Model Documentation

Stream Condition Index Model

DeSoto County, Mississippi

(Bruce A. Pruitt, K. Jack Killgore, W. Todd Slack, and Andrea Carpenter-Crowther)

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

Abstract. An ecological model was developed for DeSoto County, Mississippi. The primary problem identified in the study area is the risk of flood damages primarily in the Horn Lake Creek and Coldwater River Basins. A multidisciplinary team was convened to identify water resource problems, needs and opportunities and target stream reaches of immediate concern. Because of the high flood risk and flashy conditions, stream channels in the study area were highly eroded, and in many cases, exhibit steep banks with little to no protection. The overarching goals of the DeSoto County study were to address flood problems and adverse impacts to stream corridors. Numerous objectives were identified to:

1) Reduce flood damages to businesses, residents and critical infrastructure.
2) Reduce risk to human life from flooding and rainfall events.
3) restore stream stability, sediment transport, aquatic diversity, and riparian condition.
4) Improve land use supportive of channel stabilization and ecosystem restoration.
5) Improve overall water quality supportive of aquatic resources.

In order to meet the above goals, an ecological model, Stream Condition Index (SCI), was formulated based on the degree of statistical correlation (dependency) between15 test variables. The initial variables were tested on 29 verification sites followed by 36 validation sites. Variables were scored on a scale from 0.0 (poor condition) to 1.0 (best attainable) either on-site or normalized to the same scale during post-processing. By using several iterations of statistical analysis, a set of three ecological models called the Stream Condition Index (SCI) were developed (*listed from the ground up*): (1) Surface Assessments, Stream Assessment Reach (SAR) or project footprint scale; (2) Low-Altitude Photogrammetry; and (3) GIS Satellite Scale. All three SCI equations can be used to assess projects at multiple scales using a watershed approach (EC 1105-2-411, Planning: Watershed Plans). Based on the results of the SCI modeling, eight stream reaches were considered relatively undisturbed and best attainable reference conditions in the DeSoto County study area. In contrast, eleven stream reaches scored below 0.2 and were considered severely disturbed. Based on cover types identified remotely via GIS and ground-truthed during the field excursion, a correlation was developed between SCI and surface protection (i.e., the riparian zone nearest to the channel banks). As evidenced by a Pearson's r^2 of 0.86, extrapolation power was strong, lending itself to estimate SCI scores in watersheds and stream reaches not field verified. The findings of this study can be utilized to prioritize watersheds for restoration, enhancement and conservation, plan and conduct intensive ecosystem studies, and assess ecosystem outcomes applicable to future with and without restoration actions including alternative, feasibility, and cost/benefit analyses.

Table of Contents

List of Figures and Tables

Figures

Tables

INTRODUCTION

Setting. Located in the northwest corner of Mississippi, the study area was within DeSoto County which is bordered to the north by Tennessee, to the west by Arkansas, and to the east and south by Marshall and Tate Counties, Mississippi, respectively. Desoto County lies mostly within the 8-digit USGS Hydrologic Unit Code (HUC8) 08030204 – Coldwater, while Horn Lake Creek and the headwaters of Nonconnah lie within the 08010211 – Horn Lake-Nonconnah HUC8. In addition, three Level IV Ecoregions are found within DeSoto County: Loess Plains, Bluff Hills, and Northern Holocene Meander Belts.

Statement of Problem. The primary problem identified in the study area was the risk of flood damages in Horn Lake Creek Basin and the Coldwater River Basin. Drainage from rainfall events originating from headwaters has caused flooding of residential and nonresidential structures downstream and erosion throughout the basins. The landscape has been heavily developed and has experienced altered hydrology. Critical Infrastructure, roads, schools and medical facilities are at risk of flooding and the inundation of roads during flood events is causing safety issues countywide. Major flood damage occurred in May 2010, May 2011, September 2014, and March 2016. Three documented deaths occurred in DeSoto County related to flooding. The 2014 flood inundated the county and stranded many people in their vehicles due to flash flooding. Approximately 130 people were rescued from cars, apartments and a childcare facility. Sixty-six businesses and several homes were impacted. The county is currently raising one of the problem roadways that was inundated during this flood.

In addition to flooding many streams in the study area are experiencing channel degradation and aggradation caused by residential and commercial development, head cutting, channelization, erosive soils, agricultural practices, and other channel alterations in the DeSoto county watersheds have caused a decline in the ability of streams and adjacent lands to support the requisite functions for fish and wildlife.

Background. This study was undertaken by the USACE Memphis District and the USACE Engineer Research and Development Center (ERDC) as an integral part of the Memphis Metropolitan Stormwater Project—North DeSoto Draft Integrated Feasibility Study with Environmental Impact Statement. The purpose of the assessment was to develop a stream condition assessment method that identified existing conditions within the watershed, detailed the major water resources problems and opportunities in the watershed, and recommended tools and a strategic course of action for achieving the desired conditions in the watershed. Paramount to assessment of the DeSoto County watersheds across various degrees of ecological impairment at different scales, a set of ecological models, the “Stream Condition Index” (SCI) were formulated, tested and refined to: 1) assess existing conditions; 2) identify the problems in the watershed; 3) prioritize stream segments for restoration; 4) recommend structural and non-structural restoration design; and 5) provide a numerical assessment of alternatives for planning purposes. The SCI is a visual, multi-metric assessment tool using metrics to characterize the hydrologic, geomorphic, water quality, plant habitat and animal habitat of a selected stream reach.

