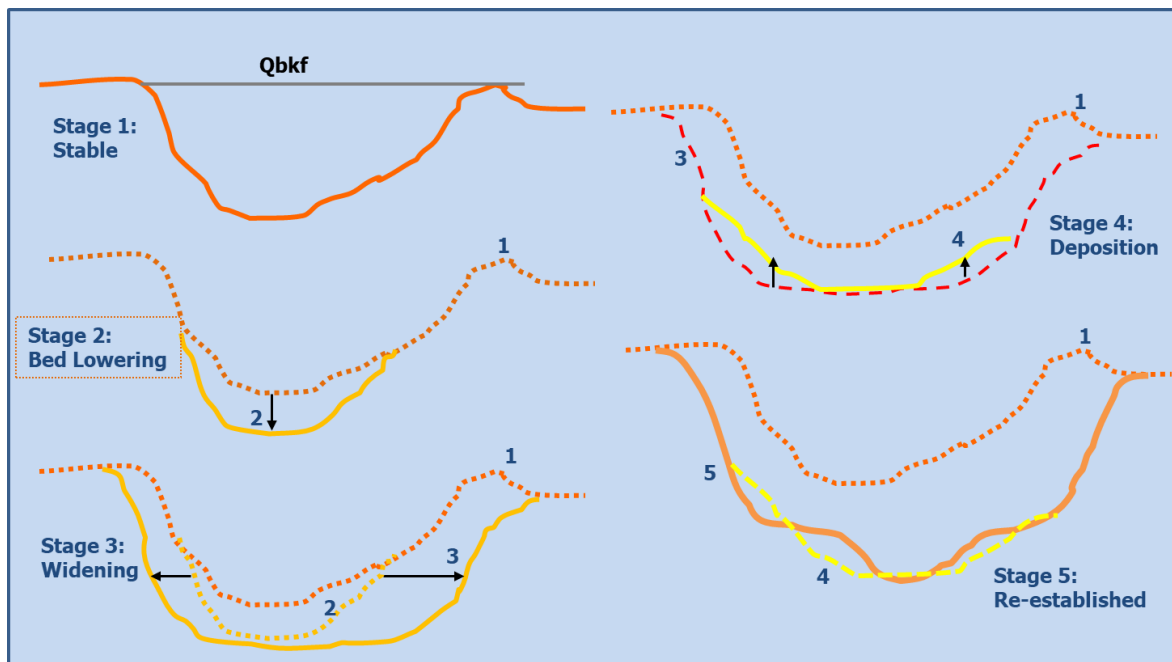
Figure 3. Channel Evolution Model (CEM), Qbkf = discharge at bankfull; solid lines represent the current CEM stage; dotted lines represent previous CEM stage (adapted from Schumm 1977).

ALT: Channel Alteration

Natural planform geometry; no structures, dikes. No evidence of down cutting or excessive lateral cutting			Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levees are set back to provide access to an adequate flood plain.		Altered channel; <50% of the reach with riprap and/ or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.			Channel is actively downcutting or widening. >50% of the reach with riprap or channel-ization. Dikes or levees prevent access to the floodplain.	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Indicators of Channel Alteration

Stream meandering generally increases as the gradient of the surrounding valley

decreases. Often, development in the area results in changes to this meandering pattern and the flow of a stream. These changes in turn may affect the way a stream naturally functions, such as the transport of sediment and the development and maintenance of habitat for fish, aquatic insects, and aquatic plants. Some modifications to stream channels have more impact on stream health than others. For example, channelization and dams affect a stream more than the presence of pilings or other supports for road crossings.

Indicators of downcutting in the stream channel include nickpoints associated with headcuts in the stream bottom and exposure of cultural features, such as pipelines that were initially buried under the stream. Exposed footings in bridges and culvert out- lets that are higher than the water surface during low flows are other examples. A lack of sediment depositional features, such as regularly-spaced point bars, is normally an indicator of incision. A low vertical scarp at the toe of the streambank may indicate down cutting, especially if the scarp occurs on the inside of a meander. Another visual indicator of current or past down cutting is high streambanks with woody vegetation growing well below the top of the bank (as a channel incises the bankfull flow line moves down- ward within the former bankfull channel). Excessive bank erosion is indicated by unvegetated banks in areas of the stream where they are not normally found, such as straight sections between meanders or on the inside of curves.

Active down cutting and excessive lateral cutting are serious impairments to stream functions and processes. Both conditions are indicative of an unstable stream channel. Usually, this instability must be addressed before committing time and money toward improving other stream problems. For example, restoring the woody vegetation within the riparian zone becomes increasingly difficult when a channel is downcutting because banks continue to be undermined and the water table drops below the root zone of the plants during their growing season. In this situation or when a channel is fairly stable, but already incised from previous down- cutting or mechanical dredging, it is usually necessary to plant upland species, rather than hydrophytic, or to apply irrigation for several growing seasons, or both. Extensive bank-armoring of channels to stop lateral cutting usually leads to more problems (especially downstream). Often stability can be obtained by using a series of structures (barbs, groins, jetties, deflectors, weirs, vortex weirs) that reduce water velocity, deflect currents, or act as gradient controls. These structures are used in conjunction with large woody debris and woody vegetation plantings.

Bankfull flows, as well as flooding, are important to maintaining channel shape and function (e.g., sediment transport) and maintaining the physical habitat for animals and plants. High flows scour fine sediment to keep gravel areas clean for fish and other aquatic organisms. These flows also redistribute larger sediment, such as

gravel, cobbles, and boulders, as well as large woody debris, to form pool and riffle habitat important to stream biota. The river channel and flood plain exist in dynamic equilibrium, having evolved in the present climatic regime and geomorphic setting. The relationship of water and sediment is the basis for the dynamic equilibrium that maintains the form and function of the river channel. The energy of the river (water velocity and depth) should be in balance with the bedload (volume and particle size of the sediment). Any change in the flow regime alters this balance (Lane 1955).