This effort represents a method of assessing ecosystems using multi-attributes across multi-scales, called the “Multi-Scale Watershed Approach” (MSWA) that was first developed and certified through the National Ecosystem Planning Center of Expertise (ECO-PCX) for the Duck River Watershed Plan, located in middle Tennessee (Pruitt et al. 2020). The concept behind the MSWA was to establish a means of utilizing readily available data and surface assessments (i.e., “boots-on-the-ground” observations) to create an overall knowledge base focusing on watershed problems and opportunities. 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, and operation, maintenance, repair, replacement and restoration of aquatic ecosystems. Ultimately, a multi-scale approach offers several advantages which are discussed in the conclusions below.

Multi-Disciplinary Team. In August 2020, the MVM requested ERDC to conduct a study on selected streams (“Targeted Streams”) in Desoto County, Mississippi (hereinafter, referred to as “DeSoto study”). Problems and opportunities, goals and objectives were discussed during a series of conference calls which were memorialized in minutes and distributed to the Project Delivery Team (PDT). The PDT membership included:

District Engineers and Scientists
Elizabeth Burks, Civil Engineer, Project Manager, MVM
Andrea Carpenter Crowther, Biologist, MVM
Cherie Price, Chief, Coastal Planning Section, MVN
Jennifer Roberts, Planner, MVN
Mike Thron, Biologist, MVM
Evan Stewart, Economist, MVN
Jon Korneliussen, Civil Engineer, MVM
Zack Tieman, GIS Specialist, MVM
Cori Holloway, GIS Specialist, MVM
Edward Lambert, Chief, Environmental Compliance Branch, MVM
Donald Davenport, Hydraulic Engineer, MVM
ERDC Engineers and Scientists
Chris Haring, Fluvial Geomorphologist, ERDC-CHL
David Biedenharn, Hydraulic Engineer, ERDC-CHL
Todd Slack, Fish Ecologist/Mussel Specialist, Project POC, ERDC-EL-EEA
Jack Killgore, Fish Ecologist, ERDC-EEA
Bruce Pruitt, Professional Hydrologist, Senior Wetland Scientist, ERDC-EL-EEA

The project sponsor was the DeSoto County Government. Stakeholders included municipalities, residents and businesses in DeSoto County to include, but not limited to, the cities of Olive Branch, Hernando, Southaven and DeSoto. Since August 2020, regularly scheduled semi-monthly conference calls were attended by the PDT including ERDC scientists. Consequently, the process of data acquisition, reduction, analysis, and interpretation was well vetted by the PDT leading to the formulation and testing of three SCI models which are the subject of this model certification request.

ECO-PCX Consultation. Nathan Richards of the National Ecosystem Restoration Planning Center of Expertise (ECO-PCX) was consulted for advice on model formulation on several occasions: pre-project consultation, prior to field surface assessments, during data reduction and interpretation, and post model formulation and associated preparation of this model documentation for certification. In addition, guidance provided by ECO-PCX as published in "Assuring quality of planning models – model certification/approval process, standard operating procedures" was followed (USACE 2012).

Project Goals. The Flood Risk Management (FRM) goal was to develop alternatives to reduce the severity of flood risk to infrastructure and human life. The federal objective of water and related land resources project planning is to contribute to National Economic Development (NED) consistent with protecting the Nation's environment, pursuant to national environmental statutes, applicable executive orders, and other federal planning requirements. Planning objectives represent desired positive changes to future conditions (USACE 2000, PGN). All objectives focused on alternatives within the study area and within the 50-year period of analysis from 2025 to 2075.

The National Ecosystem Restoration (NER) goal is to stabilize channels and connect and improve riparian buffer strips, to minimize channel degradation and erosion, and to support aquatic ecosystem form and function along main stem channels and tributaries in Desoto County. Ecosystem restoration is a primary mission of the USACE, intended to increase the quantity and/or quality of desired ecosystem resources (USACE 2000, PGN).

The overarching goals of the DeSoto study were to evaluate the stream corridors to establish current (baseline) conditions, and identify water resource problems, needs and opportunities. The results will be utilized to prioritize stream segments and watersheds for restoration, enhancement and conservation; plan and conduct ecosystem studies; and assess ecosystem outcomes ("EcoLift") applicable to future with (FWP) and without project (FWOP) scenarios including alternative, feasibility, and cost/benefit analyses.

Project Objectives. The planning objectives for this study were:

Objective 1. Reduce flood damages to businesses, residents, and infrastructure in DeSoto County.
Metric 1: The PDT will evaluate structure damage.

Objective 2. Reduce risks to critical infrastructure.
Metric 2: The PDT will evaluate water surface elevation.