If a river is not incised and has access to its flood plain, decreases in the frequency of bankfull and out-of-bank flows decrease the river's ability to transport sediment. This can result in excess sediment deposition, channel widening and shallowing, and, ultimately, in *braiding* of the channel. Rosgen (1996) defines braiding as a stream with three or more smaller channels. These smaller channels are extremely unstable, rarely have woody vegetation along their banks, and provide poor habitat for stream biota. A *split channel,* however, has two or more smaller channels (called side channels) that are usually very stable, have woody vegetation along their banks, and provide excellent habitat. Conversely, an increase in flood flows or the confinement of the river away from its flood plain (from either incision or levees) increases the energy available to transport sediment and can result in bank and channel erosion.

The low flow or baseflow during the dry periods of summer or fall usually comes from groundwater entering the stream through the stream banks and bottom. A decrease in the low-flow rate will result in a smaller portion of the channel suitable for aquatic organisms. The withdrawal of water from streams for irrigation or industry and the placement of dams often change the normal low-flow pattern. Baseflow can also be affected by management and land use within the watershed — less infiltration of precipitation reduces baseflow and increases the frequency and severity of high flow events. For example, urbanization increases runoff and can increase the frequency of flooding to every year or more often and also reduce low flows. Overgrazing and clearcutting can have similar, although typically less severe, effects. The last description in the last box refers to the increased flood frequency that occurs with the above watershed changes.

Signs of channelization or straightening of the stream may include an unnaturally straight section of the stream, high banks, dikes or berms, lack of flow diversity (e.g., few point bars and deep pools), and uniform-sized bed materials (e.g., all cobbles where there should be mixes of gravel and cobble). In newly channelized reaches, vegetation may be missing or appear very different (different species, not as well developed) from the bank vegetation of areas that were not channelized. Older channelized reaches may also have little or no vegetation or have grasses instead of woody vegetation. Drop structures (such as check dams), irrigation diversions,

culverts, bridge abutments, and riprap also indicate changes to the stream channel.

Ask the landowner about the frequency of flooding and about summer low-flow conditions. A flood plain should be inundated during flows that equal or exceed the 1.5- to 2.0-year flow event (2 out of 3 years or every other year). Be cautious because water in an adjacent field does not necessarily indicate natural flooding. The water may have flowed overland from a low spot in the bank outside the assessment reach.

Evidence of flooding includes high water marks (such as water lines), sediment deposits, or stream debris. Look for these on the banks, on the bank side trees or rocks, or on other structures (such as road pilings or culverts). Excess sediment deposits and wide, shallow channels could indicate a loss of sediment transport capacity. The loss of transport capacity can result in a stream with three or more channels (braiding).

STB: Bank Stability

Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); out- side bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
1.0 0.9 0.8	0.7 0.6	0.5 0.4 0.3	0.2 0.1

Indicators of Bank Instability

This element is the existence of or the potential for detachment of soil from the upper, middle and lower stream banks and its movement into the stream. Some bank erosion is normal in a healthy stream. Excessive bank erosion occurs where riparian zones are degraded or where the stream is unstable because of changes in

hydrology, sediment load, or isolation from the flood plain. High and steep banks are more susceptible to erosion or collapse. All outside bends of streams erode, so even a stable stream may have 50 percent of its banks bare and eroding. A healthy riparian corridor with a vegetated flood plain contributes to bank stability. The roots of perennial grasses or woody vegetation typically extend to the baseflow elevation of water in streams that have bank heights of 6 feet or less. The root masses help hold the bank soils together and physically protect the bank from scour during bankfull and flooding events. Vegetation seldom becomes established below the elevation of the bankfull surface because of the frequency of inundation and the un- stable bottom conditions as the stream moves its bedload.

The type of vegetation is important. For example, trees, shrubs, sedges, and rushes have the type of root masses capable of withstanding high streamflow events, while Kentucky bluegrass does not. Soil type at the surface and below the surface also influences bank stability. For example, banks with a thin soil cover over gravel or sand are more prone to collapse than are banks with a deep soil layer.

Signs of erosion include unvegetated stretches, exposed tree roots, or scalloped edges. Evidence of construction, vehicular, or animal paths near banks or grazing areas leading directly to the water's edge suggest conditions that may lead to the collapse of banks. Estimate the size or area of the bank affected relative to the total bank area. This element may be difficult to score during high water.

HAB: Aquatic Habitat Diversity

8 or more habitat types within the SAR			6-8 habitat types within the SAR		4-6 habitat types within the SAR			< 4 habitat types within the SAR	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Habitat Types

Runs — Bedform characterized by a disturbed surface, moderate to fast current, turbulent flow and vertical mixing of the water column. Runs often occur below or between pools and generally improve oxygen dynamics and convey nutrients and insect drift to downstream bedform forms of slower current. Increased water velocity in runs is preferred by rheophilic fish and insects and may be the only location where noticeable flow occurs in an otherwise pooled environment.

Pools—Bedform characterized by a smooth undisturbed surface, generally slow to no current, soft substrates of silt and mud, and deep enough to provide protective cover for fish (75 to 100% deeper than the prevailing stream depth).). Pools are

utilized by lentic fishes, such as sunfishes.

Pools are important breeding, resting and feeding sites for fish. A healthy stream has a mix of shallow and deep pools. A *deep* pool is 1.6 to 2 times deeper than the prevailing depth, while a *shallow* pool is less than 1.5 times deeper than the prevailing depth. Pools are abundant if a deep pool is in each of the meander bends in the reach being assessed. To determine if pools are abundant, look at a longer sample length than one that is 12 active channel widths in length. Generally, only 1 or 2 pools would typically form within a reach as long as 12 active channel widths. In low order, high gradient streams, pools are abundant if there is more than one pool every 4 channel widths.

Bedform or physical habitat diversity and abundance are estimated based on walking the stream or probing from the streambank with a stick or length of rebar. You should find deep pools on the outside of meander bends. In shallow, clear streams a visual inspection may provide an accurate estimate. In deep streams or streams with low visibility, this assessment characteristic may be difficult to determine and should not be scored.

Riffles— Bedform characterized by broken water surface, rocky or firm substrate, moderate or swift current with noticeable turbulence, relatively shallow depth (usually less than 24 inches but can be deeper). This habitat is important to Litho-Psammophilic fishes, or those species that deposit eggs over sand or gravel (Balon 1984) including species of conservation importance such as madtoms, minnows and darters. Riffle-oriented aquatic insects, including ecologically important EPT taxa (Ephemeroptera, Plecoptera, Tricoptera), require riffles to complete one or more of their life cycles.

Glides— This bedform can be combined with riffles. Glides usually occur immediately downstream of pools, are characterized with laminar (even) flow, and approximately equal depth in cross-section. In gravel based streams, gravel will accumulate in glides making for excellent breeding/egg laying habitat for fish. In general, glides are the best place to gage stream velocity and discharge.

Leaf Packs— Leaves provide allochthonous input of particulate organic matter derived from the riparian zone of streams. In addition to the nutritional value of leaf packs, they also provide feeding, resting and attachment for aquatic macroinverbrates especially shredders and grazers. This feature also provides refugia for amphibians and speleophlic fishes such as madtoms.

Undercut Banks-- Undercut banks generally from in meandering streams that erode

the outer bank with an over-hanging bench of soil often held together by the roots of plants and trees. The bank and roots provide feeding, resting and attachment for aquatic macroinverbrates especially nest builders, speleophlic fishes that deposit eggs in crevices, and overhead cover for cryptic fishes and amphibians. Undercut banks also serve as velocity refugia for nearby riffles, runs, and during flood events.

Coarse Woody Debris— Coarse woody debris (CWD) originates from limbs and twigs falling from surrounding trees enhancing habitat heterogeneity. CWD can increase retention of organic matter, alter velocity regimes, and provide stable substrates for the attachment of periphyton, in addition to providing important feeding areas for aquatic macroinverbrates (shredders, filters, and gatherers) and herbivorous and insectivorous fish.

Cobble or Larger Bed Material— Cobble and large bed material are over 60 mm in diameter and can be flat or irregular shaped rocks. They increase substrate roughness, expand boundary layers in swift water habitats, and increases overall stream bottom heterogeneity. As such, they provide "living space" for refugia and attachment for aquatic macroinvertebrates and create scour holes for fish.

Good Water Quality— Water quality requirements specific to the species and age classes of fish and aquatic macroinvertebrates. Usually within the ranges provided by Federal and State water quality standards. General guidelines are adequate dissolved oxygen greater than 5 mg/l, pH that ranges from 6 to 8, and turbidity less than 25 mg/l except after rainstorms.

Submerged Aquatic (SAV) and Emergent Vegetation— Provides habitat for feeding, breeding and refugia for aquatic macroinvertebrates and fish. Aquatic plants provide structurally complex habitats for young-of-year fishes increasing survival and recruitment, and substrates for macroinvertebrates increasing overall food resources.

Water Clarity. The condition of the water quality has a bearing on this variable. Water clarity is often an indicator of water quality in the form of turbidity, color, and other visual characteristics which can be compared with a healthy or reference stream. The depth to which an object can be clearly seen is a measure of turbidity. Turbidity is caused mostly by particles of soil and organic matter suspended in the water column. Water often shows some turbidity after a storm event because of soil and organic particles carried by runoff into the stream or suspended by turbulence. The water in some streams may be naturally tea-colored. This is particularly true in watersheds with extensive bog and wetland areas. Water that has slight nutrient enrichment may support communities of algae, which provide a greenish color to the

water. Streams with heavy loads of nutrients have thick coatings of algae attached to the rocks and other submerged objects. In degraded streams, floating algal mats, surface scum, or pollutants, such as dyes and oil, may be visible.

Clarity of the water is an obvious and easy feature to assess. The deeper an object in the water can be seen, the lower the amount of turbidity. Use the depth that objects are visible only if the stream is deep enough to evaluate turbidity using this approach. For example, if the water is clear, but only 1 foot deep, do not rate it as if an object became obscured at a depth of 1 foot. This measure should be taken after a stream has had the opportunity to "settle" following a storm event. A pea-green color indicates nutrient enrichment beyond what the stream can naturally absorb.

Nutrient Enrichment. Nutrient enrichment is often reflected by the types and amounts of aquatic vegetation in the water. High levels of nutrients (especially phosphorus and nitrogen) promote an overabundance of algae and floating and rooted macrophytes. The presence of some aquatic vegetation is normal in streams. Algae and macrophytes provide habitat and food for all stream animals. However, an excessive amount of aquatic vegetation is not beneficial to most stream life. Plant respiration and decomposition of dead vegetation consume dissolved oxygen in the water. Lack of dissolved oxygen creates stress for all aquatic organisms and can cause fish kills. A landowner may have seen fish gulping for air at the water surface during warm weather, indicating a lack of dissolved oxygen.

Some aquatic vegetation (rooted macrophytes, floating plants, and algae attached to substrates) is normal and indicates a healthy stream. Excess nutrients cause excess growth of algae and macrophytes, which can create greenish color to the water. As nutrient loads increase the green becomes more intense and macrophytes become more lush and deep green. Intense algal blooms, thick mats of algae, or dense stands of macrophytes degrade water quality and habitat. Clear water and a diverse aquatic plant community without dense plant populations are optimal for this characteristic.

FC: Fish Cover

> 7 cover types within the SAR			4 to 7 cover types within the SAR		2 to 3 cover types within the SAR			Zero to 1 cover type within the SAR	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Cover types: Logs/large woody debris, deep pools, overhanging vegetation, boulders/cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, isolated/backwater pools, other:_____.

This assessment element measures availability of physical habitat for fish to feed, find refugia from high water velocity, and utilize structure to balance predator-prey relationships. The potential for the maintenance of a healthy fish community and its ability to recover from disturbance is dependent on the variety and abundance of suitable habitat and cover available. Note, many indicators of FC overlap with HAB as described above.

Evidence of Good Fish Cover: Observe the number of different habitat and cover types *within a representative sub-section of the assessment* reach that is equivalent in length to *five times* the active channel width. Each cover type must be present in appreciable amounts to score. Cover types are described below.

Logs/large woody debris—Fallen trees or parts of trees that provide structure and attachment for aquatic macroinvertebrates and hiding places for fish.

Deep pools—Areas characterized by a smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75 to 100% deeper than the prevailing stream depth).

Overhanging vegetation—Trees, shrubs, vines, or perennial herbaceous vegetation that hangs immediately over the stream surface, providing shade and cover.

Boulders/cobble—Boulders are rounded stones more than 10 inches in diameter or large slabs more than 10 inches in length; cobbles are stones between 2.5 and 10 inches in diameter.