Objective 3. Reduce risk to human life from flooding and rainfall events throughout the county.
Metric 3: The PDT will evaluate water surface elevation.

Objective 4. Decrease channel slopes and stabilize bank lines to improve transport of stream flows and sediment to restore and protect aquatic and riparian ecosystems over a 50-year project horizon.
Metric 4: The PDT will evaluate channel dimensions, sediment transport, channel bed diversity, pools, and fish cover/canopy density, riparian zones and canopy density, habitat units, and turbidity.

Objective 5. Improve land use to support channel stabilization and ecosystem restoration including channel stability using structural and non-structural components.
Metric 5: The PDT will evaluate sediment inflows to channels, acres of riparian habitat preserved/planted.

Objective 6. Improve water quality to support aquatic resources.
Metric 6. The PDT will evaluate suspended sediment and nutrients.

Based on the above objectives, the following tasks were identified:

1. Conduct a surface assessments (i.e., field “boots on the ground”) on targeted streams.
2. Test, verify and refine the SCI within and across the targeted streams.
3. Identify watersheds at the HUC 12 scale and stream segments that need additional intensive studies.
4. Provide recommendations on long-term monitoring and condition trajectories;
5. Identify the cause and source of pollution including accelerated erosion, sediment transport and deposition, and habitat loss or aquatic biological impairment;
6. Establish attainable reference conditions at both watershed and stream segment scales;
7. Calculate Average Annual Stream Condition Units (AASCU) based on SCI scores generated on targeted streams.

METHODS

Several steps were undertaken pursuant to formulate and document a mathematical model (algorithm) supportive of achieving the project objectives and to identify key variables used in the SCI algorithm including (Figure 1):

1. Stratify study area by Level IV Ecoregions and HUC12 watersheds.
2. Map watersheds and stream reaches identified by the Memphis District for evaluation.

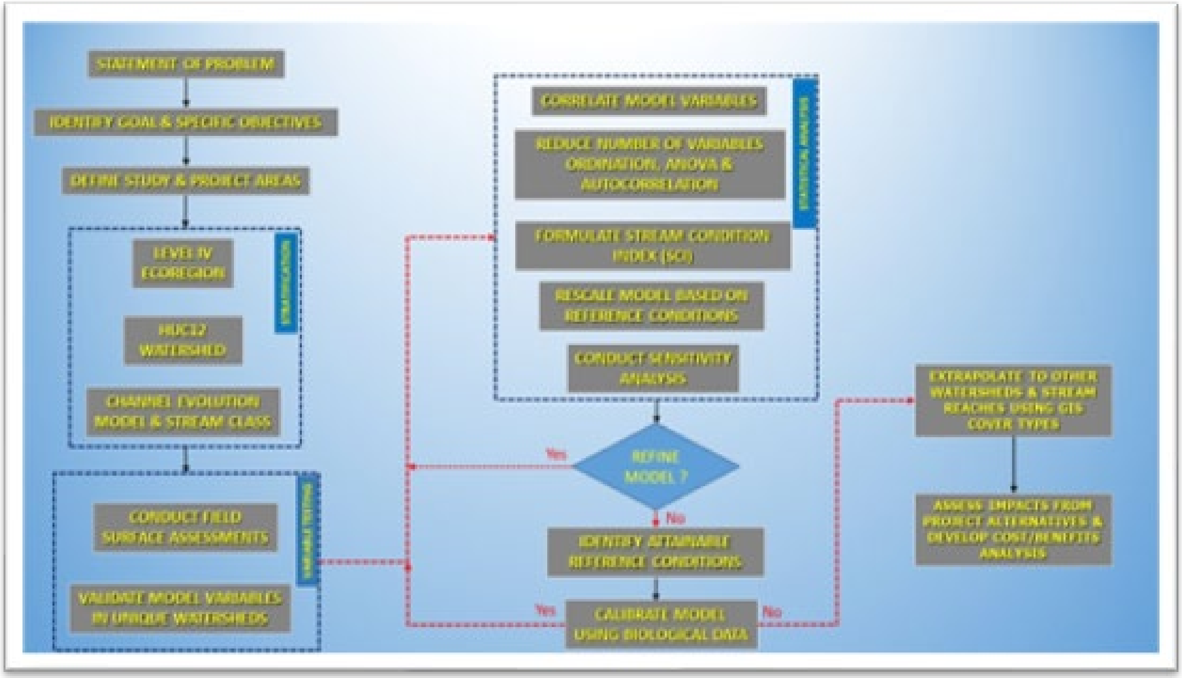

Figure 2. Model Documentation Process.

3. Classify targeted streams by the Channel Evolution Model (Schumm et al. 1984) and stream type using Rosgen's classification system (Rosgen 1994).
4. Field test variables used in the Duck River Watershed Certified Model.
5. Refine first set of test variables using statistical methods.
6. Determine logic of variable subset.
7. Conduct second level of statistical refinement using principal components analysis following by other parametric tests.
8. Review logic of second subset.
9. Formulate first SCI algorithm.
10. Verify correlations between and across SCI variables.
11. Perform sensitivity analysis on SCI.

Targeted Streams for Assessment. Major drainages within the County that were targeted in this study included (listed generally from east to west): Lick Creek, Coldwater River, Camp Creek, Bean Patch Creek, Rocky Creek, Cow Pen Creek, Nolehoe Creek, Hurricane Creek, Mussacana Creek, Nonconnah Creek, Horn Lake Creek, and Johnson Creek (hereinafter referred to as, "Targeted Streams").

Stratify by Ecoregions and Watersheds. The main purpose of stratification is to reduce natural variability (Figure 2). Stratification also facilitates statistical analysis by partitioning the dataset into subpopulations (sample sets). Consequently, subpopulations are generally more normally distributed as expressed in skewness and kurtosis.

Pursuant to identification of natural variability across physiographic regions and watersheds, the DeSoto Study area was stratified by three Level IV Ecoregion

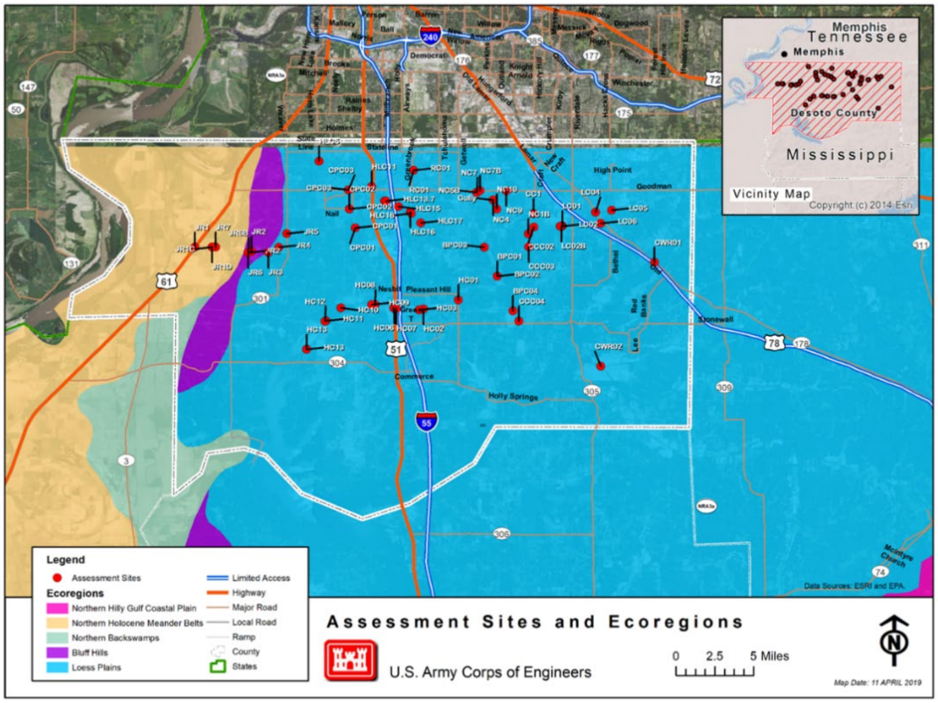

Figure 2. Mississippi Level IV Ecoregions depicting field surface assessment stations in red and DeSoto County boundary demarcated in white.

(from east to west): Loess Plains, Bluff Hills, and Northern Holocene Meander Belts (Figure 2) (Griffith et al., 1998 and Seaber et al., 1994). The second layer of stratification was by hydrologic unit code, HUC12 (Figure 3). Major watersheds included (listed from east to west): Coldwater River, Horn Lake Creek, Nesbit-Hurricane Creek, Frees Corners-Hurricane Creek, Johnson Creek and Upper Lake Cormorant Bayou. Finally, the Targeted Streams were stratified by channel evolution model – CEM (Schumm et al. 1984) and stream class (Rosgen 1994). A range of channel evolutionary stages were noted including incision (stage 2), widening (stage 3), somewhat stable with side bar formation (stage 4), and stable (stage 5). In general, the stream channels were trapezoidal in cross-section and considered a Rosgen "F" channel. However, in many cases, meandering stream channels (Rosgen "C") were forming within the "F" channel. Consequently, many stream channels were evolved from Schumm stage 3 to stage 4.

Field Surface Assessments. 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: Todd Slack, Jack Killgore, Bruce Pruitt, Chris Haring, David Biedenharn, Autumn Murray, and David May of ERDC. Rick Garay (Soil Technician, USDA-NRCS) joined the team and provided logistical support. In addition, Jon Korneliussen (MVM) accompanied the ERDC field team November 4 and 5. A subset of the targeted streams (29 stream reaches) was tested initially including: Johnson Creek, Horn Lake Creek, and Nolehoe Creek. Once site sampling methods were established November 3 – 5,