Undercut banks—Eroded areas extending horizontally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

Thick roots mats—Dense mats of roots and rootlets (generally from trees) at or beneath the water surface forming structure for invertebrate attachment and fish cover.

Dense macrophyte beds—Beds of emergent (e.g., water willow), floating leaf (e.g., water lily), or submerged (e.g., riverweed) aquatic vegetation thick enough to provide invertebrate attachment and fish cover.

Riffles—Area characterized by broken water surface, rocky or firm substrate, moderate or swift current, and relatively shallow depth (usually less than 18 inches).

Isolated/backwater pools—Areas disconnected from the main channel or connected as a "blind" side channel, characterized by a lack of flow except in periods

of high water.

Water Quality, Clarity, and Nutrient Enrichment—See HAB above.

<div align="right">

CAN: Canopy

</div>

> 90% shaded; full canopy; same shading condition throughout the reach.			25 to 90% of water surface shaded; mixture of conditions.		intentionally blank		< 25% water surface shaded in reach.	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.2	0.1

Shading of the stream is important because it keeps water cool and limits algal growth. Cool water has a greater oxygen holding capacity than does warm water. When streamside trees are removed, the stream is exposed to the warming effects of the sun causing the water temperature to increase for longer periods during the daylight hours and for more days during the year. This shift in light intensity and temperature causes a decline in the numbers of certain species of fish, insects, and other invertebrates and some aquatic plants. They may be replaced altogether by other species that are more tolerant of increased light intensity, low dissolved oxygen, and warmer water temperature. For example, many obligate riverine fish require cool, oxygen-rich water. Loss of streamside vegetation (and also channel widening) that cause increased water temperature and decreased oxygen levels are major contributing factors to the decrease in abundance of stream fishes. Increased light and the warmer water also promote excessive growth of submerged macrophytes and algae that compromises the biotic community of the stream. The temperature at the reach you are assessing will be affected by the amount of shading 2 to 3 miles upstream.

Estimating Canopy Cover: Try to estimate the portion of the water surface area for the whole reach that is shaded by estimating areas with no shade, poor shade, and shade. Time of the year, time of the day, and weather can affect your observation of shading. Therefore, the relative amount of shade is estimated by assuming that the sun is directly overhead and the vegetation is in full leaf-out. First evaluate the shading conditions for the reach; then determine (by talking with the land- owner) shading conditions 2 to 3 miles upstream. Alternatively, use aerial photographs taken during full leaf out. The following rough guidelines for percent shade may be used:

stream surface not visible ....>90
surface slightly visible or visible only in patches………………………………….. 70 − 90
surface visible, but banks not visible………………………………………………….40 − 70

surface visible and banks visible at times……………………….…………..20 – 40

surface and banks visible ....<20

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. *or* If less than one width, covers entire floodplain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. *or* Filtering function moderately compromised.
1.0 0.9 0.8	0.7 0.6	0.5 0.4 0.3	0.2 0.1

This element is the width of the natural vegetation zone from the edge of the active channel out onto the floodplain. For this element, the word natural means plant communities with (1) all appropriate structural components, and (2) species native to the site or introduced species that function similar to native species at reference sites.

A healthy riparian vegetation zone is one of the most important elements for a healthy stream ecosystem. The quality of the riparian zone increases with the width and the complexity of the woody vegetation within it. This zone:

- Reduces the amount of pollutants that reach the stream in surface runoff.

- Helps control erosion.

- Provides a microclimate that is cooler during the summer providing cooler water for aquatic organisms.

- Provides large woody debris from fallen trees and limbs that form instream cover, create pools, stabilize the streambed, and provide habitat for stream biota.

- Provides fish habitat in the form of undercut banks with the "ceiling" held together by roots of woody vegetation.

- Provides organic material for stream biota that, among other functions, is the base of the food chain in lower order streams.

- Provides habitat for terrestrial insects that drop in the stream and become food for fish, and habitat and travel corridors for terrestrial animals.

- Dissipates energy during flood events.

- Often provides the only refuge areas for fish during out-of-bank flows (behind trees, stumps, and logs).

The type, timing, intensity, and extent of activity in riparian zones are critical in determining the impact on these areas. Narrow riparian zones and/or riparian zones that have roads, agricultural activities, residential or commercial structures, or significant areas of bare soils have reduced functional value for the stream. The filtering function of riparian zones can be compromised by concentrated flows. No evidence of concentrated flows through the zone should occur or, if concentrated flows are evident, they should be from land areas appropriately buffered with vegetated strips.

Evidence of Riparian Zone Condition: Compare the width of the riparian zone to the active channel width. In steep, V-shaped valleys there may not be enough room for a flood plain riparian zone to extend as far as one or two active channel widths. In this case, observe how much of the flood plain is covered by riparian zone. The vegetation must be natural and consist of all of the structural components (aquatic plants, sedges or rushes, grasses, forbs, shrubs, understory trees, and overstory trees) appropriate for the area. A common problem is lack of shrubs and understory trees. Another common problem is lack of regeneration. The presence of only mature vegetation and few seedlings indicates lack of regeneration. Do not consider incomplete plant communities as natural. Healthy riparian zones on both sides of the stream are important for the health of the entire system. If one side is lacking the protective vegetative cover, the entire reach of the stream will be affected. In doing the assessment, examine both sides of the stream and note on the diagram which side of the stream has problems. There should be no evidence of concentrated flows through the riparian zone that are not adequately buffered before entering the riparian zone.

For the following four variables, use guidance provided by Rosgen (2001)

DEP: Root Depth

Root depth extends 80% to 100% of bank height			Root depth extends 60% to 79% of bank height		Root depth extends 30% to 59% of bank height			Root depth < 30 % of bank height	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

DEN: Root Density

Root density coverage 80 to 100% of bank			Root density coverage 60 to 79% of bank		Root density coverage 30 to 59% of bank			Root density <30 % of bank	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

SUR: Surface Protection

Top of bank surface protection 80 to 100% woody vegetation			Top of bank surface protection 60 to 79% woody vegetation		Top of bank surface protection 30 to 59% woody vegetation			Top of bank surface protection < 30% woody vegetation	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

ANG: Bank Angle

Zero to 20% slope			21 to 60% slope		61 to 80% slope			>80% slope	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Upper (UPP), Middle (MID) and Lower (LOW) Channel Bank

Structural or non-structural components protect >80% surface area of 1/3 of channel bank			Structural or non-structural components protect 60 to 70% surface area of 1/3 of channel bank		Structural or non-structural components protect 30 to 50% surface area of 1/3 of channel bank			Structural or non-structural components protect <20% surface area of 1/3 of channel bank	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Channel bank protection is assessed at three different areas on 1/3 vertical positions: upper (UPP), middle (MID) and lower (LOW). Consequently, the bank is scored three times at each bank position. If the channel is small and banks not tall (generally, first and second order streams), the same score can be used for all three positions.

Bed material composed of cobble, larger particles or heavy clay pan; stable side and mid-channel bars present; accelerated aggregation or degradation not observed. Channel bed is stable.			Bed material composed of sand or cobble; moderately stable side and mid-channel bars present; accelerated aggregation or degradation not observed.		Bed material composed of sand; moderately unstable side and mid-channel bars present; moderate accelerated aggregation or degradation observed.			Bed material composed of unconsolidated substrate; highly unstable side and mid-channel bars present or not present at all; high accelerated aggregation or degradation observed.	
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Tab 20: SCI Summary – All Variables

Users that have experience in identification of indicators of model variables (advanced user) can populate the SCI Summary directly (Tab 20). Direct use of this tab is meant for very rapid surface assessment which should take less than one hour depending on logistics. All 15 variables are assessed using this worksheet. In addition, stressors should be recorded by the stressor numbers listed on Tab 4.

The SCI model, which included 15 variables, was formulated using a modification of Duck River multi-scale watershed assessment (Pruitt et al. 2020). Since the SCI represents a multi-scale assessment method, it is recommended to collect data at several scales *(from the ground up)*: 1) **Surface Assessments**, Stream Assessment Reach (SAR) ("boots-on-the-ground") or project footprint scale; 2) **Low-Altitude Photogrammetry**; and 3) **GIS Satellite Scale**. In addition, the SCI scores can be calculated at all three scales or in any combination on the same study reach. The following data collection process is meant for guidance and is neither all inclusive nor recommended in the exact stepwise order as presented herein.

Desktop (Calculator Worksheets 1 and 2):

1. Statement of problem based on the decision that needs to be made.

2. Identify project goal and specific objectives.

3. Compile readily available and pertinent databases (see second worksheet in Excel™ Calculator).

4. Bound study area (watershed-scale) and project area (Stream Assessment Reach, SAR).

5. Stratify study area by Level IV Ecoregions and HUC12 watersheds.

6. Map stream segments for assessment in the context of their watersheds (GIS Anderson land cover types).

Field Excursion (Calculator Worksheet 3 and 4):

7. Establish the boundaries of the study and project areas. The study area may include the entire watershed, whereas, the project area represents the footprint of the assessment area or construction area within the watershed.

8. Classify SAR by the Channel Evolution Model (Schumm et al. 1984) and stream type using Rosgen's classification system (Rosgen 1994).

9. Identify stressors using surface assessments, low-altitude photogrammetry and/or satellite imagery (Calculator Tab 4).

Surface Assessment – All Variables (Calculator Worksheets 5 to 19):

10. Conduct surface assessments using 15 SCI variables (provide training, if necessary, for consistency and reproducibility among practitioners).

Advanced User (Calculator Worksheet 20):

11. Depending on the user's understanding and experience in using the SCI

model and spreadsheet, the Advanced User's worksheet can be used as a rapid assessment.

10.   Run Excel™ Spreadsheet Calculator and generate SCI scores.

Remote Satellite or Low Altitude Photogrammetry (Calculator Worksheet 21):

11.   *In lieu* of or in addition to Surface Assessments, estimate the SCI score (Figure 4). In general, riparian vegetation cover types are estimated based on Anderson cover types (Anderson et al. 1976) pertinent to the region (Table 2). It is recommended to ground-truth a statistical subset of riparian cover types that are determined remotely and extrapolate the signature of the verified cover types to other stream reaches or watersheds in the ecoregion.

Table 2. Anderson land cover types adapted to common settings found in the southeast United States.

| Level I	Level II	Score
Urban or Built-up Land	Residential (Built out) (Enter RB)	0.5
	Residential (Under Development) (Enter RU)	0.3
	Commercial	0.1
	Mixed Urban or Built-up Land (Enter MU)	0.3
	Golf Course	0.5
Agricultural Land	Pasture	0.5
	Confined Feeding Operations (Enter Cow Lots)	0.1
	Cropland/Cultivated (Enter Row Crop)	0.2
Rangeland	Scrub-Shrub (Enter Shrub)	0.7
	Herbaceous	0.7
	Grasses	0.5
	Mixed Shrub/Herbaceous (in fallow) (Enter Mixed SH)	0.7
	Invasive Species (Enter Invasive))	0.1
Forest Land	Deciduous Forest (Enter Forested)	1.0
	Evergreen Forest (Enter Forested)	1.0
	Mixed Forest (Enter Forested)	1.0
	Forested Wetland (Enter Forested)	1.0
	Non-Forested Wetland (Enter Herbaceous)	0.7
Barren Land	Bare	0.1
Bank Armoring	Rip-rap	0.1
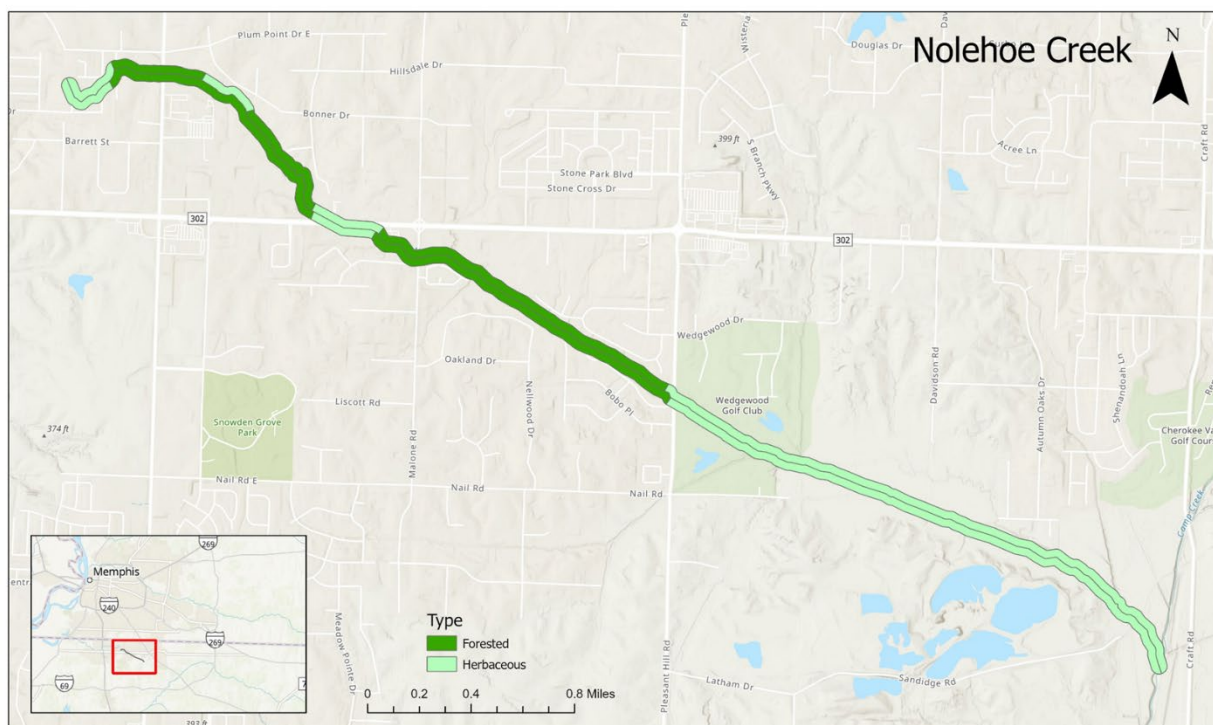
Figure 4. Distribution of Anderson cover types, forested and herbaceous, using Nolehoe Creek, DeSoto County, MS as an example (7 meter riparian width demarcated on each bank).