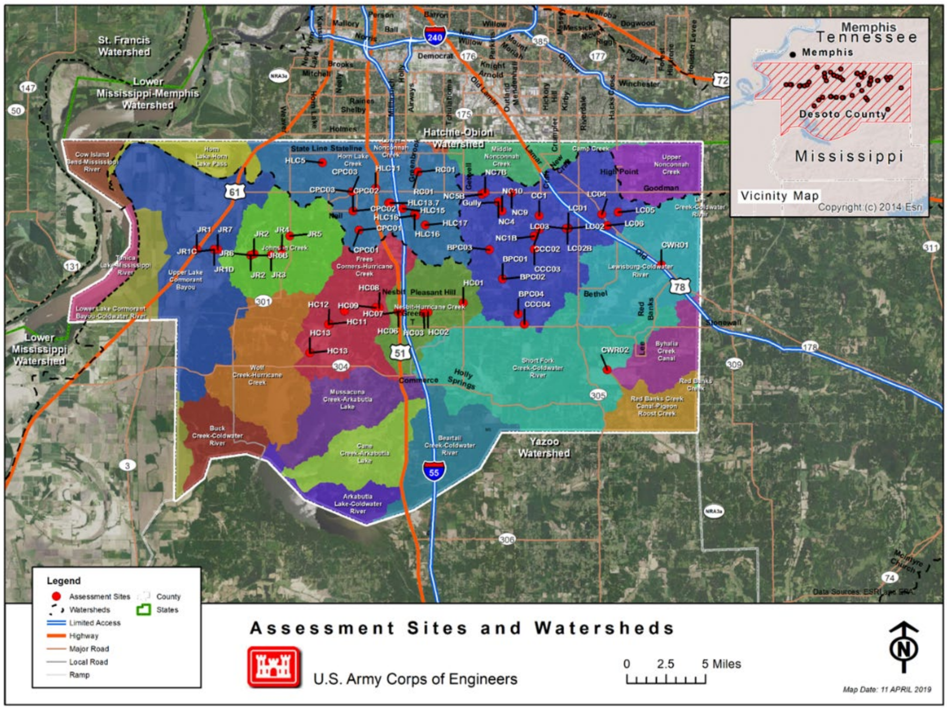

Figure 3. HUC12 watersheds depicting field surface assessment sites in red and DeSoto boundary demarcated in white.

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. Dr. Pruitt validated model variables on an additional 36 stream reaches on Hurricane Creek, Cow Pen Creek, Rocky Creek Bean Patch Creek, Lick Creek, Coldwater River and Camp Creek Canal and departed on Nov. 10.

Variable Verification and Validation. The SCI was developed from interpretation of the surface assessments conducted at a total of 65 Targeted Stream reaches: 1) 29 sites were used to verify model variables for appropriateness in the region; and 2) 36 sites were used to validate the model variables by applying them in different watersheds. Initially, 15 physical and biological attributes were identified and tested that represented stream and riparian zone conditions, as follows ("initial test variables") (Table 1):

1. CEM: Channel Evolution Model
2. ALT: Channel Alteration
3. STB: Bank Stability
4. HAB: Habitat Diversity
5. FIS: Fish Cover
6. CAN: Canopy Cover
7. RIP: Riparian Zone
8. DEP: Rooting Depth
9. DEN: Root Density
10. SUR: Surface Protection
11. ANG: Bank Angle

12. UPP: Upper Bank
13. MID: Middle Bank
14. LOW: Lower Bank
15. BED: Channel Bed Material and Stability

Table 1. Stream condition index (SCI) variable scoring and descriptions.

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 extends one active	Natural vegetation extends half of the	Natural vegetation extends a third of

	extends at least two active channel widths on each side.	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 observed	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

The above features were tested based on competency in regards to providing a rapid visual assessment, ability to discriminate between stream segments and watersheds, and capacity to determine departure from attainable reference conditions (discussed below). Because of the similarities observed in the field between CAN, RIP, UPP, MID, and LOW, they were lumped into one variable called vegetative cover (VEG). In combination with SUR, this facilitated extrapolation using GIS imagery. Consequently, candidate model variables were reduced to eleven variables:

1. CEM: Channel Evolution Model
2. ALT: Channel Alteration (Longitudinal Condition)
3. STB: Bank Stability
4. HAB: Habitat Diversity
5. FIS: Fish Cover
6. DEP: Rooting Depth
7. DEN: Root Density
8. SUR: Surface Protection
9. ANG: Bank Angle
10. VEG: Vegetative Cover
11. BED: Channel Bed Material and Stability

Major GIS Anderson land cover types used to extrapolate the 65 field verification and validation assessment sites included: cultivated crops, barren land, hay/pasture, herbaceous, forested and shrub/scrub. In addition, because of the strong correlation between VEG versus UPP, MID, LOW, CAN, and RIP, estimations of each variable can be calculated with a high degree of confidence.