Application of Stream Condition Index in Resource Planning

By conducting a visual assessment of stream condition using the SCI, conclusions can be made in regards to physical and biological stream attributes at multiple scales (watershed, stream segment or reach). Overall, the results of SCI scores can be utilized to:

1. Prioritize stream segments and watersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.

2. Evaluate project alternative analysis and cost/benefit analysis.

3. Develop performance standards and success criteria applicable to restoration actions.

4. Address impacts or improvements beyond the footprint of the project.

5. Establish monitoring plans including adaptive management.

6. Forecast future ecosystem lift or outcomes.

7. Estimate the long-term effects of climate change on ecosystem processes and functions.

8. Assess stream conditions elsewhere and compare against reference

conditions established during this watershed assessment.

9.   Justify proposed projects at the national significant priority scale.

Selection of Appropriate Equation to Calculate SCI Score

Three SCI equations for use at different scales are used in the Excel™ Calculator as described in this User Guide (*from the ground up*): 1) Surface Assessments-SAR ("boots-on-the-ground") or project footprint scale; 2) Low-Altitude Photogrammetry; and 3) GIS Watershed Scale. All three equations can be used to assess projects at the same scale or at multiple scales using a watershed approach (EC 1105-2-411, Planning: Watershed Plans).

1)   **Surface Assessments:** In general, surface assessments result in the highest data quality objectives (DQO) and the highest level of effort (LOE), thus require a relatively large number of unique field stations (minimum 20 stations recommended) unless the project study area is relatively small (e.g., less than one stream mile). Surface assessments offer several advantages including: 1) improved competence; 2) ability to assess and score each variable separately and identify problems and opportunities at the stream reach scale; and 3) facilitate restoration actions that target specific stream attributes (e.g., improve aquatic habitat (HAB) by stabilizing banks (STB) and restoring the riparian zone (RIP)).

General Project Objectives for Surface Assessments: Surface assessments should be conducted on proposed project sites that require intensive surveys necessary to identify stream features at a fine scale for restoration actions including: 1) Direct measures of channel capacity (e.g., cut and fill estimations); 2) Installation or placement of engineered structures (e.g., grade control structures, longitudinal toe stones); 3) Soil bioengineering plans and specifications; and 4) Compensatory mitigation credit calculations. Surface assessments can be combined with land cover types (GIS satellite imagery) to calculate SCI scores, loss of riparian zone vegetation, and balance debits (loss) and credits (gain) generated from structural and non-structural construction activities. See Table 1 for variable descriptions for the following SCI equation:

$$SCI = \sqrt[15]{(CEM \times ALT \times STB \times HAB \times FC \times CAN \times RIP \times DEP \times DEN \times SUR \times ANG \times UPP \times MID \times LOW \times BED)}$$

(1)

2)   **Low-Altitude Photogrammetry.** Low-altitude photogrammetry refers to high-resolution still photography (sometimes overlapped for stereoscoping) and/or video which is generally flown via fixed wing airplane, helicopter or unmanned aircraft systems (UAS) from an altitude less than 1000 feet. Low-altitude photogrammetry is

considered moderate DQO and LOE. There are several technologies available to capture the terrain, channel geometry, and vegetation signatures including, but not limited to, black and white, true color, and infrared still photography, nano-hyperspectral imaging, thermal mapping, and light detection and ranging (LiDAR).

Assuming clear line of site, low-altitude photogrammetry can detect a subset of five of the 15 variables used above in surface assessments including: channel stability (STB), aquatic habitat (HAB), surface protection (SUR), bank angle (ANG) from LiDAR cross-sectional geometry, and channel bed stability (BED) from LiDAR longitudinal profiles (Spreadsheet Calculator Tab 22).

$$SCI = \sqrt[5]{(STB \times HAB \times SUR \times ANG \times BED)} \tag{2}$$

3)   GIS Watershed Scale. SCI scores estimation from satellite imagery is considered relatively low DQO and LOE. Depending on the project objectives, the signature of vegetation cover types generated needs to be ground-truth. Consequently, if the project objective is to prioritize stream reaches at the watershed scale, ground-truth may not be necessary. However, a subset of stream reaches may need to be ground-truth. The SCI versus Surface Protection (SUR) correlation is recommended at the GIS Watershed Scale in the planning phase of the project (e.g., watershed prioritization):

$$SCI = 0.95 \, (SUR) - 0.081 \tag{3}$$

This strong regression correlation ($r^2 = 0.86$) is paramount in the extrapolation power using GIS Anderson cover types to estimate SCI in watersheds from SARs that received surface assessments to stream segments and reaches in unassessed watersheds. In addition, prioritization of stream reaches for restoration, enhancement and conservation using the SCI score based on SUR can be estimated rapidly using GIS cover types in the riparian zone (Spreadsheet Calculator Tab 23).