Statistical Analysis. Each assessment variable was scored from 0.1 (severely disturbed) to 1.0 (relatively undisturbed) (Figure 4 and Table 1). Then, the set of 65 field sites were subjected to statistical analysis for model reduction and application at multiple scales. The objective of model reduction was two-fold: (1) construct a model that was more useful for environment management; and (2) formulate a model useable at multi-scales. The number of input parameters (variables) were reduced based on scale considerations using lumping and principal components analysis (PCA). First, the initial dataset was subjected to PCA (Primer, Version 6, Plymouth, UK). PCA is capable of transforming a large set of variables to a smaller set without compromising important environmental attributes. Consequently, simplicity is traded for a small reduction in accuracy such that the correspondence between variables can be visualized. Vectors represent the direction and magnitude of correlation between the environmental variables. Based on the results of PCA using 15 variables across 65 field sites, several sites responded similarly (highlighted in green circle) to variables as evidenced by the direction and magnitude of eigenvectors (highlighted with blue lines) (Figure 4). These sites are considered attainable reference conditions given they were located in areas with intact forested riparian zones and/or existing grade control structures.

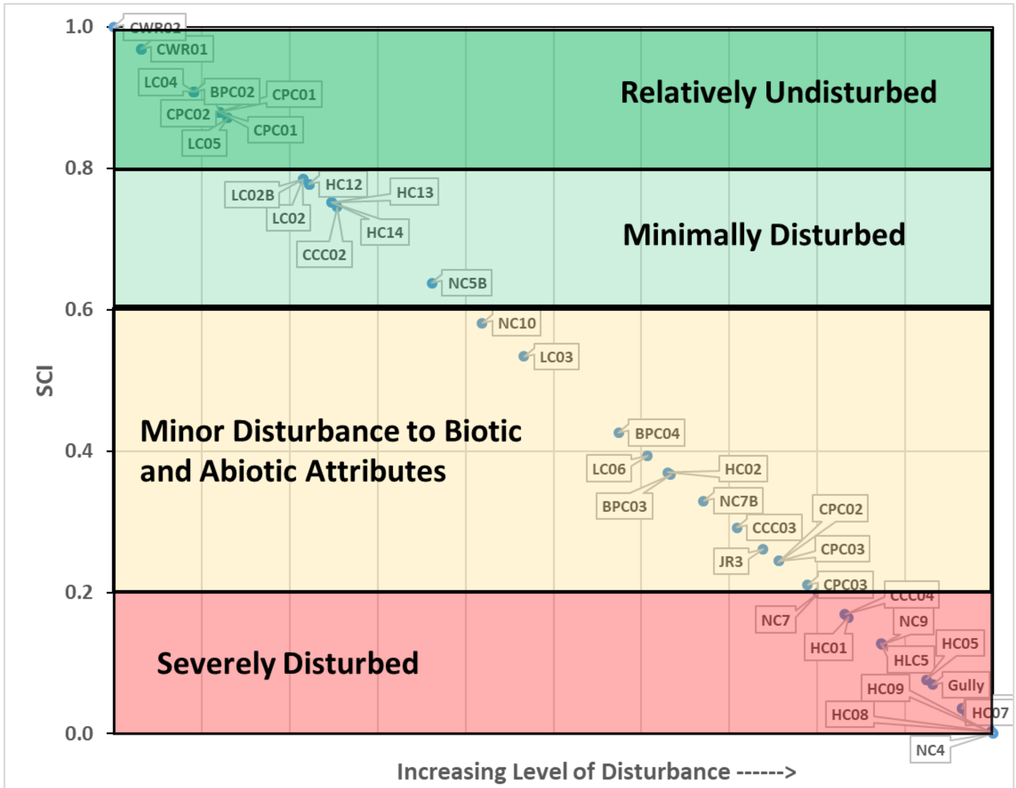

Figure 4. Ecological condition gradient highlighted in five categories based on SCI scores from 65 unique stream reaches (adapted from Pruitt et. al. 2012). Note similarity with gradient depicted in Figure 5.

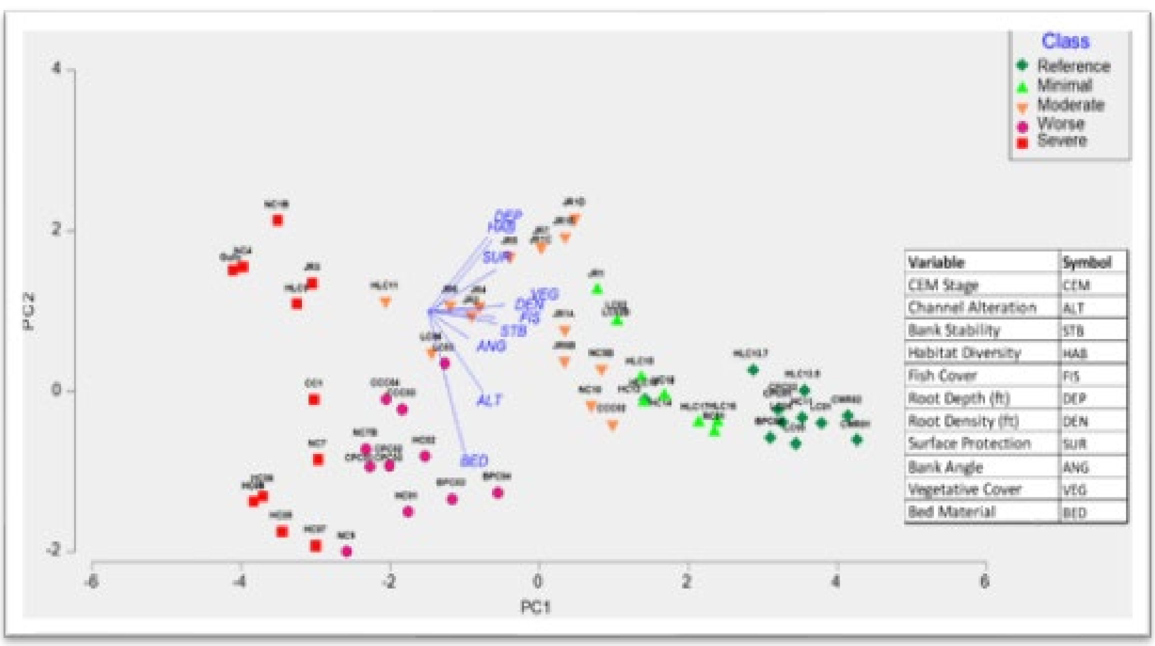

Figure 5. Dataset of 65 field surface assessment sites subjected to principle components analysis. Gradient of conditions based on variable scores oriented along PC1 axis. Eigenvectors, highlighted in blue, have both directional and magnitude components. Note grouping predominantly along watersheds.

Because of such a large dataset (n = 65), parametric statistical tests were justified based on the central limit theorem (CLT). CLT establishes that when additional variables are added, the frequency of the observation tends toward a normal distribution even if the original variables are not normally distributed. All multivariate analyses were performed using PRIMER ver. 7 (PRIMER-E Ltd™, Plymouth, UK); Anderson and Gorley 2007).

Spearman correlation coefficients were calculated between each of the variables to select those with highest correlation. Spearman correlation evaluates a monotonic relationship between two variables regardless of whether the relationship is linear or not. Consequently, in contrast to Pearson's correlation coefficient, Spearman is capable of correlating non-linear data (e.g., polynomial distribution). Spearman correlation coefficients were subjected to the t-test to determine significant correlations (2-tailed, α =0.05). With the exception of five cases (CEM vs. DEP, CEM vs. ANG, CEM vs. VEG, DEP vs. BED, and ANG vs. BED), the correlations were significant (Table 2). Some of the highest Spearman Coefficients were observed between SUR and the other ten variables (Table 3). Consequently, SUR can be estimated from GIS cover types in the riparian zone and extrapolated to other watersheds and stream reaches that did not receive surface assessments. See GIS Watershed Scale section below.

Selection of Appropriate Equation to Calculate SCI Score

Three SCI equations for use at different scales were verified and validated for model certification (*from the ground up*): 1) **Surface Assessments** ("boots-on-the-ground"); 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 competency; 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)

Table 2. Spearman correlation, T-Test for significance. Relations highlighted in red are not significant at α=0.05 level. Compare with Table 3.

T Test, one tail, p values (alpha = 0.05)											
Variables	CEM	ALT	STB	HAB	FIS	DEP	DEN	SUR	ANG	VEG	BED
CEM	1.0000	0.0001	0.0000	0.0255	0.0038	0.2365	0.0019	0.0046	0.1781	0.0518	0.0018
ALT		1.0000	0.0000	0.0078	0.0000	0.0000	0.0000	0.0000	0.0009	0.0014	0.0001
STB			1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0011
HAB				1.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0021	0.0000
FIS					1.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0005
DEP						1.0000	0.0000	0.0000	0.0004	0.0000	0.1414
DEN							1.0000	0.0000	0.0014	0.0000	0.0000
SUR								1.0000	0.0002	0.0000	0.0005
ANG									1.0000	0.0002	0.0722
VEG										1.0000	0.0001
BED											1.0000

Table 3. Spearman correlation coefficient, relations highlighted in red are not significant at α=0.05 level. Compare with Table 2.

Spearman Correlation Coefficent											
Variables	CEM	ALT	STB	HAB	FIS	DEP	DEN	SUR	ANG	VEG	BED
CEM	1.0000	0.4626	0.4965	0.2771	0.3538	0.1489	0.3783	0.3471	0.1691	0.2423	0.3790
ALT		1.0000	0.6539	0.3274	0.6753	0.4839	0.6061	0.5170	0.4028	0.3879	0.4630
STB			1.0000	0.5636	0.7423	0.6218	0.7995	0.8105	0.4590	0.5797	0.3972
HAB				1.0000	0.6492	0.7408	0.7319	0.7591	0.3745	0.6639	0.3061
FIS					1.0000	0.6362	0.8233	0.8185	0.4222	0.6658	0.4220
DEP						1.0000	0.7477	0.7523	0.4243	0.5257	0.1844
DEN							1.0000	0.9102	0.3883	0.7246	0.5433
SUR								1.0000	0.4509	0.7278	0.4186
ANG									1.0000	0.4493	0.2245
VEG										1.0000	0.4771
BED											1.0000

and credits (gain) generated from structural and non-structural construction activities. See Table 1 for variable descriptions for the following SCI equation:

$$SCI = \sqrt[15]{(CEM \times ALT \times STB \times HAB \times FC \times CAN \times RIP \times DEP \times DEN \times SUR \times ANG \times UPP \times MID \times LOW \times BED)} \quad (1)$$

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 sight, 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.