Anderson et al. (1976) or an acceptable, updated version should be used to map vegetation cover types within seven meters (~23 feet) riparian zone on stream banks (Figure 4). Depending on scale and data quality objectives, the left and right banks can be included together or separate. In this example, the banks are combined for an overall estimation of cover types within the SAR or watershed scale. SCI scores are estimated from surface protection (SUR) by calculating a weighted sum of the cover types (Figure 4 and Tab 23 of the Spreadsheet Calculator).

This multiscale approach with application of three SCI equations is described below

as scenarios using actual observational data collected in DeSoto County, Mississippi.

Scenario 1 (Surface plus GIS Satellite Assessment Scales): **Horn Lake Creek Channel Enlargement**

Project Description and Objectives (see Spreadsheet Calculator Tab 26): The Horn Lake Creek channel enlargement project located downstream of Goodman Road, Horn Lake, DeSoto County, Mississippi, is used here as an example. The Horn Lake Creek channel enlargement will increase the bottom width to 40 feet for approximately 2,900 linear feet from Mile 18.86 to Mile 19.41 (approximately 0.8 miles), downstream of Goodman Road (Figure 5). in Horn Lake, MS. The banks of the improved channel will be flattened to a 3H to 1V slope for stability (Figure 6). The enlargement and slope flattening will require 95,000 cubic yards of excavation, all of which will be disposed off site. Approximately 22,750 tons of riprap will be placed to prevent scour damage. The riprap will be placed in a three-foot deep layer on the bottom and 5 feet up both banks. The riprap will be placed over approximately 6,000 tons of filter material. The upper banks will be protected with 18,780 square yards of turf reinforcing mat. The channel improvements will be optimized during feasibility-level design. A new existing-conditions survey will provide the data necessary to finalize design elevations. Special consideration will be given to transitioning into and out of the enlargement area, utilities, and any heavily-scoured areas in the project footprint. Ten acres of tree clearing in the riparian zone will be required along the project stream reach.

During the field verification conducted on November 3-10, 2020, the ERDC field team conducted surface assessments on two SARs within the construction segment: HLC5 and HLC11. HLC05 was selected to assess ecological outcomes and calculate SCU since HLC05 was located near the middle of construction site and represented the predominant condition of the stream segment. The existing channel is characteristic of the region: deeply incised (low entrenchment ratio), trapezoidal shaped, steep, highly erodible banks, and instable channel bed dominated with sand, silt and clay. The riparian zone was assessed separately from the channel re-construction since improvements in the stream channel would be realized almost immediately. In contrast, the riparian zone restoration will require several years before a mature hardwood stand occurs. In addition, in order to capture the riparian zone condition over the entire project area, the surface protection (SUR) was estimated from GIS imagery. The following steps were followed to estimate Net EcoLift over a 50-year horizon (refer to Spreadsheet Calculator Tab 26):
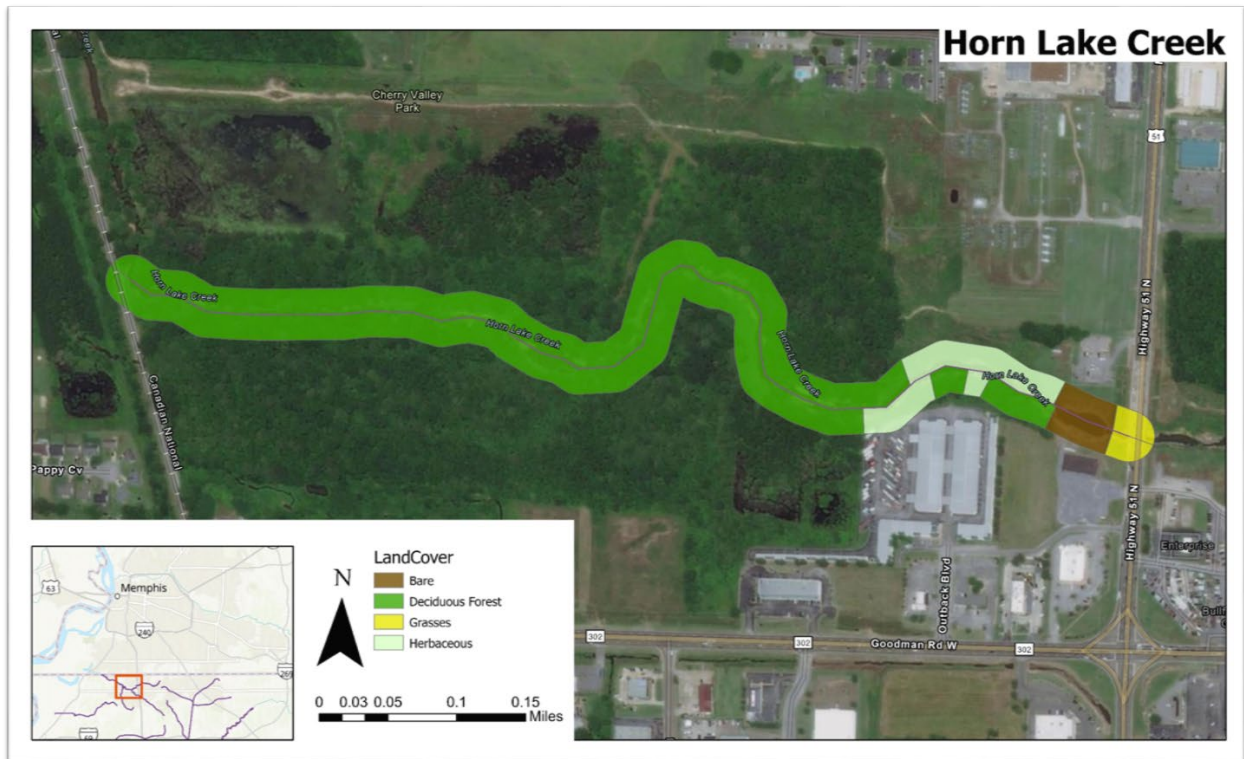
Figure 5. Distribution of Anderson cover types, forested and herbaceous, using Horn Lake Creek Channel Enlargement Project, DeSoto County, MS as an example (7 meter riparian width demarcated on each bank).

Step 1. Estimate area of riparian zone based on a 200-foot riparian width and project length of 0.8 miles.

Step 2. Calculate Future With (FWP) and Future Without Project (FWOP) from SCI equation.

Step 3. Estimate SCI and Stream Condition Units (SCU) from SUR.

Step 4. Calculate Net EcoLift from the sum of riparian forest loss and channel stability gain.

Scenario 2 (Low Altitude Photogrammetry or GIS Local Scale): **Stormwater Detention Pond Site Selection Suitability, Capacity, and Net Change in Average Annual Habitat Units (AAHU) using SCI**

Potential Project Objectives (see Spreadsheet Calculator Tab 27): The USACE Memphis District (MVM) proposed four stormwater detention ponds to reduce flood damages to businesses, residents, and infrastructure in DeSoto County, MS. The objectives were: 1) Estimate SCI scores under future with (FWP) and future without project (FWOP) scenarios; 2) Based on project area, convert the SCI scores to Stream Condition Units (SCU); 3) Estimate net change in Average Annual Habitat Units (AAHU) over a 50-year project horizon.

Four detention ponds were proposed (Lateral D, Cow Pen [Upper], Cow Pen [Ballfield], and Rocky Creeks). Since Cow Pen (Upper) and Cow Pen (Ballfield) were located adjacent to each other and share the same watershed, the contributing source area of Cow Pen (Upper) was used for watershed yield calculations (not included herein) and SCI scores.

Anderson cover types were used for the three proposed detention ponds to estimate the difference between future with (FWP) and future without project (FWOP), and ultimately average annual habitat units (AAHU). The Stream Condition Index (SCI) was calculated using the weighted sum of the cover types present in the riparian zone (Surface Protection – SUR) (see Equation 3 above).

Scenario 3 (GIS Watershed Scale): Map stream corridors at the watershed scale using Anderson cover types.
Potential Project Objectives. 1) Prioritize stream segments and watersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts; 2) Identify attainable reference conditions; 3) Establish watershed-scale, monitoring plans and forecast future conditions (trend analysis); 4) Extrapolate SCI scores from surface assessments across watersheds.

Anderson et al. (1976) or an acceptable, updated version should be used to map vegetation cover types within seven meters (~23 feet) riparian zone on stream banks (Figure 4). Depending on scale and data quality objectives, the left and right banks can be included together or separate. In this example, the banks are combined for an overall estimation of cover types within the SAR or watershed scale. SCI scores are estimated from surface protection (SUR) by calculating a weighted sum of the cover types (Figure 4 and Tab 23 of the Spreadsheet Calculator).

The SCI versus Surface Protection (SUR) correlation is recommended at the GIS Watershed Scale in the planning phase of the project (e.g., watershed prioritization):

$$SCI = 0.95 \ (SUR) - 0.081 \quad\quad\quad (3)$$

This strong regression correlation ($r^2 = 0.86$) is paramount in the extrapolation power using GIS Anderson cover types to estimate SCI in watersheds from SARs that received surface assessments to stream segments and reaches in unassessed watersheds. In addition, prioritization of stream reaches for restoration, enhancement and conservation using the SCI score based on SUR can be estimated rapidly using GIS cover types in the riparian zone (Spreadsheet Calculator Tab 23).

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. A revision of the land use classification system as presented in the U.S. Geological Survey Circular 671. United States Government Printing Office, Washington.

Griffith, G.E., J.M. Omernik, and S.H. Azevedo. 1998. Ecoregions of Tennessee. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, VA. Scale 1:940,000.

Hobbs, D. 2015. Lower Duck River: Mussel survey and inventory. Tennessee Wildlife Resources Agency.

Hobbs, D. 2016. 2015 Duck River quantitative mussel survey. Aquatic Habitat Protection Program and Tennessee Wildlife Management Agency. Fisheries Report 16-06.

Hutson, S.S. 2008. Estimated use of water in the upper Duck River watershed, central Tennessee, and water-demand projections through 2030: U.S. Geological Survey Scientific Investigations Report 2008-5058, 16 p.

Lane, E. W., 1955. The importance of fluvial morphology in hydraulic engineering. Proceedings, American Society of Civil Engineers, Vol. 81, Paper 745.

NRCS. 2011. NRCS/USACE Partnership Handbook, A field guide to working together toward shared goals.

Pruitt, B.A., K.J. Killgore, W.T. Slack, R. Matuliauskaite. 2020. Formulation of a multi-scale watershed ecological model using a statistical approach. Special Report Engineer Research and Development Center, ERDC/EL SR-20-6. https://www.erdc.usace.army.mil/Media/Publication-Notices/Article/2430578/formulation-of-a-multi-scale-watershed-ecological-model-using-a-statistical-app/

Pruitt, B.A., S.J. Miller, C.H. Theiling, and J.C. Fischenich. 2012. The use of reference ecosystems as a basis for assessing restoration benefits. ERDC TN-EMRRP-EBA-11. https://erdc-library.erdc.dren.mil/jspui/handle/11681/4066

Rosgen, D.L. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the 7th Federal Interagency Sedimentation Conference, Vol. 2, pp. 9-15, March 25, 2001, Reno, NV.

Rosgen, D. L., 1994. A classification of natural rivers. Catena, 22, 169-199.

Schumm, S. A., M. D. Harvey, and C. C. Watson, 1984. Incised Channels: Morphology, Dynamics, and Control. Water Resources. Publications, Littleton, Colorado, 200 pp.

Stoddard, J., P. Larsen, C. P. Hawkins, R. Johnson, and R. Norris. 2006. Setting expectations for the ecological condition of running waters: The concept of reference conditions. Ecological Applications 16:1267-1276

USDA. 1998. Stream visual assessment protocol. United States Department of Agriculture, Natural Resources Conservation Service, National Water and Climate Center, Technical Note 99-1.