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

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):

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

This strong regression correlation ($r^2 = 0.86$, slope $p<0.0001$; y-intercept $p=0.0204$) 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. The observed relationship between surface protection on the stream levees and the SCI scores was considered rational and intuitive because once vegetative cover is removed from the stream channel, in-stream stability is compromised which is expressed in the overall SCI score including aquatic habitat loss (HAB) and associated biological impairment (FC).

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 (Table 4).

Attainable Reference Conditions. Establishment of attainable reference conditions in the DeSoto Study area based on aquatic diversity and habitat is fundamental to develop a gradient of impacts from which departure from reference conditions can be assessed (Pruitt et al. 2012) (Figure 4). Types of reference conditions can be on-site or off-site analogs, historical, constructed or by creating a regional index (Stoddard et al., 2006). Reference sites provide a scale, against which, to compare the condition of other sites. In addition to establishing achievable performance standards, monitoring analog reference sites in conjunction with restoration sites is paramount to address variation with respect to normal seasonal fluctuations, drought, climate change and catastrophic events (*force majeure*) which may not accurately reflect the cause of success or failure due to restoration actions.

In order to determine departure from reference conditions, reference watersheds and associated stream segments were identified within each HUC 12 watershed, if present. If the natural variation associated with the attributes across reference watersheds were insignificant, the reference watersheds were aggregated for comparison against other watersheds that are considered impaired. Watersheds with similar types and degree of impairment were aggregated based on PCA results (Figure 4). However, by constructing a reference state composed of the reference conditions identified, a reference standard would consist of a stream with minimal bank failure, natural planform, high canopy shading and a relatively broad forested riparian zone.

Sensitivity Analysis. The SCI model was tested to ensure that it was capable of addressing a full range of model inputs (variables) by using a partial sensitivity analysis, the most commonly used approach. A partial sensitivity analysis uses alternative values for individual key model inputs (variables). The process involves various ways of changing input variables of the model to see the effect on the output value (SCI score). Several scenarios were tested by subjecting: (1) one variable to the range of possible input values, while keeping the other five variables constant; (2) two variables to the range of possible input values, while keeping the other three variables constant; and (3) multiple variables with positive correlations to the range of possible input values, while keeping the other variables constant. Based on each of the aforementioned treatments, a complete range (0 to 1.0) of SCI scores was observed.

Model Calibration. In order to confirm the model, a subset of the 65 Targeted Stream reaches will be sampled for biological composition including fish and macroinvertebrates and riparian zone botanical composition. Based on the results of biological sampling, the final SCI model will be calibrated by varying input variables predominantly for habitat diversity (HAB) and surface protection (SUR).

Table 4. 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

CONCLUSIONS

A total of 65 field surface assessment sites within three Level IV Ecosystems and across five major watersheds in DeSoto County were evaluated initially using a suite of 15 test variables representing physical and biological attributes. Based on statistical analyses, 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 hydrology, geomorphology and aquatic habitat.

The SCI provided an excellent method of rating stream reaches across watersheds based on their land cover types, riparian zone condition, stream geomorphology, and stream bedforms and associated aquatic habitat diversity. The SCI was formulated using statistical methods, consequently, reducing bias and subjectivity. Based on the SCI scores calculated across 65 unique stream reaches (29 field verification sites and 36 validation sites), the following can be concluded:

1. Removal, alteration and/or invasion of non-native vegetation (e.g., kudzu) is widespread in the DeSoto Study area resulting in bank stability problems as expressed in variables STB and SUR.
2. Agricultural practices, residential and commercial development, and removal of native vegetation have contributed to bank failure and erosion leading to high sediment loadings as evidenced by the condition of the riparian zone and bank stability.
3. As evidenced by reduction in fish cover and pools, fish and aquatic benthic habitat were likely adversely affected by hydrogeomorphic alteration including accelerated head cutting and associated channel widening and bank erosion hazard. However, biological sampling of fish, macroinvertebrates and mussels needs to be conducted to support this conclusion and calibrate the model.

Based on the direct relationship between SCI and surface protection (SUR), the biotic condition of the stream can be estimated from the SCI score, which is noteworthy because of the difficulty and expense of establishing biotic response variables. Consequently, by conducting a visual assessment of stream condition using the SCI, conclusions can be made in regards to fish diversity and distribution based on aquatic habitat (HAB) within a stream segment or a watershed. Overall, the results observed in this watershed assessment can be utilized to:

1. Prioritize stream segments and watersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.
2. Assess proposed 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 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 (i.e., J-Sheets) at the national significant priority scale.

The statistical treatise used in model development for the DeSoto Study area can be utilized elsewhere in other physiographies and USACE Districts. The protocol used herein for establishing stream corridor conditions is applicable to the Ecoregions and stream classes within DeSoto County. However, the protocol can be transported to other river basins with additional beta testing and model validation.

MODEL SUPPORT LITERATURE

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